



Lake Roosevelt National Recreation Area

Geologic and Soil Resources Inventory Summary



On this page: Aerial photograph facing southwest across Grand Coulee Dam and Grand Coulee. Grand Coulee is a massive, steep-walled channel incised by the Missoula Floods—a series of catastrophic glacial outburst floods that occurred at the end of the last Ice Age approximately 14,000 years ago. The floods eroded and stripped back thick layers of Miocene flood basalt comprised of the Columbia River Basalt Group. The construction of Grand Coulee Dam in the 1940s established Lake Roosevelt and regulated flooding, controlled irrigation, and provided hydroelectric power generation. NPS photograph.

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Abstract

This document summarizes the status of National Park Service (NPS) Geologic Resources Inventory (GRI) and Soil Resources Inventory (SRI) deliverables for Lake Roosevelt National Recreation Area. It also provides information on current geology and soil resources management concerns, with a focus on identified inventory needs related to geologic heritage, geohazards, and related soil features and processes. This document is intended to assist park staff with prioritizing technical assistance or new inventory and assessment funding requests in the near term (roughly 1–5 years).

The GRI hosted a baseline scoping meeting for Lake Roosevelt National Recreation Area in September 2002. Baseline bedrock and surficial geologic maps were delivered to the recreation area in 2009 and updated in 2023. SRI delivered a legacy soil database, map, and “enhanced report” in 2013. Additional soil survey reports have been published by the US National Resource Conservation Service (NRCS) that include Ferry, Lincoln, Okanogan, and Stevens counties, as well as the Colville Reservation. The most up-to-date soil data for the recreation area is available through [Web Soil Survey](#).

Lake Roosevelt National Recreation Area’s geologic heritage is ingrained in its paleontological records; Indigenous connections; and its geologic connections to historic mining. The geologic and soil resources inventory needs for the park include various data and/or GIS information related to the inventory and monitoring of geohazards, cultural resources, and fossils, in addition to geologic mapping needs. Geologic hazards identified in the park include cave and karst, climate change, disturbed lands (e.g., abandoned mineral lands, overgrazing, land use changes), flooding, mass wasting, radon, reservoir tsunamis, seismicity, swelling clays, and toxicological soil.

Additional guidance for park staff regarding proposal processes and timeframes for the new Inventories and Assessment (I&A) program is available on the [GSRI](#) and [I&A](#) SharePoint sites.

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Background of the GSRI

The Geologic and Soil Resources Inventory (GSRI) facilitates the collection of new data, or derives new information from existing data, regarding the presence, absence, abundance, distribution, and significance of geologic or soil features or processes to inform park management decisions and planning.

In the 1990s, the NPS Geologic Resources Inventory (GRI) and Soil Resource Inventory (SRI) programs were established as two of the original 12 baseline inventories in the Inventory and Monitoring (I&M) program. These baseline inventories compiled existing information, acquired new information, and helped establish a minimum level of data across more than 270 parks, which served as a common starting point for natural resource monitoring. For both the GRI and SRI, the primary deliverable was a digital (GIS) map. Between the 1990s and early 2020s, GRI scoping summaries, geologic map posters, and GRI reports were also produced for most of the 270 parks. As of 2024, the I&M program is transitioning from a baseline inventory strategy to a park-proposed inventory strategy.

The GRI and SRI are now unified as one inventory program, the Geologic and Soil Resources Inventory (GSRI), and will be integrated into the new Inventories & Assessment (I&A) Program, in which parks will submit geology- and soil-related project requests in PMIS during the Servicewide Comprehensive Call (SCC). This transition will begin in FY25, with new guidance enacted for GSRI. During this transition period, 13 “priority” parks, including Lake Roosevelt National Recreation Area, were identified as missing a baseline GRI report.

This GSRI summary serves as a substitute for a baseline GRI report and is intended to support the national park’s participation in the new inventories program. As such, it summarizes the status of GRI and SRI deliverables for LARO and provides information on current geology and soil resources management concerns with a focus on identified inventory needs. Information in this summary was compiled from existing reports, meetings with park staff, and the best professional judgment from GRI and WASO Geologic Resources Division (GRD) geoscientists.

Baseline GSRI Products

Geology

The digital geologic and surficial maps for LARO are available on the NPS DataStore accessed through the Integrated Resource Management Applications (IRMA) portal (see <https://irma.nps.gov/DataStore/Reference/Profile/2171382>). These products are adapted from multiple source maps created by the Washington Division of Geology and Earth Resources and the US Bureau of Reclamation. Additional GSRI documents include the NPS Scoping Report (Connors 2002).

GSRI source maps:

- Kiver, E. P., and D. F. Stradling. 1995. Bangs Mountain 7.5 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:24,000

- Kiver, E. P., and D. F. Stradling. 1995. Bossburg 7.5 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:24,000
- Kiver, E. P., and D. F. Stradling. 1995. Boundary 7.5 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:24,000
- Kiver, E. P., and D. F. Stradling. 1995. Boyds 7.5 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:24,000
- Kiver, E. P., and D. F. Stradling. 1995. Broadax Draw 7.5 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:24,000
- Kiver, E. P., and D. F. Stradling. 1995. China Bend 7.5 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:24,000
- Kiver, E. P., and D. F. Stradling. 1995. Grand Coulee Dam 7.5 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:24,000
- Kiver, E. P., and D. F. Stradling. 1995. Hunters 15 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:62,500
- Kiver, E. P., and D. F. Stradling. 1995. Inchelium 15 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:62,500
- Kiver, E. P., and D. F. Stradling. 1995. Jack Woods Butte 7.5 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:24,000
- Kiver, E. P., and D. F. Stradling. 1995. Keller (southern half) 15 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:62,500
- Kiver, E. P., and D. F. Stradling. 1995. Kettle Falls 7.5 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:24,000
- Kiver, E. P., and D. F. Stradling. 1995. Lincoln 15 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:62,500
- Kiver, E. P., and D. F. Stradling. 1995. Little Falls 7.5 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:24,000

- Kiver, E. P., and D. F. Stradling. 1995. Marcus 7.5 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:24,000
- Kiver, E. P., and D. F. Stradling. 1995. Mica Mountain 7.5 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:24,000
- Kiver, E. P., and D. F. Stradling. 1995. Northport 7.5 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:24,000
- Kiver, E. P., and D. F. Stradling. 1995. Onion Creek 7.5 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:24,000
- Kiver, E. P., and D. F. Stradling. 1995. Turtle Lake 15 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:62,500
- Kiver, E. P., and D. F. Stradling. 1995. Wilbur 15 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:62,500
- Kiver, E. P., and D. F. Stradling. 1995. Wilmont Creek 15 Minute Quadrangle Map, Geology of the Franklin D. Roosevelt Reservoir Shoreline: Glacial Geology, Terraces, Landslides, and Lineaments, report to Bureau of Reclamation, scale 1:62,500
- Washington Division of Geology and Earth Resources. 2016. Surface geology, 1:100,000—GIS data: Washington Division of Geology and Earth Resources, DS-18 version 3.1, scale 1:100,000

GSRI scoping report:

- Connors, T. 2002. Geologic Resource Evaluation scoping summary: Lake Roosevelt National Recreation Area <https://irma.nps.gov/DataStore/Reference/Profile/2250307>

Soils

Soil maps provide information on soil types, including scores of different characteristics and management considerations including linear extensibility (“shrink-swell”) potential, erosion potential, soil stability, suitability for site development, suitability for recreation development (e.g., trails), and many other topics. Perrone (2023) provides an overview of the use of soil data at the NPS WASO level and lists soil data currently available in the Natural Resources Conservation Service (NRCS) [Web Soil Survey](#) website along with NPS-specific uses for the data. The NRCS plans to complete all soil survey areas in the US by 2026 (Thompson et al. 2020).

The most up-to-date soils data for LARO is available via Web Soil Survey, which is updated and maintained regularly. Management-focused maps for the park or potential project areas can be developed on demand on the website. The Web Soil Survey homepage gives instructions for how to view and download soil data, which are typically broken down into county-level soil survey areas. Each survey area is assigned a code and

a name. LARO includes five soil survey areas, all of which are complete (Table 1). To view the soil data for LARO on the Web Soil Survey website, use the navigation pane on the left side of the homepage to select the soil survey “Area of Interest (‘AOI’)” tab. Under the “National Park Service” dropdown menu, select LARO to view the soil data. The AOI icons along the top of the screen allow users to select specific areas of the map and generate detailed soil data (e.g., soil suitability and limitations, soil properties, soil qualities, and ecological sites). Use the “Soil Map” tab at the top to view the soil map and the “Soil Data Explorer” tab to view the detailed soil data. See additional Web Soil Survey guidance and FAQs or contact the NRCS state soil scientist for technical assistance.

In 2013, the SRI delivered a legacy soil database, map, and “enhanced report” to the recreation area (<https://irma.nps.gov/DataStore/Reference/Profile/1048918>; accessed March 2025). Additional soil survey reports have been published by the NRCS that include Ferry, Lincoln, Okanogan, and Stevens counties, as well as the Colville Reservation ([NRCS - Washington Soil Surveys](#); accessed March 2025).

Table 1. Web Soil Survey areas related to the recreation area.

Web Soil Survey Area Code	Web Soil Survey Area Name	Status
WA025	Grant County, Washington	Complete
WA043	Lincoln County, Washington	Complete
WA065	Stevens County, Washington	Complete
WA619	North Ferry Area, Washington	Complete
WA648	Colville Indian Reservation (parts of Ferry and Okanogan counties), Washington	Complete

Possible Future GSRI Products

As the GSRI becomes integrated into the I&A Program, future GSRI products will be determined by the project proposals submitted by the parks. Moving forward, the GSRI program will fund inventory projects that include the following:

- Collect new data or derive new information from existing data regarding the presence, absence, abundance, distribution, and significance of geologic heritage, soil features or processes, or geohazards.
- Include features or processes on an individual feature- or landscape-scale.
- Include groups of features or maps of multiple features in a defined area of management needs.
- Are a snapshot in time and may set a baseline for monitoring or assessment.
- Typically include a geospatial (GIS) component.

GSRI project examples:

- Features and processes eligible for funding through the GSRI program include cave/karst, geothermal, paleontological (fossils), landslides and rockfall, other geohazards (e.g., avalanche, permafrost, volcanoes, earthquakes, tsunamis, sinkholes), eolian, erosion, soil suitability and

limitations for use, soil properties and qualities, ecological site descriptions, and other geologic or soil features or processes of management interest.

- Features and processes covered by other sources of funding and ***not*** eligible for GSRI funding are abandoned mineral lands (AML), orphaned oil and gas wells, coastal processes, coastal storm response, sea level change projections or mitigation, coastal engineering structures, or shoreline sediment movement.
- The GSRI will accept proposals for new baseline map products, such as funding a traditional geologic (bedrock or surficial) or soil mapping effort, especially at new or expanded parks outside the original 270 I&M parks. Parks requesting these products will need to indicate a management need, which the baseline data will support.

