3.11 Geology, Soils, and Geologic Hazards

Geomorphology and sediment transport in the Klamath River watershed have implications on water quality and the survivability of aquatic species that use the sediment beds for reproduction (e.g., egg laying, larval stages). This section provides material relevant to the analysis of each of these issues; however, specific impacts on water quality and aquatic biology are addressed in Section 3.2, Water Quality, and Section 3.3, Aquatic Resources. This section assesses the changes to geomorphology and the potential for shoreline landslides and erosion due to sediment transport processes within the Klamath River watershed. This analysis also assesses the potential for local sedimentation in eddies and other "dead" zones in the Klamath River channel, as well as the effects on the estuary both during and following dam removal activities. Finally, this section discusses the potential for impacts from geologic hazards such as seismology and volcanology in the project area.

3.11.1 Area of Analysis

The area of analysis, or "project area," for the Klamath Facilities Removal Environmental Impact Statement/Environmental Impact Report (EIS/EIR) for geology, soils and geologic hazards includes the riverbed and reservoir banks at the sites of the Four Facilities as well as the riverbed and adjacent banks along the Klamath River downstream of Iron Gate Dam to its mouth at the Pacific Ocean.

3.11.2 Regulatory Framework

Geology, soils, and geologic hazards within the area of analysis are regulated by state and local laws and policies, which are listed below.

3.11.2.1 State Authorities and Regulations

- Oregon Statewide Planning Goals and Regulations (Oregon Department of Land Conservation and Development, 2001)
- Oregon Revised Statute 455.477 (Oregon, State of, 2009 edition)
- Alquist-Priolo Earthquake Fault Zoning Act (California Public Resources Code, Division 2, Chapter 7.5)
- Seismic Hazards Mapping Act (California Public Resources Code, Division 2, Chapter 7.8)

3.11.2.1 State Authorities and Regulations

- Siskiyou County General Plan, Land Use and Seismic Safety elements (Siskiyou County 1975, 1980)

3.11.3 Existing Conditions/Affected Environment

The potential removal of the Four Facilities raises concerns regarding the amount and nature of sediments stored in the respective reservoirs. Data collected to date indicates that approximately 13.5 million cubic yards (yd^3) of deposits are stored in the four reservoirs and that these deposits consist of fine-grained particles (coarse sand and finer). The channel bed of the river mainstem downstream is primarily composed of cobble-sized material (Stillwater Sciences 2008; Department of Interior [DOI] 2010).

3.11.3.1 Regional Geology

The Klamath Basin lies at or near the convergence of three tectonic plates that influence the geologic setting of the region: the Pacific, Juan de Fuca, and North American Plates. Consequently, the Klamath River flows through four distinct geologic provinces, each of which changes the character of the river's channel morphology and its tributary watersheds, varying the supply of inputs such as water, sediment, nutrients, and wood (Federal Energy Regulatory Commission [FERC] 2007). The Upper Klamath Basin lies in the transition zone between the Modoc Plateau and Cascade Range physiographic provinces, with the Klamath River cutting west through the Klamath Mountain province and then the Coast Range province where it reaches the Pacific Ocean near Requa, California (Figure 3.11-1; California Department of Conservation 2002; DOI 2010).

The Modoc Plateau abuts the Basin and Range Province where volcanic ramparts transition to escarpments with the valleys of the Basin and Range province. The Basin and Range province is an area of relatively young (Quaternary to Tertiary age) volcanic rocks with lesser amounts of intrusive rocks (DOI 2010). Basin and Range faults either displace the volcanic ramparts of the Modoc Plateau or are buried beneath them. The Klamath River passes through this province from the city of Klamath Falls to the Oregon-California state line. Below the state line, the river passes through the Cascades province. The portion of the basin that straddles the Modoc Plateau and Cascade Range provinces is typically called the "Upper" Klamath Basin. As the Klamath River flows towards the Pacific Ocean, downstream from Iron Gate Dam, it passes through the Klamath Mountains geomorphic province (which includes the Trinity Alps, Salmon Mountains, Marble Mountains, and Siskiyou Mountains). Rocks here are completely different from rocks upstream of Iron Gate Dam and are composed mostly of Cretaceous to Paleozoic age metamorphosed marine igneous and sedimentary rocks. Consequently, numerous faults and antiforms[1] are exposed along the river's path as it winds its way through the Klamath Mountains to the Pacific Ocean (DOI 2010).

Below river mile (RM) 40 (from the town of Weitchpec to the Pacific Ocean) the Klamath River traverses the Coast Range province. The geology of this area is underlain mostly by the Eastern Belt of the Franciscan Complex and a sliver of the Central Belt along the coast. The Eastern Belt is composed of schist and meta-sedimentary rocks (mostly metagraywacke) with minor amounts of shale, chert, and conglomerate. The Central Belt is principally an argillite-matrix mélange that contains kilometer-sized slabs of greenstone, serpentinte, graywacke, and abundant meter-size blocks of greenstone, graywacke, chert, higher-grade metamorphics, limestone, and lenses of serpentinite

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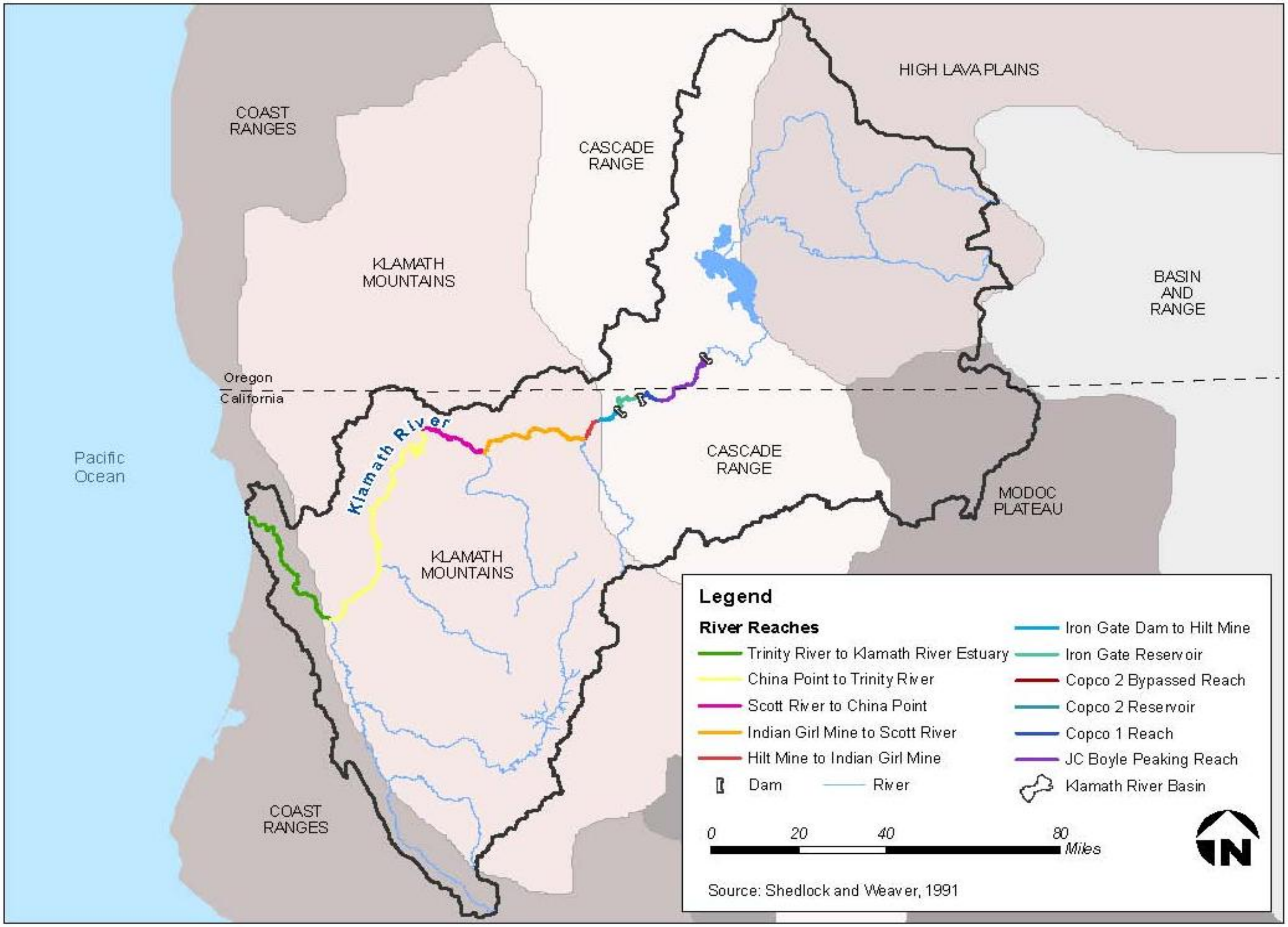
[1] An antiform refers to a fold in the geology which curves upward but which the age of the geologic layers at the surface are unknown.



Source: Shedlock and Weaver, 1991

Figure 3.11-1. Klamath Basin Physiographic Provinces

(Jayko and Blake 1987). The Franciscan Complex generally consists of sandstone with smaller amounts of shale, chert, limestone, conglomerate, as well as serpentine and blueschist. Movement of the tectonic plates results in faulting in the Coast Range and the continued uplifting of the relatively young Franciscan rocks. This movement in conjunction with high precipitation rates and weak nature of the rocks has resulted in high erosion rates that create steep hillslopes and high sediment yields (FERC 2007).

3.11.3.2 Geomorphology

In many ways the Klamath River is the reverse of most river systems. The headwaters flow through relatively flat, open country, and then flow through mountainous areas with input of cold water from the major tributaries. Accordingly, the river is warmer and flatter upstream of the project area, while downstream portions, beginning at the project area, tend to be colder and steeper. The Klamath River from the Oregon-California Stateline to downstream from Iron Gate Dam is a predominantly non-alluvial, sediment supply-limited river flowing through mountainous terrain. Downstream from the dam and for most of the river’s length to the Pacific Ocean, the river maintains a relatively steep, high-energy, coarse-grained channel frequently confined by bedrock. Much of the course of the river in the Klamath Hydroelectric Reach is bedrock controlled, interspersed with relatively short alluvial reaches; thus, the influence of the Four Facilities on river geomorphology within the project area and downstream is limited. Floodplain development is minimal, and wider valleys allowing alluvial channel migration processes are rare. The following subsections provide a more detailed description of the geology and geomorphology of each of the subject reservoirs and associated river reaches, beginning with J.C. Boyle Reservoir and continuing downstream to the river estuary.

J.C. Boyle Reservoir

The bedrock surrounding and underlying J.C. Boyle Reservoir is principally composed of moderately well-bedded to massive, moderately well-consolidated sedimentary rocks containing volcanic material. Lava flows overlie these rocks and form many of the ridges above the reservoir. In the downstream portion of the reservoir (downstream from the Highway 66 Bridge), young lava flows line the sides of the reservoir (DOI 2010).

J.C. Boyle Peaking Reach

Downstream from J.C. Boyle Reservoir, the river canyon begins to open and channel slope decreases. This reach has a relatively low gradient (approximately 0.8 percent) and alternates between pools, bars, runs, and riffles. There is a wide terrace, which supports a riparian corridor of varying width along the channel, beyond which there is a floodplain. There are several side channels in conjunction with lateral bars and islands (FERC 2007).

Copco 1 Reservoir

The Copco 1 Reservoir is at a topographic transition area on the Klamath River, such that about 80 percent of the reservoir occupies a formerly lower gradient reach of the river. This break in stream gradient is largely the result of cinder cones and associated lava flows at the downstream portion of the reservoir (FERC 2007). Thus, geologic conditions in Copco 1 Reservoir are different than those in J.C. Boyle Reservoir, even though the bedrock beneath and surrounding both reservoirs consists primarily of rocks formed from older volcanic flows overlain by younger lava flows. The rocks that underlie Copco 1 Reservoir contain thick deposits of airfall tuff and ash flows and there are several young volcanic eruptive cinders and cinder cones adjacent to the reservoir. Additionally a diatomite deposit along the southern downstream shore of the reservoir near Copco 1 Dam is even with or extending up to 20 feet above the reservoir surface (PanGeo 2008).[2] Several streams enter Copco 1 Reservoir, including Long Prairie Creek, Beaver Creek, Deer Creek, and Raymond Gulch. Sediment depositions and/or delta formations are present at the mouths of the larger streams in the reservoir (DOI 2010).

Copco 2 Reservoir

Copco 2 Reservoir is a relatively short impoundment (extending just over 0.25 mile) that lies immediately downstream from Copco 1 Dam. The reservoir is narrow and confined by a narrow bedrock canyon formed by lava flow (FERC 2007). As it is at Copco 1 Dam, rock at the Copco 2 Dam consists of a combination of lava flows and shallow intrusions. The bedrock surrounding and underlying the reservoir comprises basalt and andesite and steep slopes consisting of volcanic cobbles and boulders lie along both sides (DOI 2010).

Copco 2 Bypass Reach (RM 198.3–196.9)

Downstream from Copco 2 Dam, the Copco 2 Bypass Reach is characterized by a confined, boulder- and bedrock-dominated channel. The river in this reach is strongly influenced by the lava flow on the right bank of the river and there is minimal floodplain area. The average gradient of the reach is about 1.9 percent. Fossilized boulder-cobble bars dominate the channel cross section. Measurements of the bar by PacifiCorp during the FERC relicensing proceedings found that the median grain size was approximately 10 inches. Bedrock ledges also exist within the reach. Near the end of the reach, the Copco 2 Powerhouse discharges water into the Klamath River (FERC 2007).

Iron Gate Reservoir and Tributaries (RM 196.9–190.1)

Like Copco 1 Reservoir, Iron Gate Reservoir overlies a topographic transition on the Klamath River, where a steeper reach of river upstream (that of the Copco 2 Bypass Reach and a portion of the river inundated by Copco 1 Reservoir and Copco 2 Reservoir) transitions into the lower gradient reach downstream from Iron Gate Reservoir. In this area, the topography widens, and the channel is less restricted by the localized basalt lava flow from north of the Copco 2 Bypass Reach (FERC 2007). The reservoir has relatively steep topographic side-slopes and a narrow channel with numerous side drainages. Three of these side drainages are large, and two (Camp Creek at Mirror Cove and Jenny Creek) likely contribute substantial amounts of sediment to the reservoir. Except for these three side drainages, Iron Gate Reservoir hosts a relatively similar depositional environment throughout its length (DOI 2010).

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[2] Diatomite is a chalk-like, soft, friable, earthy, very fine-grained, siliceous sedimentary rock, usually light in color. It is principally as a filter aid; but it has many other commercial applications, such as cement additives, absorbents, fillers, and insulation (USGS 2011).

Iron Gate Dam to Hilt Mine (RM 190-181)

The first reach downstream from Iron Gate Dam consists of a narrow floodplain and terraces confined by bedrock hills of the Western Cascade Volcanics and sedimentary rocks of the Cretaceous Hornbrook Formation. The channel is mostly single thread with a few areas of split flow that form mid-channel bars and side channels of short length. Most of the bars are at least partially vegetated, leaving few areas of exposed bars in the reach. Main tributaries that enter this reach include Brush Creek, Bogus Creek, Little Bogus Creek, Willow Creek, and Cottonwood Creek. With the exception of Cottonwood Creek, these tributaries form relatively small alluvial fans at their confluences with the Klamath River. Cottonwood Creek forms a large alluvial fan at its confluence with the river. Klamath River terraces are carved into the Cottonwood Creek alluvial fan deposits, suggesting that sediment input from Cottonwood Creek is limited to areas near and within the main channel of Cottonwood Creek (DOI 2011a).

Hilt Mine to Indian Girl Mine (RM 181-174.6)

In this reach, the change in the physical characteristics of the bedrock marks a transition in channel confinement, where more resistant rocks create a narrow canyon with narrow alternating terraces along the reach length. Few bars exist in this reach; at RM 179, a mid-channel bar appears to be associated with the Williams Creek alluvial fan, which enters at the upstream end of the high terrace of the Randolf Collier rest area. The Shasta River enters from the south near RM 177 and forms a small gravel bar at its confluence with the Klamath River. The only other notable tributary in the reach is Ash Creek, which forms a fan of negligible size at its confluence with the Klamath River. Other notable features in this reach are associated with in-stream mining, including cobble-boulder benches and bars and a few wing-dam pits (DOI 2011a).

Indian Girl Mine to Scott River (RM 174.6-143)

From Indian Girl Mine, the river valley broadens slightly within the canyon and allows for the preservation of broad gravelly terraces that have been extensively mined. In areas not obscured by mining, overflow channels are present on the terrace surfaces. Unvegetated bars are more prevalent in this reach and exist as point bars along the inside bends of channel meanders as well as mid-channel bar and side channel complexes. The channel maintains a mostly single thread meandering morphology with some areas of split flow around mid-channel bars.

At Gottville, several tributaries enter from the north and form a large alluvial fan complex that constricts the river and forms the Langley Falls rapid and associated large eddy directly upstream. Downstream from Gottville, between RM 166 and 161.5, the river valley narrows to about half the width of that upstream. Low terraces and point bars exist in this reach and have been extensively mined with tailings piles still visible on some of the surfaces. Channel morphology is less winding than that upstream and is single thread with a few small mid-channel bars. At the downstream end of this subreach, the Miller Gulch alluvial fan acts to constrict the channel. The river forms an eddy between the upstream end of the Miller Gulch fan and a small tributary fan from the opposite bank.

From Miller Gulch (RM 161.5) to Horse Creek (near RM 147), the river valley broadens again to include terraces with at least two levels and gravel bars. In several locations, the channel sinuosity increases. A narrow section exists in this reach from between RM 154 and RM 150 and is confined by bedrock on both sides of the river and by the Kohl Creek alluvial fan near RM 152. From RM 150 to Horse Creek, the river returns to a broader valley with a large remnant stream channel in the Cherry Flat area that has been extensively placer mined.

From Horse Creek to Scott River (RM 143), the river valley narrows and is confined by bedrock on both sides of the river. Terraces and bars are restricted to the insides of meander bends. Several small tributaries enter in this reach, forming steep alluvial fans at the confluence with the Klamath River, some of which have narrow terraces cut on their front edges. Channel morphology is single thread with a few small, unvegetated, mid-channel bars and point bars (DOI 2011a).

Scott River to China Point (RM 143-118)

Downstream from Scott River from RM 143 to 132, the extent and height of unvegetated gravel bars increases and bars become more prevalent with discontinuous narrow alluvial terraces forming along the canyon margins. Large alluvial fans control river position from RM 141 to 139 along the south side of the river. At Seiad Valley, large alluvial fans from Seiad Creek, Little Grider Creek and Grider Creek form a wider alluvial valley in which terraces are cut on the front edges of the fans and large bars and riffles are formed along the river channel as a result of tributary sediment contributions to the Klamath River.