Geologic Setting and History

Park Establishment and Setting

Lake Roosevelt National Recreation Area (“LARO,” also referred to as the “recreation area” herein) is located along the confluence of the Columbia and Spokane Rivers in portions of Ferry, Grant, Lincoln, Okanogan, and Stevens counties, northeastern Washington. Originally established in 1946 as Coulee Dam National Recreation Area, LARO protects the natural and cultural features of the upper Columbia River watershed upstream of Grand Coulee Dam and provides diverse recreational opportunities. The namesake Lake Roosevelt is the largest reservoir in the Pacific Northwest and stretches nearly 214 km (133 mi) from Grand Coulee Dam to Onion Creek, roughly 26 km (16 mi) south of the US–Canada border (National Park Service 2015b). Following the completion of the dam in 1941, Lake Roosevelt was created with the original purposes of flood control, irrigation, and hydroelectric power; today the US Bureau of Reclamation operates the dam. The recreation area is cooperatively managed by the NPS, US Bureau of Reclamation, US Bureau of Indian Affairs, the Colville Confederated Tribes, and the Spokane Tribe of Indians. As a hydrological park, LARO is mostly comprised of Lake Roosevelt but also includes surrounding shoreline areas that range from a few feet up to 0.8 km (0.5 mi) wide. The NPS manages approximately 502 km (312 mi) of the shoreline, roughly 19,197 ha (47,438 ac) of water, and about 5,235 ha (12,936 ac) of land along the shore (National Park Service 2009). An additional 11 km (7 mi) of shoreline along the Kettle Falls arm and 47 km (29 mi) of shoreline along the Spokane arm also make up part of the recreation area. Other shoreline and water surface areas are managed as part of the Colville Indian Reservation (managing approximately 150 km [93 mi] of shoreline) and the Spokane Indian Reservation (managing approximately 60 km [37 mi] of shoreline).

The recreation area is located within two distinct physiographic provinces of northeastern Washington—the [Okanogan Highlands](#) and [Columbia Basin](#)—and features a diverse geologic landscape sculpted by a rare combination of processes including tectonism, volcanism, continental glaciation, and catastrophic Ice Age flooding (Kiver and Stradling 1995; National Park Service 2015b). In many locations across LARO, the geology exposed on one side of the lake is completely different from the other. The Okanogan Highlands that underlie northern LARO are characterized by intensely deformed bedrock that has been thoroughly dissected by streams whose valley walls have been smoothed by glacial erosion (Livingston 1969). The southern portion of the recreation area is underlain by the Columbia Basin, a broad lowland plateau defined by massive outpourings of flood basalt. Thick sequences of the Miocene Columbia River Basalt Group (named after the Columbia River Valley) diverted the river to its present course, where it loops around the northern and western sides of the plateau (Figure 1; National Park Service 2009).

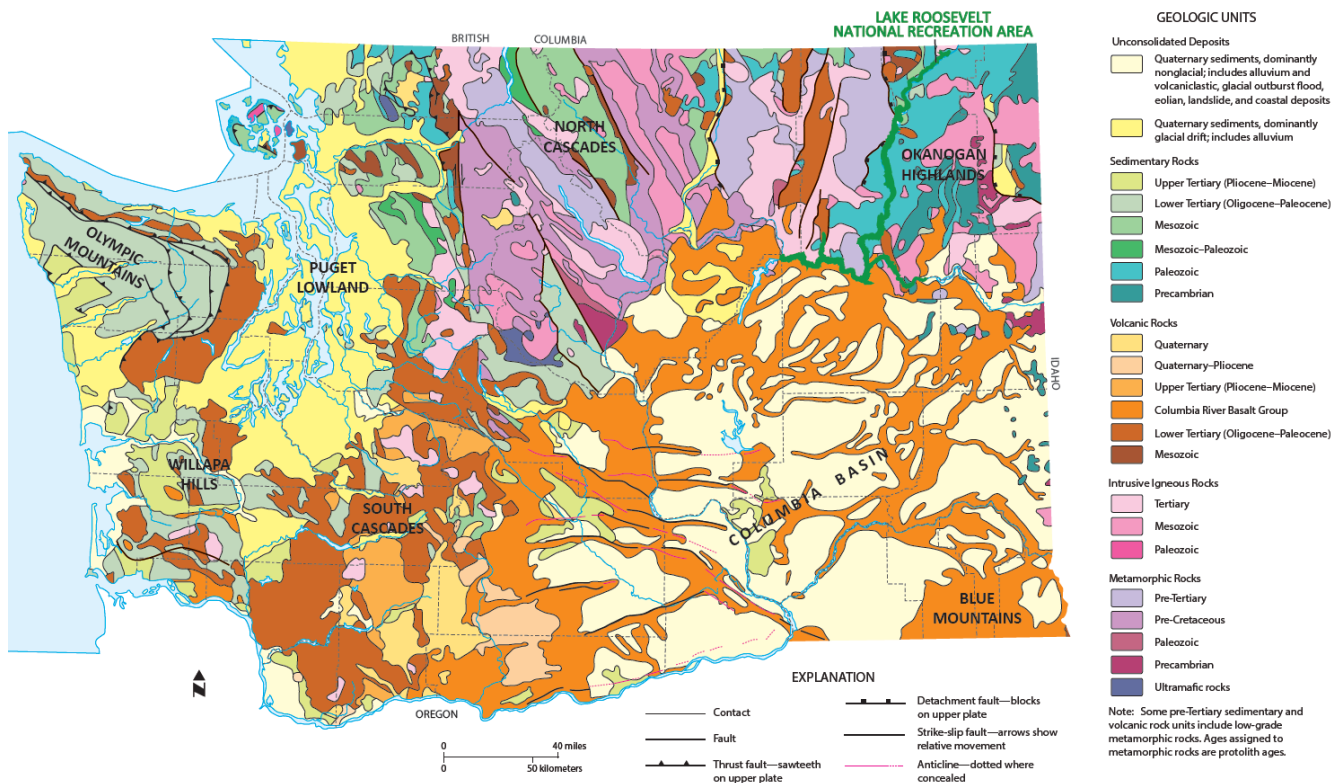


Figure 1. Physiographic province map showing the geology of Washington state. The recreation area occupies the Okanogan Highlands and the northern part of the Columbia Basin. Together, these regions have been subjected to tectonic accretion and metamorphism, widespread volcanism, glaciation, and immense glacial outburst floods. Map modified after the Washington Geological Survey.

Geologic History

Proterozoic and Paleozoic Eras: Ancient Seas

The geologic history of the recreation area is complex and records the tectonic growth of Washington state through the addition of various foreign landmasses or terranes (large, fault-bounded landmasses of distinct origin and lithology). Some of the oldest bedrock underlying the recreation area are Proterozoic and Paleozoic strata originally deposited along the western coast of ancestral North America (Table 2; Watkinson and Ellis 1987; Cheney and Rasmussen 1996; Cheney and Buddington 2014). Following deposition, these ancient marine sediments were metamorphosed and deformed by the accretion (tectonic addition or assembly) of the Quesnel terrane in the mid-Jurassic (see “Mesozoic Era”; Cheney 2016; Cheney and Zieg 2016). Today, highly deformed Proterozoic and Paleozoic rocks are generally located east of LARO and form an arcuate system of thrust faults known as the Pend Oreille River fold and thrust belt (see figure 8 of Cheney and Buddington 2014). The fold and thrust belt consists of several regional thrust sheets (bodies of rock that move along a thrust fault)—some of which underlie or cross Lake Roosevelt—that extend from the US–Canada border south, where they are obscured beneath Miocene basalts of the Columbia River Basalt Group (MI). Rocks uplifted along the thrust belt now comprise the Huckleberry Range and the Summit Range.

Mesozoic Era: Terrane Accretion, Deformation, and Volcanism

During the Mesozoic Era, approximately 200 million to 90 million years ago, the west coast of North America was an active margin defined by subduction, subduction-related volcanism, terrane accretion, and deformation (Haugerud and Tabor 2009). In the Okanogan Highlands, the Quesnel terrane was sutured to the continent during the mid-Jurassic Period about 175 million years ago and consists of a unique assemblage of Pennsylvanian to Jurassic marine sedimentary and mafic (darker rocks rich in iron and magnesium) volcanic rocks (Table 2; Cheney and Rasmussen 1996; Cheney and Buddington 2014; Cheney 2016). Rocks associated with the Quesnel terrane are predominantly located west of LARO; however, restricted exposures occur on both sides of Lake Roosevelt near the city of Marcus. The arrival of the Quesnel terrane is responsible for deforming the marginal Proterozoic and Paleozoic bedrock of North America and producing the Pend Oreille River fold and thrust belt that exists within and along eastern LARO (Cheney and Buddington 2014; Cheney 2016). In addition to terrane accretion, Mesozoic subduction generated several Jurassic and Cretaceous plutons (a crystallized igneous intrusion; **KGD** and **KI**) that intruded parts of the thrust belt. Additionally, these plutons intruded several surrounding metamorphic core complexes—areas where ancient crystalline bedrock have been uplifted and exposed along low-angle extensional or detachment faults (see “Tertiary Period”; Cheney and Buddington 2014; Cheney and Zieg 2016).

Tertiary Period: Intrusive Suites, Core Complexes, and Flood Basalts

One of the last major landmass additions to what is now Washington state was the Siletzia terrane, a large crustal block approximately 645 km (400 mi) long that merged with North America during the Eocene Epoch about 50 million years ago (Miller et al. 2023). The arrival of Siletzia generated several large strike-slip faults that transported rocks significant distances along the Pacific Northwest coast. These large faults accounted for nearly 325 km (200 mi) of displacement and are responsible for jumbling or rearranging the geology of the American Cordillera, the chain of mountain ranges that form the “backbone” of the Americas (Miller et al. 2023). Additionally, these faults fractured, weakened, and extended the crust resulting in numerous plutons that intruded and metamorphosed older preexisting bedrock.

Between 52 million and 45 million years ago, during an interval known as the Challis episode, regional extension produced numerous plutons (**EEP**, **EEPKB**, **EEPmgj**, and **EII**), grabens (downthrown crustal blocks), volcanic deposits (**ES**), and dike swarms (a group of magmatic fissures that intrude vertically into older bedrock; **Eida**) across a 2,000 km (1,240 mi) belt stretching from central British Columbia to central Idaho (Table 2; Tepper et al. 2024). Several plutonic rocks surrounding LARO belong to geochemically related, nested successions or assemblages referred to as intrusive suites; the Eocene [Coulee Dam Intrusive Suite](#) is named after exposures immediately north of LARO near the town of Coulee Dam (Carlson 1993). Intrusive suites form from a common magma source as it evolves through fractional crystallization, a process where magma chemistry changes as minerals crystallize out of melt. During the Eocene, the combination of pluton emplacement and regional extension created multiple metamorphic core complexes such as the Kettle, Lincoln, and Okanogan domes (Orr and Cheney 1987; Cheney and Rasmussen 1996; Tepper et al. 2024). These core complexes are comprised of ancient metasedimentary basement rocks of ancestral North America that have been intruded by Jurassic- and Eocene-age plutons (Cheney and Buddington 2014). One of the most distinguishing features of the core complexes is that they are almost entirely bound by Eocene detachment faults (low-angle normal faults) that helped uplift and exhume these crystalline domes (Cheney and Buddington 2014).

During the Miocene Epoch, approximately 16.8 million to 5.5 million years ago, volcanism associated with the Columbia River Basalt Group (MI) redefined the landscape of the Columbia Basin and produced one of the largest known lava flows on Earth (Reidel and Tolan 2013). For millions of years, multiple pulses of volcanism filled the valleys and constructed a sequence of flood basalt roughly 3,050 m (10,000 ft) thick (Weis and Newman 1976). Originating from swarms of fractures near the Idaho–Oregon border, these flows cover about one-third of Washington state, with some flows extending west to the Pacific Ocean (Gillespie 2015). Today, lava flows and columnar basalt of the Columbia River Basalt Group are located in southern LARO and are easily accessible at Hawk Creek Falls (Figure 2).



Figure 2. Hawk Creek Falls. Located along the easternmost Spokane arm of LARO, the falls incise through a thick sequence of columnar basalt and lava flows consisting of the Miocene Columbia River Basalt Group. NPS photograph.

Quaternary Period: The Ice Age and Missoula Floods

Glacial processes have played a large role in shaping the modern landscape of LARO and continue to do so today. During the Pleistocene Epoch, glacial lobes of the Cordilleran Ice Sheet advanced and retreated multiple times across northern Washington and excavated large swaths of the Okanogan Highlands, including the Columbia, Spokane, and Okanogan river valleys. As continental glaciers migrated south, river systems were occasionally blocked by the edge of the ice sheets to form a series of glacial lakes that included the infamous Lake Missoula. During the Wisconsin glacialiation (the most recent Ice Age), approximately 16,000 to 13,000 years ago, the Okanogan ice lobe blocked the Columbia River near the location of present-day Grand Coulee Dam and impounded glacial Lake Columbia in the valleys now occupied by Lake Roosevelt (Figure 3; Livingston 1969; Kiver and Stradling 1995; Riedel et al. 1997; Peters, n.d.). Over thousands of years, thick deposits of clay, silt, sand, and gravel (QPF and QFR) were deposited within and along the margins of the lake (Table 2). Today, spectacular rhythmite deposits found along the margins of LARO show how glacial lake sedimentation changed with the seasons. These deposits show that coarse silt or fine sand (summer accumulation) are repeatedly covered by fine silt and clay (winter accumulation);

Figure 4). Following the retreat of the Cordilleran Ice Sheet and the demise of glacial Lake Columbia roughly 13,000 years ago, the Columbia River and its tributaries incised these lacustrine (lake) sediments, leaving their surfaces standing as terraces high above the present reservoir elevation (Kiver and Stradling 1995; Riedel et al. 1997). According to Kiver and Stradling (1995), the bluffs along LARO record six prominent lake and terrace levels associated with glacial Lake Columbia that include (in order from highest to lowest elevation above sea level): (1) 731 m (2,400 ft); (2) 610–670 m (2,000–2,200 ft); (3) 512–536 m (1,680–1,760 ft); (4) 475–488 m (1,560–1,600 ft); (5) 427–451 m (1,400–1,480 ft); and (6) 402–415 m (1,320–1,360 ft). These steep, unconsolidated terrace slopes are susceptible to mass wasting and are extremely important to slope stability studies in LARO (see “Mass Wasting”). Additional glacial features located along the upper Columbia River Valley include glacial moraine and lacustrine delta deposits (Kiver and Stradling 1995).

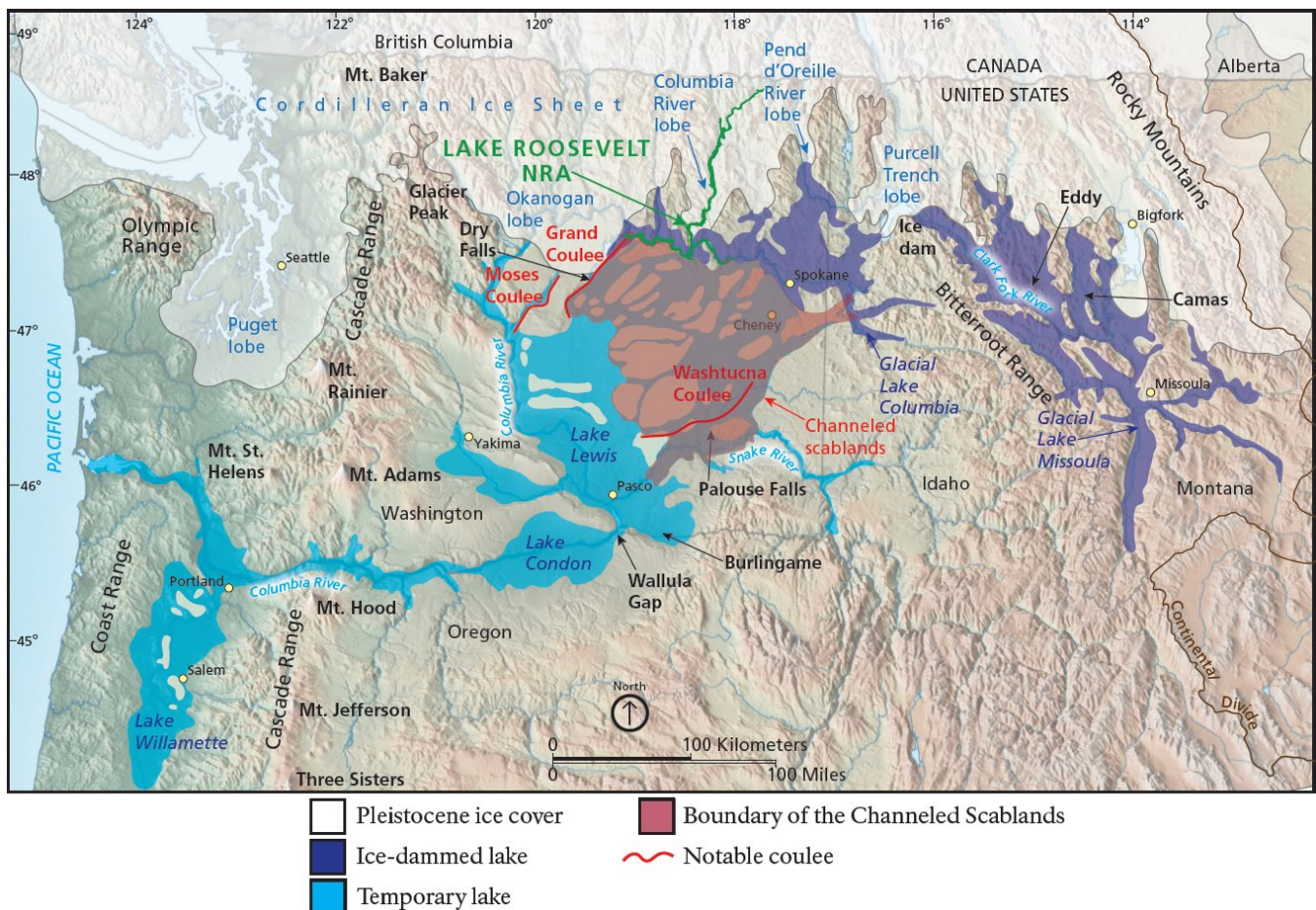


Figure 3. Simplified map of the northwestern US showing Ice Age lake systems related to the Missoula Floods. During the late Pleistocene Epoch, the recreation area was inundated by glacial Lake Columbia and subjected to dozens of glacial outburst floods originating from glacial Lake Missoula. These massive floods—known as the Missoula Floods—incised steep channels (coulees) and formed the dissected Channeled Scablands. The surficial geology of LARO predominantly consists of unconsolidated glacial and glaciolacustrine deposits that are susceptible to shoreline erosion and landslides. Figure created by Trista L. Thornberry-Ehrlich (Colorado State University).



Figure 4. Photograph of glacial lake deposits along the shoreline of Lake Roosevelt. During the late Pleistocene Epoch, glacial Lake Columbia inundated the southern portion of LARO and accumulated thick deposits of clay, silt, and sand. These exposures—called *rhythmites*—consist of alternating layers of sediment that represent annual depositional cycles within Lake Columbia. NPS photograph.

Some of the more recent significant events that impacted the geology of the recreation area are the Missoula Floods, the largest scientifically documented floods in North America. The Missoula Floods are a series of catastrophic floods (as many as 100 separate glacial outburst events) that occurred roughly 20,000 to 14,000 years ago (O'Connor et al. 2020). These floods—originally referred to as the “Spokane flood”—are named after and originated from glacial Lake Missoula, a massive body of water formerly impounded east of LARO along the Clark Fork River Valley in Montana and Idaho (see Figure 3; National Park Service 2009; O'Connor et al. 2020). Ancient glacial Lake Missoula measured approximately 7,700 km² (2,970 mi²) in area and contained about 2,100 km³ (500 mi³) of water, an equivalent to roughly half the volume of Lake Michigan (Weis and Newman 1976; Kiver and Stradling 1995). Glacial Lake Missoula was estimated to be roughly 210 m (700 ft) deeper and to have held about 175 times more water at full pool elevation than Lake Roosevelt (National Park Service 2009; Peters, n.d.). The outburst floods from Lake Missoula generated sudden giant torrents of water—some thought to be 120 m (400 ft) high with speeds approaching 100 kph (65 mph). The Missoula Floods dissected the Columbia Basin to form the Channeled Scablands, a deeply scarred landscape of flood basalts featuring canyons, coulees (steep-walled channels), plunge pools, rock basins, waterfalls, buttes, cliffs, alcoves, immense gravel bars, and giant ripple marks (QGL; Weis and Newman 1976; Kiver and Stradling 1995). The famous Grand Coulee is the largest, most scenic coulee incised by the Missoula Floods and is a recessional gorge (a deep canyon formed by glacial retreat) about 80 km (50 mi) long and about 275 m (900 ft) deep (Weis and Newman 1976). Repeated flooding has stripped back and removed the Miocene basalt flows at the head of the gorge and exposed the granite basement that

now forms the foundation of Grand Coulee Dam. Additionally, segments of the Columbia and Spokane rivers in LARO exhibit intense cutbank (outside river bend) incision related to the Missoula Floods (see figure 31 of Kiver and Stradling 1995).

Table 2. Geologic units mapped within or immediately adjacent to the recreation area.

GSRI map abbreviations for each time division and GSRI map unit symbols are in parentheses. Only geologic units mapped immediately adjacent to or within LARO are included. Boundary ages follow the International Commission on Stratigraphy (2023).

Geologic Time Unit	Age	Geologic Units (GSRI map symbol)	Geologic Events
Quaternary Period (Q): Pleistocene Epoch (PE)	2.58 million to 11,700 years ago	Mass wasting deposits, mostly landslides (Qls) Palouse Formation (Ql) Dune sand (Qd) Alluvium (Qa) Fraser-age glacial deposits (QFR) Pre-Fraser-age glacial deposits (QPF) Glacial lake outburst flood deposits (QGL)	During the Pleistocene Epoch, various ice lobes associated with the Cordilleran Ice Sheet advanced and retreated across northern Washington. These continental glaciers temporarily blocked or obstructed major river systems, creating a series of glacial lakes. Approximately 16,000 to 13,000 years ago, glacial Lake Columbia occupied the low valleys inundated by Lake Roosevelt. The catastrophic Missoula Floods repeatedly inundated the Columbia and Spokane river valleys and incised the Channeled Scablands approximately 20,000 to 14,000 years ago.
Tertiary Period (T): Miocene (M) Eocene (E) Paleocene (P)	66.0 million to 5.33 million years ago	Columbia River Basalt Group Grande Ronde Basalt (MI) Sanpoil Volcanics (ES) Eocene intrusive rocks, undivided (EII) Intrusive dacite, dike swarm (Eida) Migmatite of Johnny Gorge (EEPmgj) Keller Butte pluton (EEPKB) Paleocene–Eocene intrusive rocks, undivided (EEP)	Eocene regional extension associated with the Challis episode (about 52 million to 45 million years ago) produced several plutons, grabens, dikes, and detachment faults. These detachment faults exhumed the metamorphic core complexes (e.g., Kettle, Lincoln, and Okanogan domes) surrounding LARO. During the Miocene Epoch, approximately 16.8 million to 5.5 million years ago, a massive outpouring of flood basalt (Columbia River Basalt Group) inundated and redefined the Columbia Basin.
Mesozoic Era: Cretaceous (K) Jurassic (J) Triassic (TR)	251.9 million to 66.0 million years ago	Pre-Tertiary metamorphic rocks, undivided (pTM) Cretaceous intrusive rocks, undivided (KI) Jurassic–Cretaceous intrusive rocks, undivided (KGD)	The Quesnel terrane is accreted to the western margin of North America beginning in the mid-Jurassic. The arrival of the Quesnel terrane deformed older Proterozoic–Paleozoic strata of North America and created the Pend Oreille fold and thrust belt. Several Jurassic and Cretaceous plutons are emplaced that intrude the fold and thrust belt but also the surrounding metamorphic core complexes.