From RM 130 to 121.5, the Klamath River flows through a winding bedrock canyon with unvegetated bars located on the insides of meander bends. Valley terraces and bedrock-cored bars are prevalent in this reach. From RM 121.5 to China Point, the canyon narrows as it enters bedrock of the Jurassic Galice Formation. Bedrock benches form along the channel margins. At China Point, an extensive, unvegetated gravel bar lies on the inside of the bend along with a higher alluvial terrace. On the south side of the river, a remnant channel is elevated above the present channel. Tributaries that contribute sediment to the river in this reach include Thompson, Fort Goff, Portuguese, Grider, Walker, O’Neil, and Macks Creeks (DOI 2011a).

China Point to Trinity River (RM 118-43.5)

From China Point to Deason Flat (RM 118-104), the channel is narrow with numerous valley terraces that have been extensively mined. Well-developed bars and riffles are formed at tributary confluences and meander bends. The lower three miles of this reach (RM 107-104) contain a greater number of unvegetated bars, which are formed by sediment inputs from Elk and Indian Creeks and channel constrictions downstream from RM 104. Tributaries in this reach contain large landslides, with Indian Creek watershed containing the most of any tributary.

From Deason Flat to Dutch Creek (RM 104-92), the river flows through a narrow bedrock canyon with low bedrock benches and gravelly veneers. Wider sections interspersed in this reach have small valley terraces that have been extensively mined and unvegetated gravel bars. This reach also contains notable landslides along the main stem, the largest of which is on the west side of the river between RM 98.5 and RM 93. Independence and Clear Creeks both contribute large amounts of sediment to the river in this reach.

From Dutch Creek to Trinity River (RM 92-43.5), the river is contained in a narrow bedrock canyon with intermittent alluvial reaches. This reach also includes the wider alluvial valley at Orleans (RM 58.5). Geomorphic features include valley terrace and bars, alluvial terraces and bars, bedrock benches and alluvial fans. Numerous landslides lie along the river and interact with the river through sediment contributions and controlling channel position. This reach is the downstream limit of channel mining on the Klamath River. Tributaries that are major contributors of sediment include Salmon River, Trinity River, Bluff Creek, Camp Creek and Ukonom Creek (DOI 2011a).

Trinity River to Klamath River Estuary (RM 43.5-0)

From Trinity River to Cappell Flat (RM 43.5-35), a narrow bedrock canyon with few bars and no floodplain or terraces exists, and is primarily bedrock controlled. Landslides and alluvial fans are less common, but locations still exist where these features have temporarily dammed the river based on remnant boulders in the channel and deposits on opposite banks.

From Cappell Flat to Starwein Flat (RM 35-10), the river flows through a narrow, confined valley with minimal floodplain and terraces. Bars are well developed and are either alternate bars formed in straighter reaches or point bars formed at meander bends. The extent of the bars increases in the downstream direction. Tributaries create split flow channels, mid-channel bars and riffles at their confluences with the main stem. Major sediment contributors include Blue, Pecwan, Cappell, Bear, and Tectah Creeks.

From Starwein Flat to the mouth (RM10-0), the river transitions into a wide valley with floodplain surfaces and narrow terrace remnants. Well-developed bars of variable height lie along the reach and several large pools and few riffles are present. Turwar Creek is the only major sediment producer in this reach, contributing mostly fine materials to the Klamath River (DOI 2011a). The lower seven miles of the Klamath River to its mouth at the Pacific Ocean is classified as a "Confined River System" with a relatively steep gradient. The river channel is largely confined by banks of hard bedrock, which keep it from forming shallow braided channels. Thus, the river is relatively narrow with cross-channel widths typically between 650 and 800 feet except at large bends and areas where bank/bar erosion is active. In these areas, the channel width increases up to 1,600 feet (the river makes several large bends that are controlled by the local geology). The relatively narrow river banks and highly variable flow (commonly 18,000 to +30,000 cubic feet per second [cfs]) make the river system "flashy", creating large variations in bedload capacity and bedload sediment gradations (DOI 2010).

The mouth of the river is characterized by a wave-dominated delta with a large barrier island parallel to the coastline (i.e., offshore sandbar). Behind the barrier island is a shallow lagoon about 2,500 feet long by less than 1,000 feet wide. This area of the Klamath River is highly dynamic, changing positions during large flood events and transporting most of its suspended load or silt and clay out to sea. The limited size of the lagoon is dominated by deposits of medium grained sand and silty sand with only very local accumulations of fine-grained materials (DOI 2010).

3.11.3.3 Sediment Supply and Transport

The Klamath River is supply limited for fine material (sands and small gravels), but capacity limited for large material (cobbles and boulders) (DOI 2011a). Practically no substantial sediment is supplied to the Klamath River from the watershed above Keno Dam; because of its large surface area, Upper Klamath Lake traps practically all sediment entering it from its tributaries.

The Lead Agencies estimate average annual sediment delivery at approximately 200,000 tons per year (ton/yr) from Keno Dam to Iron Gate Dam. The Scott River supplies approximately 607,000 tons/yr; the Salmon River supplies 320,000 tons/yr; and the Trinity River supplies 3.3 million tons/yr. The total annual delivery of sediment to the ocean from the Klamath River is estimated at 5.8 million tons/yr. The total annual delivery of sediment with a size greater than 0.063 millimeters (mm) [coarse sand] is estimated to be 1.9 million tons/yr (DOI 2011a). Table 3.11-1 provides the cumulative annual sediment carried downstream by the Klamath River and shows the proportion of coarse material and fine material within the load.

3.11.3.4 Reservoir Substrate Composition

In 2010, DOI conducted a sediment sampling study in the subject reservoirs to describe sediment composition and determine sediment thickness throughout all major sections of the reservoirs[3]. The study found that fine-grained sediment in all of the reservoirs but Copco 2 Reservoir consisted primarily of elastic silt and clay, with lesser amounts of elastic silt with fine sand. The sediment was determined to be mostly an accumulation of silt size particles of organic material such as algae and diatoms, and silt size particles of rock. The average grain size decreases nearer to the dams because smaller particles settle more slowly than larger particles. Accordingly, the upper reaches of each reservoir contained a higher percentage of silt, sand, and gravel than the lower reaches, which contain more clay, sandy elastic silt and elastic silt with trace sand. The elastic silt in all of the reservoirs had the consistency of pudding, and had very high water content (greater than 100 percent). The fine-grained sediment was also found to have a low cohesion and to be erodible; where water flowed greater than 2 to 4 miles per hour, accumulations of sediment were less than a few inches (DOI 2010). Table 3.11-2 describes the physical properties of the sediment in each reservoir, and the following paragraphs summarize the findings for each reservoir.

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[3] The study also addressed the chemical composition of the reservoir sediment. A summary of these results and the associated implications are addressed in Section 3.2 Water Quality.

Table 3.11-1. Cumulative Annual Sediment Delivery to the Klamath River

Source Area	River Mile	Cumulative delivery[1]		
		Total (tons/year)	% particles ≥0.063 mm	% particles ≤0.063 mm
Keno Dam to Iron Gate Dam	192.7	151,000	16%	84%
Iron Gate Dam to Cottonwood Creek	184.9	160,961	16%	84%
Cottonwood Creek	184.9	175,560	17%	83%
Cottonwood Creek to Shasta River	179.3	177,715	18%	82%
Shasta River	179.3	199,259	19%	81%
Shasta River to Beaver Creek	163.3	231,710	21%	79%
Beaver Creek	163.3	279,869	23%	77%
Beaver Creek to Scott River	145.1	373,073	25%	75%
Scott River	145.1	980,393	29%	71%
Scott River to Grider Creek	129.4	1,048,860	30%	70%
Grider Creek to Indian Creek	108.4	1,099,934	30%	70%
Indian Creek	108.4	1,173,246	30%	70%
Elk Creek	107.1	1,211,930	30%	70%
Clear Creek	100.1	1,253,972	30%	70%
Dillon Creek	85.8	1,282,389	30%	70%
Indian Creek to Dillon Creek	85.8	1,354,759	30%	70%
Dillon Creek to Salmon River	66.5	1,440,282	30%	70%
Salmon River	66.5	1,760,904	31%	69%
Salmon River to Camp Creek	57.3	1,785,769	31%	69%
Camp Creek	57.3	1,831,523	31%	69%
Camp Creek to Red Cap Creek	53.0	1,855,021	31%	69%
Red Cap Creek	53.0	1,897,796	31%	69%
Red Cap Creek to Bluff Creek	49.8	1,913,925	31%	69%
Bluff Creek	49.8	2,014,594	31%	69%
Bluff Creek to Trinity River	43.4	2,035,830	31%	69%
Trinity River	43.4	5,353,164	32%	68%
Blue Creek	16.1	5,455,971	32%	68%
Trinity River to Mouth	0.0	5,834,091	32%	68%

Source: Adapted from Stillwater Sciences 2010

Notes:

1. Density = 1.5 tons/yd^3. Mass report in US short tons. Above Cottonwood Creek, assumes 16 percent of total load is ≥0.063 based on grains size distribution of reservoir sediment (Gathard Engineering Consulting 2006). Below Cottonwood Creek, assumes 10 percent of total load is bedload and 24 percent of suspended load is sand ≥0.063. Coarse sediment delivery to the ocean is less than presented in this table when attrition by abrasion is considered.