Geologic Time Unit	Age	Geologic Units (GSRI map symbol)	Geologic Events
Paleozoic Era: Permian (P) Pennsylvanian (PN) Devonian (D) Silurian (S) Ordovician (O) Cambrian (C)	541.0 million to 251.9 million years ago	Marine metasedimentary rocks (TRM) Metavolcanic rocks (TRPmv) Metacarbonate (Pcb) Marine metasedimentary rocks (Pmm) Metasedimentary and metavolcanic rocks, mixed (PMDM) Argillite (PMOar) Metacarbonate (PMOcb) Marine metasedimentary rocks (Ommc) Metavolcanic rocks (Omvc) Wacke (Owc) Ledbetter Slate (OmmI) Metaline Formation (OCM) Maitlen Phyllite (CMP) Reeves Member	Paleozoic strata that surround LARO were deposited along the western margin of North America but also represent rocks that comprise the Quesnel terrane. Marine carbonates, shales, and sandstones typify the shelf rocks of North America. The Quesnel terrane consists of a unique assemblage of Pennsylvanian to Jurassic marine sedimentary and mafic volcanic rocks.
Proterozoic Era: Neoproterozoic (Z) Mesoproterozoic (Y)	1.6 billion to 541.0 million years ago	Addy Quartzite (CZqa) Gypsy Quartzite, undivided (CZqg) Metasediments of Cayuse Mountain-Mill Canyon area, hornfels (OYCM) Togo Formation, low-grade quartzite (YT)	Coastal shelf deposition along the ancient western margin of North America.

Geologic Heritage

Geologic heritage (also called “geoheritage”) evokes the idea that the geology of a place is an integral part of its history and cultural identity. In 2015, the NPS GRD, in cooperation with the American Geosciences Institute, published a booklet introducing the American experience of geoheritage, geodiversity, and geoconservation: *America's Geologic Heritage: An Invitation to Leadership*. This publication introduces key principles and concepts of America's geoheritage, which are the focus of ongoing collaboration and cooperation on geologic conservation in the United States. The booklet includes the following five big ideas:

- America’s geologic landscape is an integral part of its history and cultural identity, and Americans have a proud tradition of exploring and preserving geologic heritage.
- America’s geologic heritage, as shaped by geologic processes over billions of years, is diverse and extensive.
- America’s geologic heritage holds abundant values—aesthetic, artistic, cultural, ecological, economic, educational, recreational, and scientific—for all Americans.
- America’s geologic heritage benefits from established conservation methods developed around the world and within the United States.
- America’s geologic heritage engages many communities, and involvement by individuals will ensure its conservation for future generations.

Additional information about the geology of Washington state, including its geoheritage connections, can be found at the Washington State Department of Natural Resources “Washington 100” website:

<https://wa100.dnr.wa.gov/> (accessed March 2025).

Paleontology

Paleontological resources (fossils) are any evidence of life preserved in a geologic context (Santucci et al. 2009). They may be body fossils (any remains of the actual organism such as bones, teeth, shells, or leaves) or trace fossils (evidence of an organism’s activity such as nests, burrows, tracks, or feces). Fossils may occur in rocks or unconsolidated deposits, in museum collections, or in cultural contexts, such as building stone.

According to Kenworthy et al. (2005), one identified fossil specimen was collected from within LARO near Fort Spokane and still merits proper identification (see “Inventory Needs”). Several geologic formations exposed along the Lake Roosevelt shoreline have produced fossils in the vicinity of the recreation area. However, the likelihood of discovering extensive paleontological resources in LARO is scarce due to limited shoreline outcrops that are predominantly (about 90%) made up of various Ice Age deposits (Riedel 1997; Kenworthy et al. 2005; National Park Service 2009). Fossils may be preserved within surficial deposits associated with cultural sites; some excavations unearthed faunal remains dating back to nearly 10,000 years ago (Kenworthy et al. 2005). The Ksunku site, located on the north end of Hayes Island, contains bone assemblages that can be considered both archeological and paleontological in nature. Several other faunal remains of deer, beaver, and elk date back between 9,000 and 6,000 years ago and could be considered

paleontological resources (Justin Tweet, NPS Geologic Resources Division, personal communication 11 February 2025).

Indigenous Connections

Long before Lake Roosevelt was created, Indigenous Peoples fished, hunted, and gathered wild fruits and vegetables in the upper Columbia River Valley for thousands of years (National Park Service 2015b). The recreation area preserves over 200 cultural sites that contain a diverse suite of geological resources, including pictographs (rock paintings), petroglyphs (rock carvings), hunting or fishing implements (e.g., projectile points, knives, net weights or sinkers), tools (e.g., bifaces, scrapers, choppers, cobble spall hammers, perforators, mortars, pestles, whetstones), soapstone and clay pipe fragments, lithic cores, lithic flakes, and shells (Figure 5; Collier et al. 1942; National Park Service 2008, 2009; Pouley 2008). Many of these Indigenous items consist of and reflect the rich assemblage of bedrock underlying and surrounding the recreation area, including quartzite, argillite, amphibolite, chalcedony, basalt, obsidian, and granite.



Figure 5. A large boulder of amphibolite rock sits on display near Kettle Falls, LARO. Kettle Falls was a historic fishing village along the Columbia River that was used by Indigenous Peoples for thousands of years. The resistant amphibolite is more abrasive than the surrounding bedrock and was used as a whetstone to sharpen tools for fishing or hunting. Numerous grooves along the surface of the boulder record many generations of usage. The boulder is a glacial erratic, a large rock deposited by Ice Age glaciers as they retreated north into Canada thousands of years ago. NPS/B. Worbes.

Kettle Falls was once an important center of fishing, hunting, trapping, and trade during more than 9,000 years of continuous habitation (Bell and Hinson 2009; National Park Service 2015b). During the fishing season, the annual gathering of Pacific Northwest tribes formed a village called Takumakst or “The Fishery”; it is speculated the village featured about 50 dwellings constructed from cedar planks covered with mats (Ackerman 1996; McKay and Renk 2002; Pouley 2008). Prior to the construction of Grand Coulee Dam and subsequent creation of Lake Roosevelt, the Columbia River formed a series of waterfalls flanked by angled slabs of bedrock. The rocky ledges produced a natural barrier for migrating salmon and steelhead trout, who were much easier to catch as they navigated the rapids (Figure 6). The name “Kettle Falls” originated from French-Canadian fur traders who noted that boulders revolving in the current had worn huge, kettle-shaped holes in the stream bed below the falls (Figure 7; see [Kettle Falls](#); accessed February 2025).



Figure 6. Historic photograph of Kettle Falls circa 1933. Prior to the completion of Grand Coulee Dam, Kettle Falls was a series of rocky rapids navigated by salmon and steelhead trout during the spawning season. For thousands of years, Kettle Falls was an annual gathering place for Indigenous tribes who used the area for fishing, hunting, trapping, and trade. US Bureau of Reclamation photograph.

The completion of Grand Coulee Dam in the 1940s resulted in the inundation of hundreds of cultural sites and the loss of historic fisheries (including Kettle Falls), forever changing the cultural, spiritual, and economic lives of the Colville and Spokane tribes (Collier et al. 1942; Bottenberg 2008; Pouley 2008; National Park Service 2015b). Through its establishment and management, LARO protects cultural sites and resources associated with enduring human interactions with the Columbia River and surrounding landscape, including traditional villages and gathering locations, the Kettle Falls Archeological District, and other

submerged sites along Lake Roosevelt (National Park Service 2015b). Seasonal drawdowns in Lake Roosevelt still partially expose cultural sites in LARO, making these resources susceptible to erosion, degradation, and looting (see “Geologic Resource Protection”).



Figure 7. The kettles at Kettle Falls. The falls are named after these kettle features, which formed as large boulders spun and ground down through the bedrock below the rapids. US Bureau of Reclamation photograph.

Mining

The upper Columbia River watershed is rich in mineral deposits, and numerous mines and placer deposit localities are located within and around the recreation area (Moen 1979). In the fall of 1854, gold was discovered by an employee of the Hudson Bay Company on the sandbars of the Columbia River near Fort Colville (McKay and Renk 2002). As news about placer gold leaked, a gold rush ensued that attracted prospectors and fortune-seekers with dreams of mineral wealth; among this group were many [Asian Pacific pioneers](#) who contributed greatly to the development of Washington state. Many prospectors were Chinese immigrants who arrived in large numbers and panned for gold along the sand and gravel bars of the Columbia River from Keller Ferry to China Bend (McKay and Renk 2002; National Park Service 2015b). By the mid to late 1800s, widespread mining activities occurred for various metals, primarily gold, silver, copper, lead, and zinc (Barton and Turney 2010). The mining boom stimulated development throughout the

Pacific Northwest and created demands for new businesses, settlements, farms, and ranches. According to McKay and Renk (2002), mining booms spurred the growth of agriculture in the region, particularly in the relatively temperate Colville River Valley (east of Colville, Washington) and in the Columbia River Valley south of Fort Colville. Although active mining has ceased within the recreation area, abandoned mineral lands within and surrounding LARO present significant concerns related to mining waste, water quality issues, and upstream contaminants (see “Abandoned Mineral Lands”).

Grand Coulee Dam

The landscape of LARO is largely defined by Lake Roosevelt, created by the construction of Grand Coulee Dam in the 1940s for the purposes of flood control, irrigation, and hydroelectric generation. In addition to these responsibilities, the dam and reservoir support navigation, provide a wide array of water-based recreational opportunities, and sustain migratory fish populations. The dam is the largest hydroelectric power-generating complex in the United States and features three major power-generating plants in addition to a pump-generating plant. Grand Coulee Dam is part of the Columbia Basin Project, the largest multipurpose project operated by the US Bureau of Reclamation. The bedrock underlying the dam consists of crystalline granite varying from coarse-grained along the eastern abutment (substructure at the ends of a dam) to fine-grained porphyritic near the western abutment (Bottenberg 2008). As construction of the dam began in 1933, the project faced several challenges, including diverting the river, removing or blasting “unsound” rock material, grouting to seal cracks in the bedrock foundation, large landslide events, and assessing or relocating dozens of cultural sites (see “Mass Wasting”; Bottenberg 2008). During World War II, the immense power generated by Grand Coulee Dam was used by plants and shipyards to build planes, ships, and tanks for the war effort; the dam also powered top-secret facilities tasked with processing plutonium for the atomic bomb (Bottenberg 2008).