Key:

mm: millimeters

Table 3.11-2. Physical Properties of Reservoir Sediment

Reservoir	Location	Volume yd^3	% Clay[1]	% Silt[1]	% Sand[1]	% Gravel [1]	Liquid Limit (%)	Plasticity Index (%)	Moisture Content (%)	Porosity (%)	Dry Bulk Density lb/ft
J.C. Boyle	Upper Reservoir	380,000	17.3	26.2	56.5	0.0	45.5	14.7	173	0.82	29.5
	Lower Reservoir	620,000	38.2	49.7	12.1	0.0	173	60.6	345	0.90	16.3
	Pre-Reservoir		3.7	9.5	28.4	58.5	44.9	12.7	23.4	0.38	101
Copco I	Upper Reservoir	810,000	27.9	46.8	25.1	0.2	109.3	49.3	287	0.88	19.2
	Lower Reservoir	6,630,000	55.8	34.2	10.0	0.0	154.3	59.1	295	0.88	18.7
	Pre-Reservoir		35.6	42.2	22.2	0.0	105.0	41.5	153	0.80	32.6
Iron Gate	Upper Reservoir	830,000	35.4	43.1	21.6	0.0	70.9	29.9	192	0.83	27.0
	Lower Reservoir	2,780,000	60.7	25.5	13.5	0.4	118.7	51.4	276	0.88	19.8
	Pre-reservoir		33.6	16.9	20.4	29.1	60.6	32.5	37.9	0.50	81.8
	Upper Tributary	300,000	31.8	42.7	25.5	0.0	60.7	22.7	102	0.73	44.4
	Lower Tributary	800,000	61.8	32.0	6.1	0.0	112.2	49.6	284	0.88	19.3

Source: DOI 2010; DOI 2011a.

Notes:

[1] Clay = 0 to 0.005 mm; Silt = 0.005 to 0.075 mm; Sand = #200 to #4 sieve; Gravel = #4 to 3 inch

Key:

yd^3: cubic yards

lb/ft: pounds per foot

J.C. Boyle Reservoir

As shown in Table 3.11-2, the upper portion J.C. Boyle Reservoir primarily has coarse-grained sediment, both as pre-reservoir alluvium and reservoir sediment. The reservoir has an abundance of gravel/sand bars and cobbles exposed above the reservoir water surface, with sub-surface sand and gravel found by stab-sampling. The reservoir also likely has small, local accumulations of fine grained reservoir sediment within the upper 5,000 feet of the reservoir, but most of the reservoir sediment in this section is coarse grained. The reservoir sediment becomes finer grained with distance downstream. Sediment sampling conducted by the DOI indicates that about 5,000 feet downstream, reservoir sediment is three to five feet thick and composed of silty sand to poorly graded sand with silt with less than about 15 percent fine grained material (DOI 2010).

Only thin deposits of reservoir sediment were present at the sample sites in the middle section of the reservoir. The reservoir sediment consisted of fine-grained elastic silt with substantial accumulations of organic material. Pre-reservoir material consisted of coarse grained alluvium (silty gravel and sand), and bedrock consisted of volcaniclastic rock intensely weathered/decomposed to lean clay. Reservoir sediment was thickest in the lower section of the reservoir (ranging from 14 to 22 feet thick). Sediment in the lower section was uniformly elastic silt with greater than 90 percent fine-grained material. The sediment overlaid coarse grained pre-reservoir alluvium consisting mostly of silty gravel with sand (DOI 2010).

Copco 1 Reservoir

The upper portion of Copco 1 Reservoir has a sediment thickness ranging from 3.5 to 8.0 feet consisting of elastic silt with sand. Sediments in the rest of the reservoir are relatively uniform and composed of elastic silt, containing between 88 and 99 percent fine-grained material. Sediment thickness in the main reservoir ranges from 1.3 to 9.7 feet deep (DOI 2010).

Copco 2 Reservoir

The upper 500 feet of the Copco 2 Reservoir contained deposits primarily composed of cobble boulders. Similarly, the channel invert appeared to be covered mostly with angular gravel to boulder size talus and minor interstitial sand. Flow velocities in the reservoir channel at the time of sampling were relatively fast, therefore, it is likely that sediment composed of silt and clay did not deposit or had been previously eroded. Results of core drilling attempts show that cobbles, boulders, gravel, and sand formed the deposits in the bottom of the reservoir and there is a lack of fine-grained sediment (DOI 2010).

Iron Gate Reservoir

Iron Gate Reservoir has relatively steep side-slopes and a narrow channel with numerous side drainages. Three of these side drainages are large, and two likely contribute substantial amounts of sediment to the reservoir. Except for the three principal side drainages, Iron Gate Reservoir has a relatively similar depositional environment throughout its length. Only the upper 6,000 feet of the reservoir has a substantial percentage of sand within the reservoir sediment. Sediment thickness ranged from 1.4 to

9.2 feet, with most samples having a thickness of less than 5 feet. Reservoir sediment was relatively uniform throughout the reservoir and consisted of elastic silt with 85 to 98 percent fine-grained material (DOI 2010).

3.11.3.5 Slope Stability/Landslides

Landslides (both into the subject reservoirs and the mainstem Klamath River) are one potential source of sediment supply to the river system. Potential landslide/rock fall areas include relatively steep slopes underlain by tuff, as well as areas of deep colluvium/talus slopes that could produce slumps and debris flows. Talus slopes are found along the Klamath River between J.C. Boyle Dam and Copco 2 Reservoir. Identified slope stability/landslide occurrences and observations at reservoirs in the study area include the following.

Recent observations of the subject reservoirs identified no areas of unstable slopes or existing landslides adjacent to J.C. Boyle Reservoir or Copco 2 Reservoir.

No areas of large-scale active landslides were observed in the slopes adjacent to Copco 1 Reservoir. Several small-to-medium sized landslide features are present on the north shore of the reservoir that may have been caused by rainfall and/or subsurface groundwater flows (Figure 3.11-2). However, the preliminary evaluation conducted by PanGeo indicates that the slopes in these areas are currently stable. Other areas of past landslides include an old, inactive slide that is visible on the westernmost end of the reservoir and a colluvium fan on the north shore immediately west of Spannus Gulch. In addition to potential sediment inputs from past landslides, wave action at the shoreline of the reservoir has eroded sand and volcaniclastic tuff beneath diatomite beds and has resulted in the calving of diatomite into the reservoir creating vertical exposures as high as 20 feet in the diatomite. The diatomite that has calved into the reservoir has most likely been eroded and re-deposited within the reservoir. Elsewhere around the reservoir, shoreline erosion has been minimal (PanGeo 2008).

Within Iron Gate Reservoir, the adjacent hillside slopes are generally considered stable with no active landslide areas. However, geomorphic features suggestive of old, inactive landslides (including small slumps a few meters wide and possible slides covering square miles) were identified on the south rim slopes above the reservoir and may have contributed to past sediment input into the reservoir. In addition, a low level of wave-induced shoreline erosion at the margin of the reservoir was observed and reported in the PanGeo (2008) study. However, the erosion has not substantially undercut or disturbed the hillside slopes, and the exposed material along the shoreline comprises relatively competent volcanic or volcaniclastic rock. According to the PanGeo study, recent erosion rills in the red volcaniclastic materials underlying the hillside slopes indicate that these fine-grained materials may be vulnerable to rapid erosion in the future if subjected to concentrated water flows (PanGeo 2008).

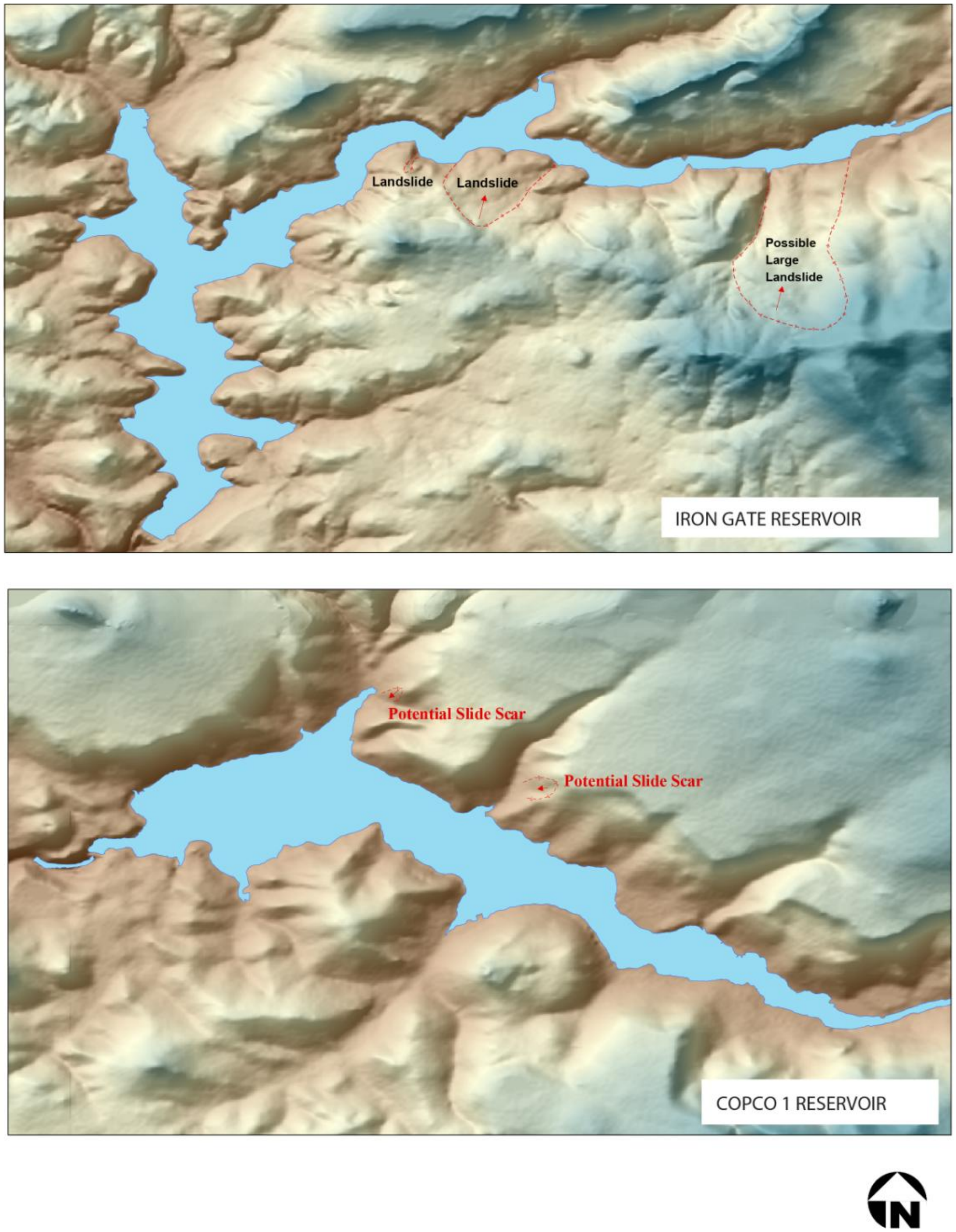

Figure 3.11-2. Existing Potential Landslide Areas

Potential landslide/rockfall areas downstream from the Four Facilities include all steep slopes underlain by tuff, as well as areas of deep colluvium/talus slopes that could produce slumps and debris. Talus slopes are found through the Klamath River Canyon (the stretch of river between J.C. Boyle and Copco 2 Dams). Continuous creep of talus and rapid rockfalls are likely on and near talus slopes, and the potential exists for slow-to-moderate migration of some of the large slides. Landsliding is also prevalent in the Franciscan geology of the lower Klamath River watershed and along tributary watersheds within the Klamath Mountain geomorphic province, such as the Salmon River (FERC 2007). As discussed above when describing the geomorphology of the river, existing landslide areas are present downstream from the Scott River confluence.

Soils

Upper Klamath River

Soils in the vicinity of the Upper Klamath River, surrounding J.C. Boyle Reservoir, and along the river south to the Oregon-California border generally consist of lacustrine and alluvial clay, silt, fine-grained sand and peat (Priest et al 2008). The primary soil association along both sides of the river is Skookum-rock outcrop-Rubble land complex with 35 to 70 percent slopes. Immediately surrounding Keno Impoundment, soils consist of the Bly-Royst complex (Natural Resources Conservation Service [NRCS] 2005).

Klamath Hydroelectric Project

Soils along the Klamath River and on reaches between the subject reservoirs are less homogenous in California. However, the various soil formations can be grouped generally into those on steeper slopes, floodplain or terrace surfaces, or directly along the river itself. The soils on steeper slopes are shallow to moderately deep and comprise a 7-8 inch surface horizon of gravelly loam, and an underlying horizon of gravelly, clayey loam. Floodplain and terrace soils are comprised of deep, well-drained alluvium and colluvium. Directly along the river, soils are comprised of unconsolidated alluvium, colluvium, and fluvial deposits. These geologically recent deposits consist of unconsolidated sand, silt, and gravels deposited by water or erosion (FERC 2007).

Below Iron Gate Dam

Soils along the Klamath River below Iron Gate Dam are generally composed of associations consisting of gravelly clay loam and gravelly sandy loam (Holland-Clallam, Skalan, Weitchpec, and Lithic Mollic Dubakella associations). Soils on steeper slopes are deeper (22 to 60 inches) than those on less steep slopes and along the floodplain. These soil associations are all classified as well-drained, with low to no flooding frequency or ability for ponding water. Soils directly along the river in floodplain areas are comprised of alluvial deposits consisting of sand and gravels (NRCS 2007 and 2008).

3.11.3.6 Faults and Seismicity

Review of available fault and earthquake epicenter maps for northern California and southern Oregon show no fault lines or earthquake epicenters beneath Iron Gate Dam or the Copco Dams and Reservoirs. However, volcanic vents occur very close to the two Copco Dams. Faults exist beneath the J.C. Boyle Dam and Reservoir. However, these faults have not moved within the past 1.5 million years and, therefore, are termed not active (Personius et al. 2003). No earthquake epicenters are mapped beneath the J.C. Boyle Reservoir, but one of the largest earthquakes ever recorded in Oregon occurred in 1993 in and around the Klamath Falls areas approximately 15 miles north of the J.C. Boyle Reservoir.

In California, the nearest active fault to the Four Facilities is the Meiss Lake fault, approximately five miles east of the Klamath River near the California/Oregon Stateline in Siskiyou County. The next nearest California-zoned active fault in relation to the Four Facilities is the Mahogany Mountain fault zone approximately 6 miles east (Jennings and Bryant 2010).

3.11.3.7 Volcanic Activity and Associated Strata

The High Cascades geomorphic province consists of a narrow band of shield volcanoes built on top of the eastern portion of the Western Cascades strata. The High Cascades are represented in the vicinity of the Four Facilities by the extinct cones of Eagle Rock Mountain to the south of the Klamath River valley, the Secret Spring Mountain and McGavin Peak to the southeast, and Mount Shasta to the Northwest. There are also a series of basaltic volcanoes extending northward into Oregon towards Klamath Falls, which have been dissected by subsequent basin and range block faulting (PanGeo 2008).

In addition to the large shield volcanoes with their multiple eruptive events, numerous smaller vents and volcanoes are present in the area. The majority of the volcanism in the Upper Klamath Basin consists of single events from a given vent and most of the smaller explosive cones are formed from the interaction of flow material intersecting ground water (hydrovolcanic events). High Cascades volcanism continues to the present day (PanGeo 2008). During the last 10,000 years, Mount Shasta has erupted once per 800 year period, and once per 600 years over the last 4,500 years. The last known eruption was radiocarbon dated to approximately 200 years ago (Miller 1980).

The rocks in the vicinity of the Four Facilities range in age from roughly 45 million years old up to the present. Copco and Iron Gate Dams are in the Western Cascades. The volcanic activity that formed the Western Cascades is thought to have started between 42 and 45 million years ago (Eocene) and continued until approximately 10 and 5 million years ago. Over time, the main area of volcanic activity shifted eastward and narrowed. The intensity of volcanism also diminished and erosion activity erased much of the evidence of the original volcanoes. Estimates of the thickness of the Western Cascades strata range from between 12,000 and 15,000 feet to greater than 20,000 feet (PanGeo 2008).

In the vicinity of Copco Reservoir, up to half of the Western Cascade strata are exposed in the Klamath River Canyon as a result of river down cutting. In this exposure, the Western Cascade strata are comprised of inter-bedded tuffs, ash, and lava flows dipping to the east at approximately 25 degrees. The eastern dipping strata of the Western Cascade is overlain by the nearly flat lying High Cascade strata composed of younger Pliocene lava flows with a thickness of up to 500 feet. The inter-bedded strata of the Western Cascade can form aquifers and when coupled with a remnant volcanic heat source and sealed by overlying High Cascade lava flows, geothermal reservoirs can form (Hammond 1983).

3.11.4 Environmental Consequences

3.11.4.1 Environmental Effects Determination Methods

The environmental consequences of the alternatives focus on changes to geomorphology and sediment transport. This analysis discusses potential increases in geologic hazards downstream from the reservoirs, as well as potential increases in erosion in the Upper Klamath Basin under implementation of each of the alternatives.

DOI used the Sedimentation and River Hydraulics-One Dimension Version 2.4 sediment transport model to analyze the potential transport of reservoir sediment downstream based on different drawdown scenarios. The analysis below uses the results of DOI's sediment transport modeling to evaluate changes in downstream sediment regimes and the effect of the changes on shoreline geology downstream from the reservoirs. The analysis also qualitatively analyzes the potential for local sedimentation in eddies and other low gradient zones in the Klamath River channel.

3.11.4.2 Significance Criteria

For the purposes of this EIS/EIR, impacts would be significant if they would result in the following:

- Substantial soil erosion into reservoir areas or along the Klamath River.
- Cause new or exacerbate existing landslides along the banks of the reservoirs.
- Incomplete flushing of sediment with substantial deposition downstream, which adversely affects other associated resources (i.e., Water Quality, Fish Resources, Mollusks, and Benthic Invertebrates).
- Exposure of people or structures to adverse effects resulting from rupture of a known earthquake fault, strong seismic ground shaking, or volcanic activity.
- Remove access to diatomite beds for extraction.

3.11.4.3 Effects Determinations

Alternative 1: No Action/No Project

Under the No Action/No Project Alternative, J.C. Boyle, Iron Gate, and Copco 1 Reservoirs would continue to trap sediment at rates similar to historical rates. Based on historic sediment trapping rates and sediment levels in each reservoir, it is estimated that approximately 23.5 million yd^3 of sediment would be stored behind the dams in 50 years time (i.e., by 2061). Studies conducted by DOI indicate that the trapping efficiency of J.C. Boyle Dam may decrease slightly as the reservoir capacity decreases but the rate at which this may happen is uncertain and is not likely to change substantially over the next 50 years (DOI 2011a). It is likely that after the storage capacity reduces to a certain level, sedimentation in the reservoirs would stop and sediment would begin to pass through the reservoir pools and be transported downstream. Table 3.11-3 summarizes the current estimated volume of sediment in each reservoir, the respective sediment trapping rate, and the anticipated sediment volume in each reservoir in 50 years.