Geologic Resource Management Issues and Inventory Needs

This section briefly summarizes the geologic resource management issues, inventory needs, and geologic hazards that have been identified by discussions with LARO staff. Geologic resource management issues refer to problems related to geologic resources. Inventory needs are highlighted to summarize what is currently known and what is needed to ensure good management of the LARO. Geologic hazards refer to notable hazards stemming from geologic features or processes that may require active management. Refer to the [Guidance for Geologic Resource Management SharePoint](#) for more information regarding geologic resource management.

Summary of Geologic and Soil Hazards

Park resources are not only visitor attractions but may also be potentially hazardous. The landscape of LARO presents a variety of geologic hazards, or “geohazards”—naturally occurring, dynamic geologic processes that have the potential to cause damage, loss of property, and/or injury and loss of life. The Addressing Climate Change and Natural Hazards Handbook (National Park Service 2015a, 2023), grounded in NPS Policy Memorandum 15-01 (Jarvis 2015), provides a process and information to help teams and decision-makers identify, avoid, and mitigate risks associated with environmental change hazards and effects on proposed and planned facility investments. The handbook supports NPS planning guidance, policy directives, and executive orders and does not supersede existing mandated compliance processes and policies. Additional guidance for facility management (e.g., [Climate-Smart Planning Principles](#) and [Recommended Practices](#)) has been developed to support effective decision-making.

According to PM 15-01, managers should apply the handbook guidance to identify options to manage natural hazard and climate change risks throughout all levels of facility planning and design. Project teams are required to submit the completed Natural Hazards Checklist (Table 3) as part of Regional and Bureau Investment Review Board submissions. This information can also be used as part of the updated (2024) Automated Investment Review Board (AIRB) submittal process at the Investment Concept (IC) stage. Table 3 includes selected geologic and soil hazards listed in Part 1 of NPS (2023). The GSRI team has added additional hazards where appropriate for the park. If needed, Part 2 of the handbook could inform the completion of the checklist, such as whether a hazard is applicable. Contact the NPS Geologic Resources Division with any questions.

Table 3. Geologic hazards checklist.

This summary table is a synthesis of existing GSRI-compiled map data and information, as well as published US Geological Survey and other government agency information. It is suitable for use at park-scale discussions and assessments. It is not a substitute for site-specific investigations or NEPA analysis. Ground-disturbing activities should neither be approved nor denied based on the information here. This table is modeled after the Natural Hazard Checklist (see National Park Service 2015a, 2023 and Jarvis 2015). It is meant to provide general information to identify the full range of natural hazard-based risks for the recreation area.

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Sources of Geohazard Information
Earthquake	Falling objects Collapsing structures Inoperability of major building systems (e.g., power, sewer, water) Trigger to other hazards (e.g., landslides) Human injury or casualty	Potential hazard (low; DOI SHIRA)	Kiver and Stradling (1995) US Department of Interior (DOI) Strategic Hazard Identification and Risk Assessment (SHIRA) Risk Mapper Report United State Geological Survey (USGS) Earthquake Hazard Probability Map (Petersen et al. 2023)
Slope movements (also called “mass wasting”)	Landslides (e.g., mudflows, rockfalls, slumping or creep) Shoreline recession, leading to damage or loss of private and public property Damage to or loss of park infrastructure Damage to or loss of natural or cultural resource sites or features Landslide-generated reservoir tsunamis Human injury or casualty	Known hazard (susceptible to landslides; DOI SHIRA)	DOI SHIRA Risk Mapper Report GSRI GIS hazard layers or slope movement deposits (e.g., “mass wasting deposits”) Jones (1954) Jones et al. (1961) Kiver and Stradling (1995) USGS Landslide Inventory and Susceptibility
Permafrost	Not applicable	Not applicable	Not applicable
Cave/karst	Surface collapse Ceiling collapse Rock fall Human injury or casualty	Potential hazard (high; DOI SHIRA)	DOI SHIRA Risk Mapper Report
Shrink/swell soils	Sinking or lateral shifting of the ground beneath roads, trails, or structures Damage to infrastructure (e.g., buildings, utility systems) Increased susceptibility to slope movements Human injury or casualty	Potential hazard (low to moderate; USDA Web Soil Survey)	USDA Web Soil Survey

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Sources of Geohazard Information
Coastal storm surge/ sea or lake level change/shoreline erosion	Reservoir fluctuations and controlled releases govern landslide susceptibility and shoreline erosion Periods of draw down temporarily expose natural or cultural resource sites to erosion and looting Controlled releases of Lake Roosevelt expose sediments contaminated by industrial waste, creating a source of toxic airborne dust.	Known hazard	Jones (1954) Jones et al. (1961) National Park Service (2009) Pouley (2008) Riedel et al. (1997)
Tsunami	Lake Roosevelt has experienced inland reservoir tsunamis generated by large landslides along the shoreline Shoreline erosion and stabilizing vegetation removal Increased susceptibility to slope movements Damage to infrastructure (e.g., buildings, roads, utility systems) Human injury or casualty	Known hazard	Jones et al. (1961) National Park Service (2009) Riedel et al. (1997)
Riverine Flood	Flooding (driven by storms, prolonged rainfall or snowmelt) capable of generating mass wasting events Enhanced surface runoff and stream flow capable of carrying sediment, rock, and woody debris Stream channel migration Stream bank erosion Destruction of infrastructure (e.g., roads, trails) Destruction of cultural or paleontological sites Human injury or casualty	Potential hazard (extreme; DOI SHIRA)	Carrell (1981) DOI SHIRA Risk Mapper Report Federal Emergency Management Agency (FEMA) Map Service Center National Park Service (2009) Riedel et al. (1997) Wagner et al. (2009)
Flash Flood	Rapid flooding along tributaries and side canyons along Lake Roosevelt Enhanced mass wasting susceptibility Enhanced surface runoff and stream flow capable of carrying sediment, rock, and woody debris Stream channel migration Stream bank erosion Destruction of infrastructure (e.g., roads, trails) Destruction of cultural or paleontological sites Human injury or casualty	Potential hazard	Kiver and Stradling (1995) National Park Service (2009)

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Sources of Geohazard Information
Volcanic eruption	Ash clouds can obscure sunlight, generate lightning, and limit visibility Fine ash is abrasive and causes mechanical failure in vehicles and aircraft Ash suspended in water can damage hydroelectric facilities, irrigation pumping stations, sewage-treatment facilities, and stormwater systems Wet ash deposits become sticky, heavy, highly conductive, and capable of short-circuiting transformers or powerlines Airborne ash can cause or exacerbate respiratory and vision problems	Potential hazard	Gardner et al. (1995) Hoblitt et al. (1995) Schilling (1996) Scott et al. (1995) Volcanoes and Lahars WA - DNR Waitt et al. (1995) Wolfe and Pierson (1995)
Hydrothermal activity	Not applicable	Not applicable	Not applicable
Radon	Health hazard	Potential hazard (high to moderate; US EPA).	DOI SHIRA Risk Mapper Report Otton (1992) US Environmental Protection Agency (EPA) Map of Radon Zones
Toxicological soil (arsenic ¹ , asbestos or erionite ² , <i>Bacillus anthracis</i> [causes anthrax] ² , cadmium ² , lead ¹ , and selenium ³)	Health hazard	¹Potential hazard (very high) ²Potential hazard (high) ³Potential hazard (low)	DOI SHIRA Risk Mapper Report

Cave and Karst

Karst topography develops in limestone, dolostone, gypsum, and other rocks by dissolution, as the rock is chemically and physically eroded by rainwater containing dissolved carbonic acid. Over time, dissolution can create open spaces or voids in the bedrock that develop into larger interconnected cavities or passages. Karst topography presents several hazards (e.g., surface collapse, ceiling collapse, rock fall), as the dissolution of bedrock often weakens its structural integrity. Although the distribution of caves and other karst features is poorly understood at LARO, the bedrock underlying the recreation area includes carbonate rocks that are susceptible to karstification. According to the DOI SHIRA Risk Mapper report, the recreation area is considered an area of high hazard regarding both current and future karst development. Colorful tall tales surrounding the recreation area include the story of Nathaniel “Texas Jack” Reed, an outlaw who supposedly lived in a cave located in the canyon walls of Rattlesnake Canyon (now inundated by Crescent Bay Lake).

Climate Change

Although climate change planning is beyond the scope of this GSRI summary, a discussion of climate change is included because of the potential disruption it may cause to the recreation area’s resources, including geologic resources. The climate at LARO is already changing; all future climate model projections include temperatures above the recent historical average (1979–2012), and average annual precipitation is anticipated to be highly variable (National Park Service 2015b; Climate Change Response Program 2024). Alpine glaciers and snowpacks—critical reservoirs that sustain LARO’s rivers, ecosystems, recreational opportunities, and hydroelectric power generation—are receding, which will likely impact the availability of water (National Park Service 2015b). Projected increases in several variables (e.g., air temperatures, evaporation rates, droughts, and precipitation) may negatively affect reservoir levels, groundwater aquifer recharge, as well as watershed quality and flow. These modifications to water availability are likely to impact additional geologic processes (e.g., floods, landslides, shoreline erosion), in addition to ecological processes (e.g., invasive species, phenology), wildfire occurrence, visitation, and park management procedures (Bell and Hinson 2009; Climate Change Response Program 2024).

Climate change manifestations that may intensify geologic hazards include the following:

- Increased average temperatures
- Increased frequency and intensity of storms
- Increased frequency and magnitude of fires
- Increased susceptibility to mass wasting events
- Increased extreme weather scenarios, including drought and flooding
- Decreased water availability as alpine glaciers and snowpacks dissipate

Disturbed Lands

Disturbed lands are those areas where natural conditions and processes have been directly impacted by development, including facilities, mining, roads, dams, and campgrounds; agricultural activities such as farming, grazing, timber harvest, and irrigation ditches; and overuse or inappropriate use. Restoration aims to restore a site, watershed, or landscape to a previous condition, typically a desirable historic baseline. Human activity often disturbs lands, leading to unintended and long-lasting issues that affect other resources. Many

of these disturbances obliterate soil profiles, exacerbate the invasion of exotic plants, result in contamination of water and soil, and/or cause erosion and sedimentation. These damages, in turn, frequently impair the quality of habitats, disrupt ecosystem functions, and cause problems for parks managing areas as wildlands. Usually, lands disturbed by natural phenomena such as landslides, earthquakes, floods, and fires are not considered for restoration unless influenced by human activities.

Abandoned Mineral Lands

Numerous mines located within, adjacent to, and upstream from the recreation area pose a considerable threat with respect to mine waste, water quality issues, and mine-related materials. The rich mining history of the Pacific Northwest is credited to precious metallic deposits (e.g., gold, silver, copper, lead, and zinc) that also contain trace elements known to be hazardous in high abundance. For nearly a century, mining and smelter operations upstream from LARO processed ore deposits and discharged several hundred tons of industrial waste, such as process wastewater and slag (a glassy, granular waste product), into the Columbia River (Figure 8; Bell and Hinson 2009; National Park Service 2009). Although ore refinement technology has greatly improved over the last 50 years and slag discharge has been discontinued, issues related to trace element contamination have existed in Lake Roosevelt since the late 1980s (Barton and Turney 2010).