No future substantial erosion or landslides are expected to occur downstream from any of the Four Facilities under the No Action/No Project Alternative. As described in Section 3.11.3 (Existing Conditions/Affected Environment), river elevation downstream from the dams is primarily controlled by large boulders and bedrock, and only limited adjustment is possible. **There would be no change from existing conditions as a result of the No Action/ No Project.**

Table 3.11-3. Estimated Future Sediment Volume in Reservoirs under the No Action/No Project Alternative

Reservoir	Original Storage Capacity (acre-ft)	Current Sediment Volume (yd^3)	Sedimentation Rate (yd^3/yr)	2061 Sediment Volume (yd^3)	% Reduction in Storage Capacity
J.C. Boyle	3,495	1,000,000	19,600	2,020,000	36
Copco 1	46,867	7,400,000	81,300	11,600,000	15
Copco 2	73	0	0	0	0
Iron Gate	58,794	4,700,000	100,000	9,900,000	10
Total	109,229	13,100,000	201,000	23,500,000	13

Source: DOI 2011a

Key:
yd^3: cubic yards
yd^3/year: cubic yards per year
lb/ft: pounds per foot

Under the No Action/No Project Alternative, Copco 1 Reservoir would continue to prohibit access to diatomite beds. Diatomite beds are at the southern shore of the reservoir near the dam and are even with or extending up to 20 feet above the reservoir surface. Wave action at the shoreline has eroded the diatomite. Because of their location in the reservoir and existing erosion, diatomite resources are currently inaccessible for extraction purposes. **There would be no change to the existing conditions of diatomite beds under the No Action/No Project Alternative because the resources would continue to be inaccessible.**

Alternative 2: Full Facilities Removal of Four Dams (Proposed Action)

Soil disturbance associated with heavy vehicle use, excavation, and grading could result in erosion during removal activities. As described in the Affected Environment, shoreline erosion is generally not a substantial factor affecting the Iron Gate and J.C. Boyle Reservoirs, although it is an issue at Copco 1 Reservoir, where eroded sand and volcaniclastic tuff has resulted in the subsequent calving of diatomite into the reservoir. This existing erosion is caused by wave action in the reservoir (PanGeo 2008). Soil disturbance associated with heavy vehicle use, excavation, and grading could result in erosion during removal activities at Iron Gate and J.C. Boyle Reservoirs and could exacerbate existing erosion at Copco 1 Reservoir. Prior to demolition, coverage under the General Stormwater National Pollution Discharge Elimination System (NPDES) Permit for Construction Activities in both Oregon and California would be required as per Section 402 of the Clean Water Act. Coverage under this permit requires the development and implementation of an Erosion and Sediment Control Plan prior to deconstruction that describes best management practices (BMPs) to prevent erosion during demolition activities. Implementation of these BMPs would minimize the potential for erosion into the reservoir areas. **Erosion impacts into the reservoir areas would be short-term and less than significant.**

Drawdown of the four reservoirs could cause instability along the banks of the reservoirs. Reservoir drawdown proposed under the Proposed Action could trigger new landslides or exacerbate existing landslides along the banks of reservoirs in the project area. Slumping and some mudflows are expected to occur from reservoir drawdown actions. Slopes with inclinations from 18 to 40 degrees would be most susceptible to slumping. The amount of slumping that could occur would be dependent on the drawdown rate (slower drawdown rates would result in fewer slides and less slumping). The slumping that would occur is part of the design, in that it would remove the unstable portions of the newly-exposed slopes while there is sufficient flow in the river to transport the material downstream. The PanGeo (2008) study, which was described in Section 3.11.3 (Existing Conditions/Affected Environment), concluded that the hillside slopes below the pool levels behind Iron Gate, Copco 1, and J.C. Boyle Dams would likely perform relatively well and remain stable during drawdown activities. In addition, no large-scale landslides are anticipated in newly exposed areas and any new slides that may develop would most likely be below the existing water level in the reservoirs, although such slides could create higher deposition on the terraces above the newly formed river channel. **These potential landslide impacts would be short-term and less than significant.**

Reservoir drawdown at Copco 1 would reduce the potential for erosion and future landslides. Because existing erosion at Copco 1 Reservoir is largely the result of wave action, emptying the reservoir would remove this source of shoreline erosion. As noted above, no large-scale landslides are anticipated in newly exposed areas during drawdown. In the long-term with implementation of reservoir restoration actions including hydro seeding, landslides and erosion would not be expected at a higher frequency or of a larger size than what is currently contributed from the slopes adjacent to the reservoirs. **Thus, long-term impacts with regards to erosion and potential landslides at Copco 1 Reservoir would be less than significant.**

Drawdown of reservoirs could cause bank erosion downstream. The drawdown of the four reservoirs would occur simultaneously beginning in January 2020. Based on the current project schedule and drawdown rate restrictions, the controlled released would maintain the minimum required flows in each reach. Section 3.6, Flood Hydrology, discusses historic flow rates and discharge statistics for each of the reservoirs. The proposed drawdown rates are consistent with the historic discharge rates from the reservoirs and would be adjusted depending on the water year; therefore, flow rates downstream from the dams are not anticipated to increase substantially above median historic rates, if at all (discharges from the reservoirs would be similar to seasonal 10-year flood flows from the reservoirs).

Although some landslides and erosive areas have been identified in the lower river, based on the expected flow rates that are similar to existing flow rates, substantial amounts of additional erosion are not expected to occur downstream from any of the dams as a result of reservoir drawdown. **Any erosion downstream would be minimal; these impacts would be short-term and less than significant.**

Drawdown of reservoirs and release of sediment would result in short-term increases in sedimentation in slow-moving eddies and pools downstream from the reservoirs and in the Klamath River estuary. During reservoir drawdown in 2020, the sediment behind the four dams would be released downstream. DOI conducted modeling of the reservoir drawdown and erosion of reservoir sediment. The drawdown of Iron Gate Reservoir would ultimately control sediment released from Copco 1 and 2, and J.C. Boyle Reservoirs due to its location furthest downstream. Since all reservoirs would be drawn down concurrently, sediment released from the upstream reservoirs would remain suspended and is not anticipated to settle within Iron Gate Reservoir. However, the released sediment would likely exceed the carrying capacity of the river during some water year types, and would result in sedimentation and particle settling downstream in eddies, pools, and the Klamath River estuary. The potential for deposition downstream is dependent on particle size and the water year type in 2020, and subsequent years. In general, sediment transport capacity in a dry year would be small and any downstream sediment deposition would stay in place, until the next substantial series of storms or snowmelt came. In contrast, during a wet year, suspended sediment would be more likely to be carried through the river to the ocean without substantial settling and deposition[4].

To determine how much sediment would be moved through the river, a study compared the settling velocity[5] of the reservoir sediment to the velocity profiles downstream from Iron Gate Dam. Based on the slope of the river and composition of river substrate downstream from the dam, as well as the daily average discharge (approximately 3,000 cfs), the study found that particles with a settling velocity less than 0.23 ft/s have the potential to be mobile as suspended sediment. This corresponds to sediment particles finer than 0.68 mm (coarse sand) (Table 3.11-4; Stillwater Sciences 2004).

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[4] Representative dry, median, and wet water years were defined as the 90%, 50%, and 10% exceedance flow volumes for the period from March to June at Keno on the Klamath River. The dry, median, and wet water years were 2001, 1976, and 1984, respectively.

[5] Settling velocity is the rate at which particles suspended in a fluid subside and are deposited. Settling velocity is dependent on gravitational force, the type of fluid, how smoothly and quickly the fluid is flowing, and the particle size and shape.

Table 3.11-4. Estimated Particle Sizes that would be Suspended at Average and Maximum Daily Discharge Rates

Discharge	3,000 cfs	7,000 cfs
Shear velocity	0.58 ft/s	0.76 ft/s
Maximum settling velocity for suspension	0.23 ft/s	0.34 ft/s
Corresponding particle size	0.42 mm	0.68 mm
Corresponding size class	Medium sand	Coarse sand

Source: Stillwater Sciences 2004

Key:
cfs: cubic feet per second (discharge rate)
ft/s: feet per second
mm: millimeters

Modeling conducted by DOI analyzed the deposition rate of the released sediment downstream of Iron Gate Dam for a two year period following commencement of drawdown activities. Three types of water year scenarios were analyzed (dry, wet, and average). The results of the modeling found that under all three water year types, fine sediment would be transported downstream as suspended sediment (DOI 2011a). As described in the Affected Environment, sediment sampling in the reservoirs has indicated that, with the exception of Copco 1, the majority of sediment is composed of fine-grained elastic silt. Therefore, it is expected that deposition would occur in pools or along vegetated area during low-flow periods, but that the deposition would be flushed downstream during high-flow events. Any settling or sedimentation of fine sediment in eddies or pools is expected to be minimal and short-lived. Further, as described in Section 3.11.3.2, Geomorphology, there is no sandbar within the mouth of the Klamath River itself; rather the sandbar is located offshore. As a result, the majority of the suspended sediment load from the river is carried out to sea and does not remain in the estuary itself. The amount of sediment delivered to the ocean in a given year is entirely dependent on the water year type.

In a wet year, the additional sediment load from removal of the dams would be relatively small compared to a dry year. However, the amount of sediment delivered to the ocean following removal of the dams is still expected to be less than the average annual supply. The only reservoir material that would be transported to the estuary would be fine material which is not expected to deposit at the estuary (DOI 2011a). Downstream of Iron Gate Dam, a substantial increase in sand content is expected in the reach between the dam and Bogus Creek. Sand is expected to increase by up to 40 percent in the month immediately following reservoir drawdown. Under a wet year scenario, the sand would decrease to below 20 percent within a year; however, under a median or dry scenario, a subsequent wet year would be required to flush the sand material from the bed. Downstream of Bogus Creek, it is expected that sand may take longer to be flushed downstream and under dry or median year scenarios it could take 5 to 6 years for sand in the bed to return to equilibrium levels between Bogus Creek and Willow Creek and up to 10 years between Willow Creek and Cottonwood Creek (DOI 2011a).

Particles greater than coarse sand would be deposited in eddies and slow-moving pools downstream following dam removal, primarily between Iron Gate Dam and Cottonwood Creek. Under the wet year scenarios, the coarse sediment load would take approximately 15 months (until March 2021) to be completely flushed downstream and into the Pacific Ocean. Although the coarse material would deposit temporarily in slow-moving portions of the river, there would be no substantial change in river bed elevation. In contrast, if drawdown were to occur during a dry year, modeling indicates that substantial deposition would still be present between Iron Gate Dam and Shasta River at the end of the two year modeling period. However, the model results indicated that under all three water type scenarios, the maximum thickness of sediment deposition immediately downstream from Iron Gate Dam would be less than 2 feet (DOI 2011a). Further, when considered in comparison to sediment loading from other existing sources along the Klamath River (refer to Table 3.11-1 above), the magnitude of the anticipated sediment release from behind the reservoirs is relatively small. A study by Stillwater Sciences (2010) assessed the sediment loading to the Klamath River based on the cumulative sediment load already contributed by tributaries to the river. The numeric modeling predicted high, medium, and low values for reservoir sediment release based on different hydrologic scenarios and the assumed dimensions of the new channel that would be created within the former reservoirs. The model predicted that the median fine-grained and total sediment load released by dam removal would not be substantially more than the cumulative average annual fine-grained and total sediment delivery between Iron Gate Dam and the Scott River. The model also predicted that the overall contribution of reservoir sediment to the river system decreased substantially downstream (Stillwater Sciences 2010).

The total sediment transport capacity of the river was not assessed in the Stillwater Sciences Study, and as such it does not demonstrate that the additional sediment load from dam removal would not deposit in the Klamath River. Rather, the findings of the analysis suggest that the release of sediment downstream during reservoir drawdown would not exceed the existing sediment load added by any tributary, and as such, the transport capacity of the river may be sufficient to transport the additional load, particularly since the river is supply-limited in regards to fine-grained material and sand.

Sedimentation impacts are therefore expected to be short-term. The significance of impacts with regard to sediment deposition is dependent on the corresponding impacts of the deposition on aquatic biology (see Section 3.3, Aquatic Resources) and water quality (see Section 3.2, Water Quality). As discussed in these sections, sediment deposition would not result in substantial adverse impacts and no mitigation measures are indicated. **Therefore, impacts with regard to sediment deposition downstream of Iron Gate Dam would be short-term and less than significant.**

Drawdown of reservoirs could result in changes to seismic or volcanic activity. As described in the Affected Environment, although the Four Facilities are in a historically seismic active area, the nearest active fault is approximately five miles from the dams proposed for removal. It is noted that faults do exist under J.C. Boyle Reservoir. However, these faults are reported not to have moved within the past 1.5 million years and, therefore, are termed as not active (Personius et al. 2003). Under the Proposed

Action, the Four Facilities would be removed within a one year period between November 2019 and December 2020. Sediment currently held behind the dams would be released during the same year period. Although there is substantial literature regarding the inducement of seismicity by reservoir filling, little is documented with regard to the drawdown of reservoirs of this size. Consequently, it is not expected that reservoir draining would cause such actions. Reservoir draining is also not expected to cause volcanic activity due to the distance from volcanic hazards (e.g., Mount Shasta). Further, following removal of the Four Facilities, no new structures would be constructed in the project area. **Therefore, the impacts with regard to increased risk of hazards associated with ground rupture or seismic shaking during reservoir drawdown would be less than significant.**

Following dam removal, reservoir sediment remaining could result in changes in the amount of erosion in the river channel. DOI 2011a, using representative dry, median, and wet years from the hydrologic period of record between 1961 and 2008, indicated that if dam removal occurred during a wet year, up to 56 percent of the reservoir sediment would be eroded. In contrast, if removal were to occur during a dry year, about 38 percent of the sediment would be eroded. The remaining sediment would be expected to remain on the reservoir terraces and dry. However, as discussed in Section 3.11.3.4 (Reservoir Substrate Composition), sediment in the reservoirs is fairly shallow (4-8 feet thick). Therefore, following erosion of the sediment during dam removal, the remaining sediment would be much more like a landscape veneer than a wedge along the newly formed river channel.

Field tests (DOI 2011a) were conducted to determine the characteristics of dried reservoir sediment. Table 3.11-5 shows a comparison of the depth of wet and dry sediment samples. As the table shows, the desiccated depth of the sample was about 60 percent of the initial depth. Deep cracks developed in the soil and the sample pulled away from the container edges. The estimated reduction in volume of the sample was about 66 percent. The porosity changed from 0.82 to approximately 0.46 and the bulk density increased from 29.5 pounds per cubic foot (lb/ft^3) to approximately 87 lb/ft^3. The bulk density of the dried reservoir sediment would be similar to that of the pre-dam sediment in the reservoir area. Erosion tests conducted by the Agricultural Research Service (Simon and Bell 2010) found that the erosion resistance of dried sediment was more than 10 times higher than the resistance of wet sediment. Therefore, minimal erosion is expected following completion of reservoir drawdown and dam removal activities. **The impact of dam removal on erosion would be long-term but less than significant.**

Table 3.11-5. Comparison of Wet and Dry Reservoir Samples

Container	Initial Thickness (inches)	Final Thickness (inches)	% of Original Thickness
1	7.00	4.25	60
2	7.88	4.63	59
3	4.50	2.75	61

Source: DOI 2011a.

Following dam removal, reservoir sediments remaining could result in changes to downstream sediment deposition. As discussed above, once dry, the remaining sediment in the former reservoir areas would be unlikely to erode downstream except during storm and other high-flow events. As previously discussed, the Klamath River is supply-limited for fine-grained material. Further, based on the estimated settling velocity of the remaining sediment and average flows during wet years and storm events, it is expected that any eroded sediment would be transported as suspended sediment flushed downstream. **Therefore, impacts of dam removal on downstream sediment supply would be long-term, but less than significant.**

Following dam removal, the reservoir sediment remaining would dry and could affect restoration activities and/or future road construction activities. As discussed previously, following dam removal an estimated 44 to 62 percent of the sediment in the reservoirs would remain and is expected to settle on the terraces of the new river channel. Initial sampling conducted on the sediment indicates that once dry, it has a tendency to crack and substantially decrease in porosity. This characteristic would not necessarily limit the range of restoration activities but could limit future construction activities (e.g., access road construction, recreation facilities) that could occur in the former reservoir area. Limitations on future construction due to sediment properties are analyzed in the Reservoir Restoration Study (DOI 2011b). **The potential limiting characteristics of the remaining sediment in the reservoirs would be considered a significant impact, but mitigation measure GEO-1 would reduce these impacts to less than significant.**

Following dam removal, diatomite beds near Copco Reservoir would be inaccessible. Under Proposed Action, the ownership of the reservoir land would be transferred to the Dam Removal Entity (DRE). After transfer it is likely that the DRE would not allow access to the diatomite beds for commercial extraction. Additionally, any paleontological resources potentially contained within the diatomite beds would remain inaccessible. **Therefore, there would be no change from existing conditions for diatomite beds under the Proposed Action because the resources would continue to be inaccessible.**

Following reservoir drawdown, the Yreka water supply pipeline would be relocated. The existing water supply pipeline for the City of Yreka passes under the Iron Gate Reservoir and would have to be relocated prior to the decommissioning of the reservoir to prevent damage from deconstruction activities or increased water velocities once the reservoir has been drawn down. The pipeline would either be suspended from a pipe bridge across the river near its current location, or rerouted along the underside of the Lakeview Bridge just downstream of Iron Gate Dam. The construction of a pipe bridge would not affect sediment supplies, contribute substantially to erosion, or expose people or populations to geologic hazards. Placing the pipe along the Lakeview Bridge would have less impact than the construction associated with the pipe bridge. **Therefore, there would be no change in the existing conditions of geology, soils, or geologic hazards as a result of the pipeline relocation.**

Following reservoir drawdown, recreational facilities currently located on the banks of the existing reservoirs would be removed. The existing recreational facilities provide camping and boating access for recreational users of the reservoirs. Once the reservoirs are drawn down, these facilities would be removed. The removal of the recreational facilities would not affect sediment supplies, contribute substantially to erosion, or expose people or populations to geologic hazards. **Therefore, there would be no change in the existing conditions of geology, soils, or geologic hazards as a result of the recreational facilities.**

Keno Transfer

The Keno Transfer could have adverse effects to geology, soils, or geologic hazards. The Keno Transfer is a transfer of title for the Keno Facility from PacifiCorp to the DOI. This transfer would not result in the generation of new impacts on geology and soils compared with existing facility operations. Following transfer of title, DOI would operate Keno in compliance with applicable law and would provide water levels upstream of Keno Dam for diversion and canal maintenance consistent with agreements and historic practice (Klamath Hydroelectric Settlement Agreement [KHSA] Section 7.5.4). **Therefore, the implementation of the Keno Transfer would result in no change from existing conditions.**

East and West Side Facilities

The decommissioning of the East and West Side Facilities could have adverse effects to geology, soils, or geologic hazards. Decommissioning of the East and West Side canals and hydropower facilities of the Link River Dam by PacifiCorp as a part of the KHSA will redirect water flows currently diverted at Link River Dam into the two canals, back in to Link River. Redirection of flows would not change sedimentation rates in Upper Klamath Lake and the action would have no impact to geology and soils. **Therefore, the decommissioning of the East and West Side Facilities would result in no change from existing conditions.**

KBRA

The KBRA has one element that could result in changes to geology, soils and geologic hazards:

- Phases I and II Fisheries Restoration Plans

Phases 1 and II Fisheries Restoration Plans

Implementation of the Phase I Fisheries Restoration Plan could result in construction related sediment erosion. Several ongoing resource management actions related to fishery health and water quality may be amplified under the Phase I Plan (Section 2.4.3.9). The following sections describe the ongoing actions and types of new programs that could be implemented, and their anticipated short-term and long-term effects at a programmatic level.