In 2001, a joint publication by the USGS, US Fish and Wildlife Service, Washington State University, and the US Environmental Protection Agency (EPA) reported elevated concentrations of arsenic, cadmium, copper, lead, mercury, and zinc in sediment samples collected from Lake Roosevelt, the upstream reach of the Columbia River, and several of its tributaries (Bortleson et al. 2001). Additional elevated concentrations of these elements were reported in shallow, nearshore sediments along the reservoir by Majewski et al. (2003). In general, concentrations for most metals increase upstream closer to the contamination source and dissipate downstream or down reservoir; these abundances reflect suspended sediment dispersal (Bortleson et al. 2001; Majewski et al. 2003; Barton and Turney 2010). According to National Park Service (2009), additional water and soil quality concerns have been related to the uranium mine on the Spokane Indian Reservation as well as the Young American mine near [Bossburg Flat](#). Contaminated sediments in and around Lake Roosevelt are periodically exposed during controlled releases, which then become a source for airborne toxic dust.

In 2014, the NPS was notified of explosive material that had been found on the west side of Lake Roosevelt north of Kettle Falls. Following the spring drawdown of the reservoir, several tubes of packaged explosive were discovered along the shore and were promptly destroyed by the Spokane Bomb Squad. Often used in mining or excavation operations, these materials were located downslope from adjacent mining sites and would have required additional actions or materials for detonation.

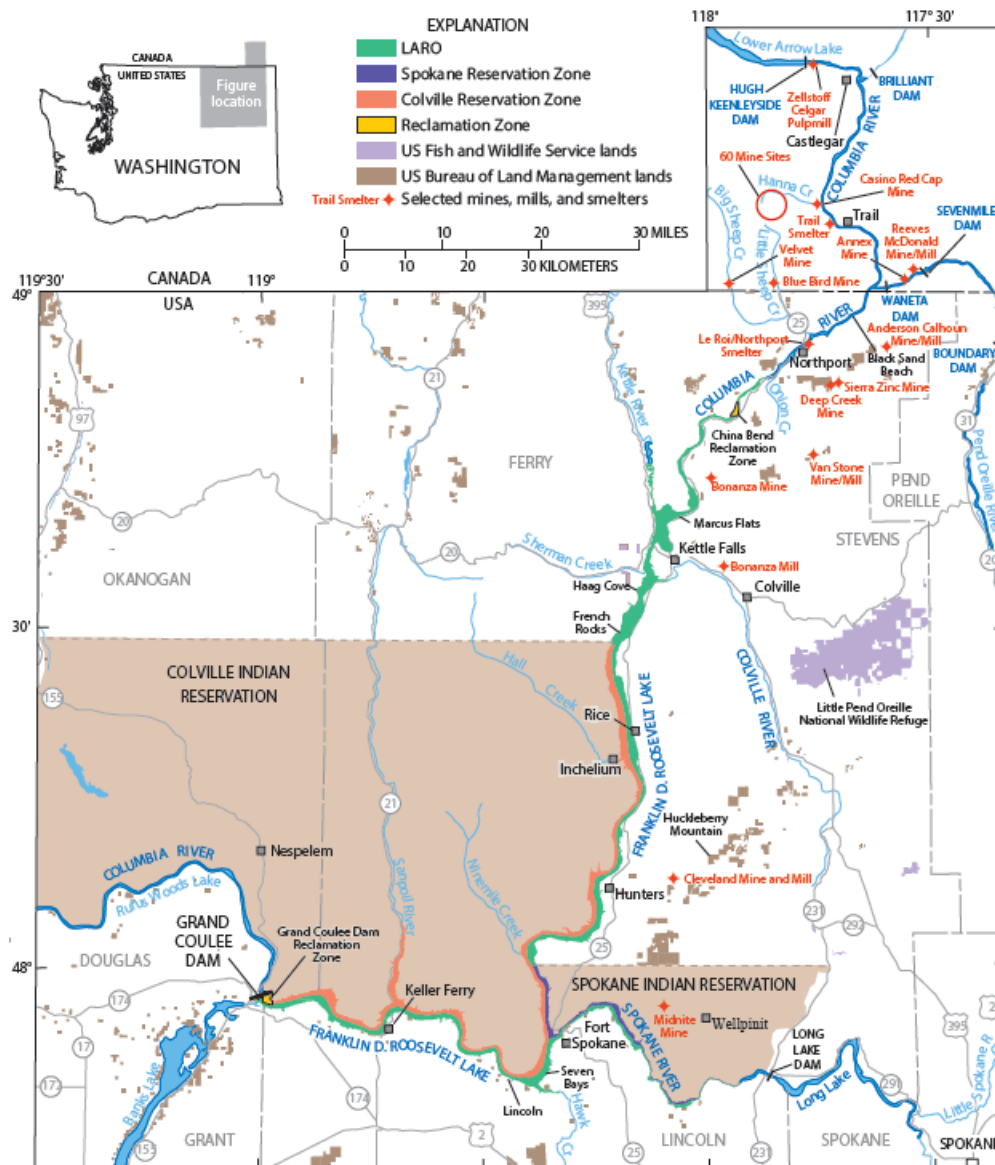


Figure 8. A map of select mine sites, mills, and smelters adjacent to or upstream of LARO. Many of these sites are sources of heavy metals and organic contaminants that impact the water quality of Lake Roosevelt and its tributaries. Figure modified from Barton and Turney (2010).

Overgrazing

Surrounding the recreation area are several grazing allotments that have been negatively impacted by overgrazing practices, resulting in slope instability and resource degradation. The conversion of forest to grass pasture has negatively impacted the soil stability, hydrologic function, and biological integrity of these allotments; some sites will continue to degrade without revegetation efforts or grazing restrictions (Bell and Hinson 2009). Grazing cattle limit the ability of the reservoir shoreline to withstand erosional forces (e.g., wave action, mass wasting) but also promote localized bank instability along streams and stream access points (Wagner et al. 2005; Bell and Hinson 2009). The removal of shoreline vegetation hinders the cohesive nature of the substrate, often promoting surficial processes such as rilling (shallow channel erosion) or

gullying (large channel erosion) that can lead to soil degradation and loss (Riedel et al. 1997; Wagner et al. 2005; National Park Service 2009).

Land Use Changes

The long, linear nature of LARO makes it susceptible to land use changes adjacent to or upstream from the recreation area. A combination of agricultural, industrial, residential, and transportation developments have negatively modified range and forest lands, introduced non-native or invasive species, and altered natural drainage patterns by increasing runoff and sedimentation. The upper Columbia River Valley contains numerous mines and timber mills that are known sources of trace element contamination and other pollutants (see “Abandoned Mineral Lands”; Riedel et al. 1997; Bortleson et al. 2001; Barton and Turney 2010). Additionally, the water quality of Lake Roosevelt is impacted by runoff from wastewater treatment plants, nearby farms or ranches, shoreline erosion, recreational waste (e.g., campsites, exhaust, unspent boating fuels), as well as rural and suburban developments along the shoreline (Riedel et al. 1997; National Park Service 2009). As the population continues to grow, increased water demand may further stress or threaten the quality and quantity of local groundwater sources, the Columbia River watershed, and Lake Roosevelt.

Flooding

Flood control management was one of the original purposes guiding the construction of Grand Coulee Dam and the establishment of Lake Roosevelt. The upper Columbia River watershed that feeds into LARO encompasses nearly 116,500 km² (45,000 mi²), and most of the water (roughly 89%) originates from glacial ice, lakes, and snowpacks high in the Canadian Rocky Mountains (National Park Service 2009). Flooding is often driven by large storm events (e.g., atmospheric rivers, hurricanes) combined with seasonal melting of snowpacks and glaciers in the Canadian Rockies. Each spring, Lake Roosevelt is strategically drawn down roughly 9–24 m (30–80 ft) to accommodate spring runoff or meltwater (Carrell 1981; Riedel et al. 1997; National Park Service 2009). Roughly 90% of Lake Roosevelt’s shoreline consists of unconsolidated Quaternary deposits that are highly susceptible to flooding, erosion, and flood-induced landslides (National Park Service 2009).

At the recreation area, floods can range from minor inconveniences to life-threatening emergencies, as riverine and reservoir flooding can temporarily inundate park infrastructure and resources, destabilize or erode shorelines, instigate landslides, damage roadways, and carry large rocks or woody debris. During flood events, increased precipitation and runoff strengthen tributary flow and erosion, producing a large amount of sediment and debris that is transported toward Lake Roosevelt. Rising reservoir levels and disturbed lands prevent the establishment of anchoring vegetative communities, which can leave areas of shoreline destabilized and exposed to erosion (Wagner et al. 2005). In April 2007, flood-related landslides damaged several roads along the west side of Lake Roosevelt, including a section of US Highway 395 near mile marker 250. Additional flood-induced landslides were documented along the Kettle River in May 2018. According to National Park Service (2009), although flash flooding presents a potential risk in the tributaries and side canyons of the lake, there is no evidence that flash flooding has occurred to date.

Mass Wasting

The term “mass wasting” is used to describe downhill movements of rock, soil, or ice and includes several types of landslide phenomena, such as debris (or snow) avalanches, debris flows, slumping or slope creep, and rockfalls. At LARO, roughly 90% of Lake Roosevelt’s shoreline consists of unconsolidated Ice Age

sediments that are susceptible to landslides and bank erosion. Terraces surrounding the lake have failed at hundreds of sites, resulting in the costly destruction of public and private property, infrastructure damage, natural resource loss, and visitation restrictions (Figure 9; National Park Service 2009). In addition to causing millions of dollars in damages, landslides pose a considerable safety threat; some of the largest landslides in LARO occur without warning and generate massive reservoir tsunamis (see “Reservoir tsunamis”; Jones et al. 1961; Kiver and Stradling 1995; Riedel et al. 1997; National Park Service 2009). Additionally, historic landslides (pre-Grand Coulee Dam) have temporarily obstructed or dammed the Columbia River, resulting in floods that impacted floodplains, orchards, and farms (Jones 1954; Jones et al. 1961; Riedel et al. 1997).



Figure 9. Photograph of a November 2024 landslide across from Colville Flats. Unconsolidated terrace deposits along the shoreline are susceptible to erosion or landslides, which contribute a large amount of rock and woody debris into Lake Roosevelt. NPS/Eric Weatherman.

Landslides at LARO are primarily generated by reservoir level fluctuations, as annual controlled releases draw down Lake Roosevelt to accommodate spring runoff and meltwater. Rapid drawdowns of the reservoir can influence pore-water pressures in the shoreline substrate which leads to slope instability and failure (Riedel et al. 1997). The degree of landslide risk can be mitigated in-part by controlling the rate and volume of reservoir withdrawal. Landslide risk is a minor concern for a 9 m (30 ft) drawdown, a moderate concern for a 9–15 m (30–50 ft) drawdown, and a major concern for drawdowns greater than 15 m (50 ft; Riedel et al. 1997; National Park Service 2009). Additionally, drawdown rates more than 0.5–0.6 m/day (1.5–2.0 ft/day) are believed to increase landslide susceptibility (Riedel et al. 1997; National Park Service 2009).

Other causes of landslides at the recreation area include wave action, freeze-thaw, enhanced runoff, flooding, and human activity (e.g., construction, development).

According to River and Stradling (1995) and National Park Service (2009), there are six types of landslides surrounding Lake Roosevelt: (1) slump-flow; (2) skin slides; (3) multiple alcove; (4) mudflow; (5) unconformity; and (6) bedrock. Slump-flow landslides are the most frequent and involve medium to large earth movements (greater than 5,730 m³ [202,500 ft³]) that display a degree of downward rotational slip (Kiver and Stradling 1995). Skin slides are the second most frequent landslide type and involve the removal of basal shoreline material that drives a slow but persistent retreat of terrace slopes. Multiple alcove landslides represent some of the largest mass wasting events along the upper Columbia River Valley and generally produce two or more alcoves (steep-sided hollows) along the reservoir shoreline. Although these landslides are limited in number, they appear to occur along higher shoreline terraces where bedrock channels are buried beneath Quaternary surficial deposits (Jones et al. 1961; Kiver and Stradling 1995). These channels act as conduits for groundwater flow, which can saturate hillslopes, leading to slope instability and failure. Mudflows are rapid failures in which material behaves and moves like a thick fluid. Unconformity landslides occur where unconsolidated sediments overlie bedrock and typically involve sliding or slump movements along the unconformity contact. Although the bedrock underlying LARO is relatively stable, small rockslides are prone to occur and often result from lateral or vertical stream incision, undercutting of valley walls by flood currents, and human disturbances (e.g., road, railroad, trail construction; Kiver and Stradling 1995). Additionally, faults and fractures associated with the Pend Oreille River fold and thrust belt traverse portions of LARO and influence the structural integrity of bedrock slopes (see “Proterozoic and Paleozoic Eras”). One of the largest recognized bedrock landslides in the recreation area occurred at Whitestone Rock, an Eocene dome consisting of intrusive dacite (**Eida**). Vertical fractures along the east face of Whitestone Rock are a product of exfoliation (weathering where rock layers peel away in sheets) that weakens the bedrock and facilitates landslides (Figure 10).



Figure 10. A view of Whitestone Rock along the south shore of Lake Roosevelt. Standing nearly 183 m (600 ft) above the surface of the reservoir, Whitestone Rock consists of Eocene intrusive rocks that are vertically fractured along its eastern face. These fractures facilitate exfoliation and bedrock landslides. NPS photograph.

Reservoir tsunamis

Landslides in LARO can displace significant volumes of shoreline material into Lake Roosevelt and generate massive lake waves or reservoir tsunamis capable of damaging infrastructure (e.g., boats, docks) and threatening natural resources or lives. According to Jones et al. (1961), the largest recorded tsunami event occurred in April 1952 and was caused by a multiple alcove landslide in the Reed terrace area approximately 160 km (100 mi) upstream from Grand Coulee Dam. The landslide caused the shoreline to rapidly retreat nearly 610 m (2,000 ft) in one day and resulted in the widespread collapse of material into Lake Roosevelt. The turbulent landslide damaged three roadways, claimed agricultural land, and created a 20 m (65 ft) tall wave that crashed upon the opposing shoreline (Jones et al. 1961; Riedel et al. 1997; National Park Service

2009). The landslide that generated the tsunami was associated with abundant groundwater, which destabilized the unconsolidated sand deposits underlying the shoreline:

Some triggering effect, such as the slight increase of weight caused by excessive water or excessive pressure in the pores of the sands, started the sands surging from beneath the heavy section of unstable silt and clay. Like other landslides in the Reed terrace area, without warning, there was an instantaneous collapse, and the materials flowed with great turbulence into Franklin D. Roosevelt Lake. Great quantities of water poured out at the base of the sand and gravel cap; however, the greatest quantities came out sporadically at many different locations. A large spring would gush out suddenly in one place and then taper off as another gushed out elsewhere. (Jones et al. 1961, p. 17)

In March 1969, a landslide just north of the Washington State Route 25 bridge caused a 15–18 m (50–60 ft) tsunami that struck the opposite shoreline. Damages associated with the tsunami were fortunately limited, as the reservoir level was very low at the time. The landslide generated a massive amount of debris that managed to clog the Spokane arm for several days (Figure 11). Damage from this landslide has left visible scars on the hillside, and there is still debris remaining at the bottom of Lake Roosevelt. Another large, notable landslide occurred along the Reed terrace in April 1944, which generated waves reaching a maximum height of approximately 9 m (30 ft; Jones et al. 1961). One of the most recent reservoir tsunamis occurred in January 2009 and resulted in a 9 m (30 ft) wave that damaged docks at Breezy Bay, Moccasin Bay, Sunset Point, and Arrowhead Point (Washington State Military Department 2013).



Figure 11. Historic photograph of the March 1969 landslide at LARO. The landslide occurred along the Spokane arm of Lake Roosevelt just north of the Washington State Route 25 bridge and generated a 15–18 m (50–60 ft) tsunami that struck the southern shore of the lake. A large amount of rock and woody debris collapsed into the lake, congesting the Spokane arm for several days. Landslide scars are still visible today. US Bureau of Reclamation photograph.

Radon

Radon is a naturally occurring gas created by the decay of radioactive elements present in many rocks. Although radon is almost always present in small amounts in soil and rocks, some types of rock (e.g., volcanic rocks, granites, dark shales, phosphate-rich rocks, and metamorphic rocks) have the potential to produce above-average amounts of radon gas that can pose a known health risk (Otton 1992). According to the EPA map of radon zones, Ferry, Stevens, and Okanogan counties are identified as zones of highest potential (zone 1) for elevated indoor radon levels that may exceed 4 pCi/L; Lincoln and Grant counties are zones of moderate potential (zone 2) between 2 and 4 pCi/L (see <https://www.epa.gov/radon/epa-maps-radon-zones-and-supporting-documents-state>; accessed February 2025). The EPA has guidance for radon mitigation.

Seismicity

Washington state is ranked second in terms of seismic risk in the United States, with at least 15 major damaging earthquakes recorded since 1872 (Washington Geological Survey 2017). The Okanogan Highlands

and Columbia Basin in eastern Washington represent areas of relatively low seismic risk compared to the rest of the state (Petersen et al. 2023). However, the western margin of North America is an active plate boundary defined by seismicity and volcanism. Large historic earthquakes throughout the Pacific Northwest, including the [1872 North Cascades earthquake](#), may have had impacts on the upper Columbia River Valley of LARO (Kiver and Stradling 1995). The recreation area is surrounded by multiple seismic stations within a radius of 32 km (20 mi) that are part of the Pacific Northwest Seismic Network (see <https://pnsn.org/seismograms/map>; accessed February 2025). The closest seismic monitoring station to LARO is located approximately 4.0 km (2.5 mi) southeast of Hawk Creek Falls in Davenport; additional nearby stations are in the cities of Colville and Hunters, Washington.

Swelling Clays

Swelling clays, or shrink-swell clays, include minerals such as smectites that are physically altered by the presence of water and tend to swell when wet and shrink when dry. As swelling clays expand or contract, the change in volume can undermine the integrity of the substrate, increase the susceptibility of slope failure, and cause infrastructural problems along roadways or trails. According to the USDA NRCS Web Soil Survey, several soils mapped adjacent to Lake Roosevelt are rated “low” to “medium” in linear extensibility (a determination of shrink-swell potential; see “Soils”). Linear extensibility ratings are based on the percentage of volume change as soil dries and include four assessment categories: (1) low, <3%; (2) medium, 3–6%; (3) high, 6–9%; and (4) very high, >9%. The ratings for LARO indicate that swelling clays can cause low to moderate volume change capable of damaging buildings, roads, and other structures.

Toxicological Soil

According to the DOI SHIRA Risk Mapper report, soils within LARO have potentially high amounts of arsenic, asbestos or erionite (fibrous silicate minerals), cadmium, lead, selenium, and *Bacillus anthracis*—a naturally occurring soil pathogen known to cause anthrax. Naturally occurring asbestos or erionite occurs in certain geologic settings (e.g., those containing ultramafic or mafic rocks [rocks with low silica content] and fibrous minerals) and can introduce health issues if disturbed by natural erosion or human activities. Inhalation of fine airborne particles of asbestos or erionite can cause various respiratory illnesses, including mesothelioma and other types of cancer. Soil maps show that potentially hazardous concentrations of arsenic, cadmium, lead, and selenium occur within the top 5 cm (2 in) of soil based on 2010 sampling (DOI SHIRA). For more information on naturally occurring arsenic, cadmium, lead, selenium, and their potential health impacts, visit the US Department of Health and Human Services Agency for Toxic Substances and Disease Registry (see <https://www.atsdr.cdc.gov/>; accessed February 2025).

The bacteria *Bacillus anthracis* causes the rare, naturally occurring disease anthrax, which can cause severe illness in both humans and livestock exposed to spores. For more information on the public health risks associated with anthrax, visit the US Centers for Disease Control and Prevention's anthrax website (see <https://www.cdc.gov/anthrax/about/index.html>; accessed February 2025).

Volcanism

Volcanism has shaped the American Cordillera region for millions of years and continues to do so today. According to the USGS, Washington state has five volcanoes listed as having high or very high threat potential: (1) Glacier Peak; (2) Mount Adams; (3) Mount Baker; (4) Mount Rainier; and (5) Mount St. Helens. Although LARO is located outside the proximal hazard zones for lahars, lava or pyroclastic flows, ballistic ejecta, rock fall, and thick tephra, the recreation area is still susceptible to volcanic ash that can be

carried downwind for hundreds of miles (Gardner et al. 1995; Hoblitt et al. 1995; Scott et al. 1995). Plumes of volcanic ash can block or obscure sunlight, generate lightning (and fires), and restrict visibility, thereby slowing or stopping vehicle travel. Ash clouds consist of fine particles of airborne glassy material that are abrasive and may damage mechanical devices and increase maintenance problems; these clouds are extremely dangerous to aircraft and may cause engine failure. The suspension of ash in water can lead to damage at hydroelectric facilities (i.e., Grand Coulee Dam), irrigation pumping stations, sewage-treatment facilities, and stormwater systems (Waitt et al. 1995; Wolfe and Pierson 1995). Accumulations of ash exceeding about 10 cm (4 in) on the roof of a building may instigate structural damage or collapse (Hoblitt et al. 1995; Wolfe and Pierson 1995). Wet deposits of ash can become sticky, heavy, highly conductive, and capable of short-circuiting transformers or power lines. Airborne ash can cause or exacerbate respiratory or vision problems.

Scattered across LARO are numerous ash deposits that record several Cascadian eruptions including the cataclysmic eruption of Mount Mazama approximately 6,800 years ago (resulting in Crater Lake), as well as the violent 1980 eruption of Mount St. Helens (Kiver and Stradling 1995; Riedel et al. 1997). According to a USGS volcanic hazards assessment report by Scott et al. (1995), the recreation area has a 0.02–0.2% annual probability of accumulating 1 cm (0.4 in) or more of tephra sourced from active Cascade volcanoes—the majority of which may come from by Mount St. Helens (Figure 12). The 1980 eruption of Mount St. Helens deposited roughly 0.5 to 8.0 cm (0.25 to 3.0 in) of ash across the Washington communities of Yakima, Ritzville, and Spokane (Hoblitt et al. 1995; Scott et al. 1995). These ash falls disrupted transportation, business activity, and community services for nearly two weeks (Hoblitt et al. 1995; Scott et al. 1995). Lessons learned from the 1980 eruption are used throughout the Pacific Northwest to prepare governments, businesses, and citizens for the next potential volcanic threat.