Floodplain Rehabilitation

Floodplain rehabilitation work would include activities to improve or restore connections between channels and floodplains to create and maintain off-channel habitat accessible to overwintering juvenile salmonids. In the short-term (i.e., during construction activities), these activities may involve the use of backhoe equipment to dig channels, remove/reposition levees and dikes, and conduct mechanical planting. These construction activities could result in increased erosion as a result of ground disturbance. In the long term, increased seasonal off-channel habitat, wetland restoration, and levee setbacks, may reduce sediment erosion due as a result of potential reduction in flood flow velocity in some flood events through the reestablishment of floodplains.

Woody Debris Placement

In-stream and streambank large woody debris placement may include both mobile wood (i.e., unanchored) and complex stationary (i.e., anchored) structures and may be used to create off-channel fish habitat or provide cover in deeper pools. In the short term, these activities may involve the use of construction equipment to place large wood in the stream channel or along banks. These activities could result in increased erosion as a result of ground disturbance in construction staging areas and on the stream banks and in the streambeds.

Fish Passage Correction

Correction of fish passage issues throughout the Klamath Basin may include culvert upgrades or replacement to meet current fish passage standards and correction of other fish blockages to restore access to new or historical habitats. In the short term, these activities may include in-channel construction of culverts through existing roadways, which could result in increased erosion as a result of ground and riverbank disturbance.

Mechanical Thinning and Prescribed Burning

Mechanical thinning and prescribed burning of upland forest areas may be used to mimic some of the functions and characteristics historically provided by a natural fire regime. In the short term, thinning and prescribed burning could increase sediment erosion through reduction in groundcover. In the long term, thinning and prescribed burning may reduce the potential for catastrophic fires and the associated high rates of erosion and nutrient release (primarily phosphorus) to tributaries and the main-stem Klamath River.

Road Decommissioning

Road decommissioning would reduce road densities in areas with a high potential for slope failure and would stabilize hillsides. In the short-term these construction activities could result in increased erosion as a result of ground disturbance. In the long-term, these activities would decrease the incidence of road failure and would minimize a source of landslide and erosion generated input of sediment into water bodies in the Klamath Basin.

Gravel Augmentation

Gravel augmentation involves the direct placement of spawning size gravel into the stream channel. Gravel augmentation can increase spawning habitat in systems by increasing the amount of area with suitable substrate. Gravel augmentation activities may involve transportation of gravel from an off-site source using dump trucks and placement in the stream using backhoes. In the short term, this could introduce fine sediments into the river channel. Depending on the water year during which gravel augmentation takes place, this sediment could result in temporary deposition downstream.

Summary

Construction actions including the operation of construction equipment and the associated soil disturbance could result in erosion into the active river channel and could cause new or exacerbate existing landslide areas. Additionally gravel augmentation could result in temporary sediment transport and deposition downstream of the construction site. Construction activities associated with the Restoration Plan would not occur in the same location or at the same time as hydroelectric facility removal. Therefore, erosion effects would not add to potential effects of dam removal activities. However, negative short-term effects of increased sediment erosion, and landslides generated by the restoration plan's construction activities could occur, but would be reduced by construction-related BMPs that would be implemented. **Given implementation of BMPs (see Appendix B), the short-term effects on sediment erosion and landslides and would be less than significant. In the long-term, implementation of the Phase I and II Fisheries Restoration Plans would be expected to generate a beneficial reduction in sediment erosion through improved river channel stability, and generate no change from existing conditions for landslides. Implementation of specific plans and projects described in the KBRA will require future environmental compliance as appropriate.**

Alternative 3: Partial Facilities Removal of Four Dams

Under this alternative, short-term demolition activities and drawdown of reservoirs would still occur; however, demolition would consist only of in-stream facilities and select ancillary facilities. Impacts to soils and sediments would be the same as those described for the Proposed Action.

Keno Transfer

The geology and soils impacts of the Keno Facility Transfer under the Partial Facilities Removal of Four Dams Alternative would be the same as for the Proposed Action.

East and West Side Facility Decommissioning

The geology and soils impacts of the East and West Side Facility Decommissioning under the Partial Facilities Removal of Four Dams Alternative would be the same as for the Proposed Action.

KBRA

Under this alternative, the KBRA would be fully implemented; therefore, impacts to soils and sediments would be the same as those described for the Proposed Action.

Alternative 4: Fish Passage at Four Dams

Short-term construction under the Fish Passage at Four Dams Alternative could change erosion patterns. Under this alternative, no demolition of the Four Facilities would take place; however, short-term construction activities would occur during installation of fish passage at the four dams. The potential exists for short-term increases in erosion along the banks of the reservoirs during construction activity. Prior to any construction, coverage under General Stormwater Permits and the development and implementation of Erosion and Sediment Control Plans would be required as per Section 402 of the Clean Water Act. **Accordingly, erosion impacts would be short-term and less than significant.**

Under the Fish Passage at Four Dams Alternative, J.C. Boyle, Iron Gate, and Copco 1 Reservoirs would continue to trap sediment at rates similar to historical rates. The reservoir drawdown and sediment transport impacts described under the Proposed Action would not occur. **The reservoirs would continue trapping sediment and there would be no change from existing conditions.**

Under the Fish Passage at Four Dams Alternative, the Copco 1 Reservoir would continue to prevent access to the diatomite beds. Diatomite resources and any associated paleontological resources are currently inaccessible due to the presence of the Copco 1 Reservoir. **There would be no change from existing conditions for the diatomite beds because the resources would continue to be inaccessible.**

Alternative 5: Fish Passage at J.C. Boyle and Copco 2, Remove Copco 1 and Iron Gate

Reservoir drawdown could cause instability along the banks of the reservoirs, reservoir bank instability, and construction generated erosion. Under this alternative, only Iron Gate and Copco 1 Dams would be removed and fish passage would be installed at Copco 2 and J.C. Boyle Dams. Impacts associated with short-term construction and demolition activities would be as described for the Proposed Action. **Impacts associated with reservoir drawdown and sediment transport would be similar to the impacts described for the Proposed Action. However, the magnitude of any impacts would be less than described for the Proposed Action due to the retention of sediment behind J.C. Boyle and Copco 2 Dams.**

Following dam removal, the diatomite beds near Copco Reservoir would become more accessible. Diatomite resources and any associated paleontological resources are currently inaccessible due to the presence of the Copco 1 Reservoir. **Therefore, there would be no change from existing conditions for the diatomite beds because the resources would continue to be inaccessible.**

3.11.4.4 Mitigation Measures

Mitigation Measure by Consequences Summary

Mitigation Measure GEO-1 – Prior to commencing construction of new recreation facilities or access roads in the former reservoir areas, geotechnical analysis of the proposed site should be conducted by a qualified geologist to determine the limitations of construction on the sediment. If geotechnical tests indicate that the sediment is not suitable to accommodate the proposed activities, the site should be avoided or a sediment removal or treatment plan should be developed and sediment should be removed prior to beginning construction activities.

Effectiveness of Mitigation in Reducing Consequences

Implementation of Mitigation Measure GEO-1 would ensure that any remaining sediment in the former reservoir areas are appropriately studied and dealt with prior to construction, such that any future proposed activities do not result in significant erosion or sedimentation downstream.

Agency Responsible for Mitigation Implementation

The Dam Removal Entity would be responsible for implementing mitigation measure GEO-1.

Remaining Significant Impacts

Following implementation of GEO-1, no significant adverse impacts associated with Geology and Soils are anticipated. If the deposition of reservoir sediment downstream resulted in adverse impacts to fish habitat or habitat for other aquatic species, impacts would be considered significant. The potential for such impacts and mitigation for them have been addressed in the relevant chapters of this EIS/EIR.

Mitigation Measures Associated with Other Resource Areas

Several other mitigation measures require construction, including mitigation measures H-2 (flood-proof structures), GW-1 (deepen or replace affected wells), WRWS-1 (modify or screen affected water intakes), REC-1 (develop new recreational facilities and access to river), TR-6 (assess and improve roads to carry construction loads), and TR-7 (assess and improve bridges to carry construction loads). These measures could disturb soil because of construction activities associated with heavy vehicle use, excavation, and grading. Prior to demolition, coverage under the General Stormwater NPDES Permit for Construction Activities in both Oregon and California would be required as per Section 402 of the Clean Water Act (refer to Section 3.2, Water Quality, for more information). Coverage under this permit requires the development and implementation of an Erosion and Sediment Control Plan for each reservoir area. Implementation of these plans would minimize the potential for erosion during demolition activities. **These impacts would be short-term and less than significant.**

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