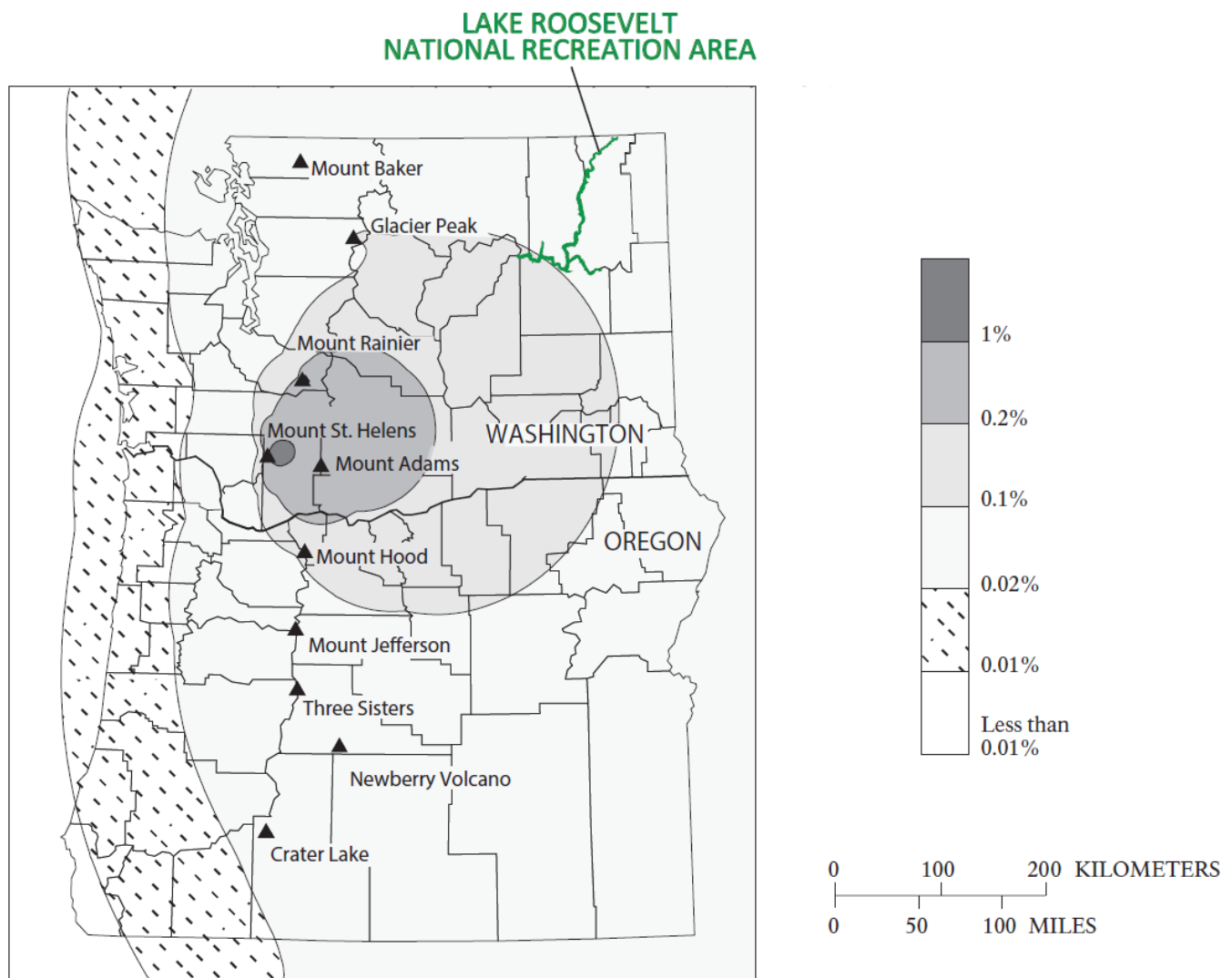


Figure 12. Map showing the annual probability of 1 cm (0.4 in) or more of ash accumulation in Washington and Oregon from major Cascade volcanoes. The recreation area is susceptible to volcanic ash that can travel hundreds of miles. Fine particles of ash can cause several problems, including limited visibility, mechanical or electrical system failure, structural issues, and health concerns. The probability distribution is heavily impacted by Mount St. Helens, which is known for generating large amounts of tephra. Modified figure 2a from Scott et al. (1995).

Geologic Resource Protection

Legislatively Required Geologic Inventories

The NPS GRD has developed an article series (<https://www.nps.gov/articles/series.htm?id=FA0A8F89-CD67-1CCE-5A6608B444E8A7C0>; accessed February 2025) that summarizes the laws, regulations, and policies that specifically apply to geologic and soil resources or processes. These protection measures were established to maintain the integrity of these resources or processes while minimizing the impacts of natural or human activity.

The core responsibility of the NPS is to preserve and protect park resources, processes, systems, and values unimpaired for present and future generations. According to National Park Service (2006), the NPS will

preserve and protect geologic resources, features, and processes as integral components of park natural systems. The goals of the NPS are to assess the impacts of natural processes and human activities on geologic resources; maintain and restore the integrity of existing geologic resources; integrate geologic resources management into NPS operations and planning; and interpret geologic resources for the benefit and enjoyment of park visitors (National Park Service 2006). Various management protection policies applicable to geologic resources, features, and processes are included in National Park Service (2006) and are also organized at the following website: <https://home.nps.gov/subjects/geology/geoheritage-nps-management-policies.htm> (accessed February 2025).

Paleontological and Cultural Resources

The paleontological and cultural resources of LARO are invaluable and provide a unique glimpse into the geologic and historic past. Although fossils are limited, some are associated with cultural sites that are susceptible to temporary inundation by Lake Roosevelt, burial or destruction by shoreline erosion and landslides, negligence, and looting. Since the establishment of the recreation area in the 1940s, cultural resource management has evolved from a minor concern for NPS managers to one that has dominated relationships with the other managing partners, including the US Bureau of Reclamation, US Bureau of Indian Affairs, Colville Confederated Tribe, and Spokane Tribe of Indians. The greater importance of the issue mirrors not only the increased legislation that governs federal actions concerning cultural resources, but also shows the growing collaboration with Indigenous tribes in managing these resources, including the physical remains of their cultural and spiritual heritage (McKay and Renk 2002). Today, the challenge for land managers is to find the balance that ensures the protection of these vital resources while satisfying agency or tribal needs and mandated requirements.

Many cultural features located along the Columbia and Spokane rivers—including approximately 35 sites—were permanently compromised by the construction of Grand Coulee Dam and the infilling of Lake Roosevelt (Pouley 2008). Today, the annual drawdowns of the reservoir expose cultural resources to damage or looting from visitors or relic collectors (National Park Service 2009). During the late 1960s, shoreline monitoring became a serious concern as archeologists and other NPS staff discovered looters searching for cultural resources during periods of low water. To help combat the situation, LARO adopted a successful campaign that included apprehending violators, public education through press releases (including newspapers, radio, and television), and partnering with the US Attorney’s office to develop procedures dealing with repeat offenders (McKay and Renk 2002).

All paleontological and cultural resources are nonrenewable and subject to science-informed inventory, monitoring, protection, and interpretation. Cultural resources are protected through the [Antiquities Act of 1906](#). Protection measures for fossils are outlined by the 2009 Paleontological Resources Preservation Act (PRPA). For additional information regarding paleontological resource laws, regulations, and policies, the NPS GRD developed the following summary article: <https://www.nps.gov/articles/paleontology-legal-instruments.htm> (accessed February 2025).

Hydrological Resources

As a hydrological park, one of the main management concerns for LARO is the water quality and quantity of Lake Roosevelt, including its numerous tributaries. The water quality (e.g., temperature, pH, dissolved oxygen, nutrients) of the reservoir is a complex and critical resource issue impacted by a myriad of variables

such as climate change, land usage, visitation, shoreline erosion, landslides, and controlled dam releases. Over many decades, mines, timber mills, and other industrial plants upstream of Lake Roosevelt released heavy metals and other pollutants into the Columbia River (see “Abandoned Mineral Lands”; Riedel et al. 1997; Bell and Hinson 2009). Multiple studies by the USGS, US Fish and Wildlife Service, Washington State University, and the US EPA show elevated concentrations of arsenic, cadmium, copper, lead, mercury, and zinc in sediment samples collected from Lake Roosevelt, the upstream reach of the Columbia River, and several of its tributaries (Bortleson et al. 2001; Majewski et al. 2003; Barton and Turney 2010). Most of the upper Columbia River watershed (roughly 89%) originates from glacial ice, lakes, and snowpacks high in the Canadian Rocky Mountains (National Park Service 2009). Seasonal meltwater contributions to the Columbia River help buffer the chemistry of Lake Roosevelt and regulate reservoir levels. Projected climate change scenarios for LARO include an increased likelihood of extreme temperature and weather events (e.g., storms, drought) combined with glacier and snowpack reduction (see “Climate Change”). The decrease or disappearance of glaciers and snowpacks will likely impact both the quality and quantity of Lake Roosevelt, the upper Columbia River watershed, and regional groundwater sources.

Inventory Needs

The following table (Table 4) presents geologic and soil resources inventory needs that were identified during the 2024 follow-up meeting, in NPS planning documents, or through literature review.

Table 4. List of identified geologic and soil resources inventory needs for the recreation area.

Subject	Inventory Need(s)	Reference(s)
Geohazards	Investigate how shoreline erosion might be affecting geologic and cultural resources. Basic questions to be answered include: Are there public safety issues or hazards associated with shoreline slumping? Is LARO losing cultural and natural resources, such as paleontological and archeological site localities and the sedimentary record of the glacial outburst floods, to erosion? What are suitable erosion mitigation techniques, especially to protect cultural sites?	Connors (2002)
Geohazards	Develop a comprehensive shoreline erosion control management plan. The plan should identify all threatened resources and prioritize site mitigation activities. Reservoir shoreline assessments of Jones (1954) and Jones et al. (1961) could be combined with known natural resource locations to prepare a prioritized erosion control plan.	Riedel et al. (1997)
Geohazards	Areas where lineaments (faults or fractures) intersect Lake Roosevelt coincide with several highly unstable slope areas and should be looked at in more detail. The position of the Columbia River valley itself is at least partially, if not wholly, controlled by geologic characteristics or features of the bedrock, such as folds and faults. Thus, more detailed lineament studies and their correlation with active slopes would be a useful endeavor to properly identify and understand more about high-risk areas.	Kiver and Stradling (1995)

Subject	Inventory Need(s)	Reference(s)
Mapping	An inventory of Ice Age features (e.g., Missoula Flood deposits, erratics, rhythmites) that includes the feature type, occurrence, and distribution. The recreation area needs help developing a mapping framework to track Ice Age flood features due to their extensive occurrence. A geologic map of these Ice Age features could help LARO management with respect to interpretation, geologic resource protection, and geohazard mitigation.	2024 follow-up meeting
Mapping	Geologic maps that differentiate surficial deposits, rather than consolidating them into a few cover units, would provide greater value to LARO for management, resource stewardship, health and safety, and interpretive purposes. Detailed, site-specific geologic maps may help inform managers about geologic-related concerns and mitigation strategies.	Connors (2002)
Mapping	Detailed wetland maps, particularly at development sites along the Lake Roosevelt shoreline. Wetland mapping in the National Wetland Inventory is at a 1:24,000 scale and not detailed enough for site-specific development protocols.	Riedel et al. (1997)
Paleontology	Identification of fossil specimen collected inside LARO near Fort Spokane. To date, no consensus has been reached regarding the taxa or origin of the specimen.	Kenworthy et al. (2002)

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