3.11 Geology, Soils, and Mineral Resources

3.11.1 Area of Analysis

This section analyzes potential impacts on geology, soils, and mineral resources related to implementation of the Proposed Project. The Area of Analysis for geology, soils, and mineral resources includes the riverbed and reservoir slopes at the sites of the Iron Gate, Copco No. 1, and Copco No. 2 dam complexes; as well as the Klamath River bed and banks from the California-Oregon state line to the Pacific Ocean, including the Klamath River Estuary. Areas of the Upper Klamath Basin in Oregon are discussed in this section only to the extent they pertain to potential impacts to geology, soils, and mineral resources in California.

The assessment of potential impacts to geology, soils, and mineral resources includes the following reaches of the Klamath River defined by changes in physiography, presence of the developments included in the Lower Klamath Project, and tidal influence (Figure 3.11-1):

1. Hydroelectric Reach (from the upstream extent of J.C. Boyle Reservoir to Iron Gate Dam), including the following:
    a. J.C. Boyle, Copco No. 1, Copco No. 2, and Iron Gate reservoirs
    b. J.C. Boyle Bypass and Peaking reaches
    c. Copco No. 2 Bypass Channel;
2. Klamath River downstream of Iron Gate Dam to the Pacific Ocean;
3. Klamath River Estuary; and
4. Pacific Ocean nearshore environment.

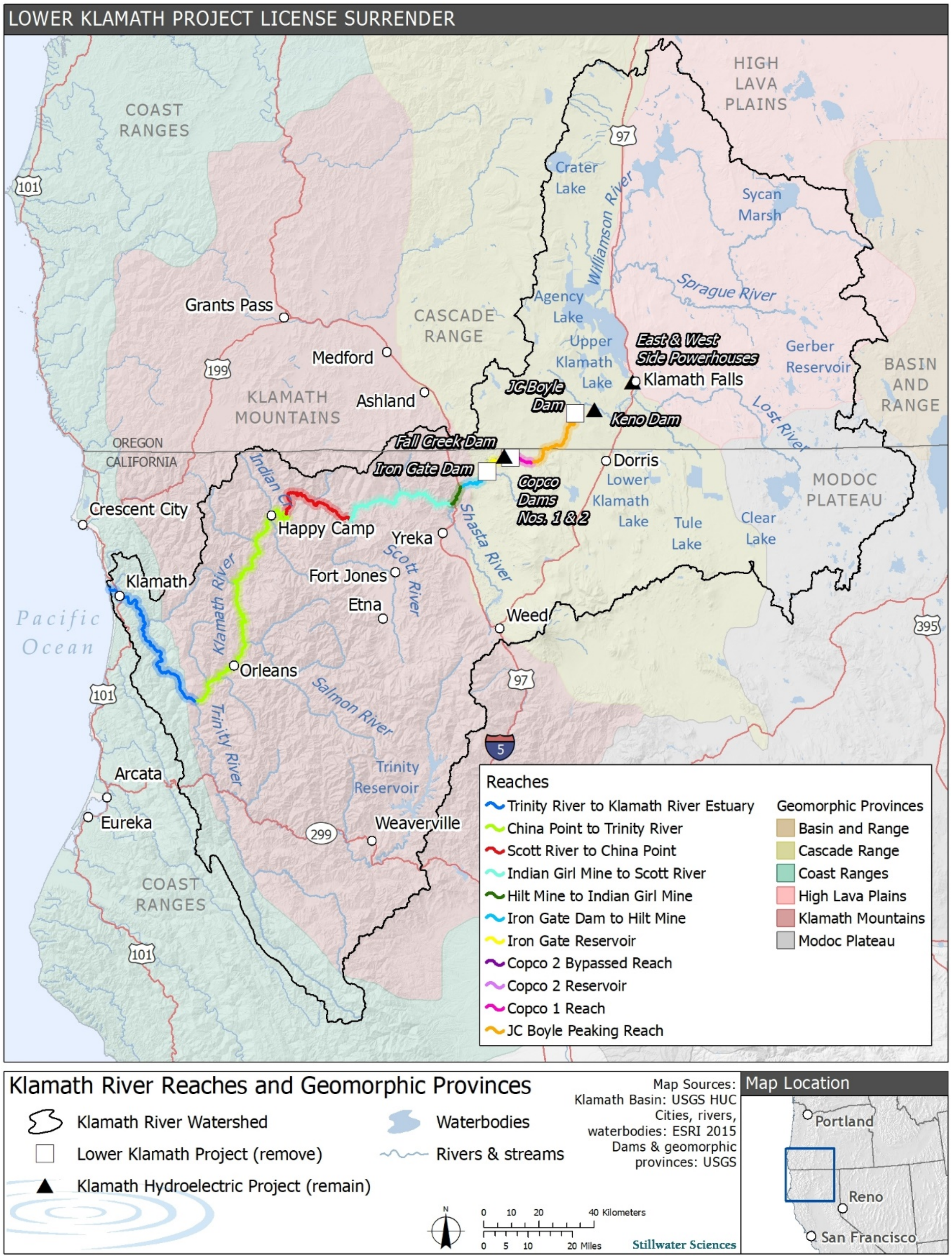

Figure 3.11-1. Geomorphic Provinces in the Klamath Basin and Geomorphic Reaches within the Area of Analysis for Geology and Soils.

3.11.2 Environmental Setting

The Proposed Project would erode sediment from reservoir deposits and transport this sediment to downstream reaches of the Klamath River. The following description of the geology and soils environmental setting therefore focuses primarily on the geology and geomorphology of the reservoir, channel, and floodplain environments directly and indirectly affected by dam removal and the associated release of stored sediment to downstream reaches of the Klamath River.

The Klamath River traverses approximately 260 river miles (approximately 214 river miles in California and 46 river miles in Oregon), originating in Upper Klamath Lake in southern Oregon and cutting southwest through the Klamath Mountains and northern California Coast Range to the Pacific Ocean near Requa. With a watershed area of approximately 15,722 mi^2, the Klamath River produces the second largest average annual runoff (Kruse and Scholz 2006) and sediment flux (Willis and Griggs 2003) of California's rivers.

The USBR refers to areas upstream of Iron Gate Dam as the Upper Klamath Basin and areas downstream of Iron Gate Dam as the Lower Klamath Basin (USBR 2012). These generalized basin areas are further subdivided based on geomorphic terrains with distinctly different geologic, geomorphic, hydrologic, climatic, vegetative, and resulting land use characteristics.

3.11.2.1 Regional Geology

Bedrock Geology

The geologic history of the Klamath River basin follows the interaction of three tectonic plates: the Pacific, the North American, and the Juan de Fuca. As a result, the Klamath River downstream of J.C Boyle Dam flows through three distinct geomorphic provinces: the Cascade Range Province, the Klamath Mountains Province, and the Coast Range Province (Figure 3.11-1) (CGS 2002). Each geomorphic province uniquely influences hydrology; channel morphology; and the supply of water, sediment, nutrients, and wood originating from tributary rivers and streams.

The portion of the Upper Klamath Basin located upstream of Upper Klamath Lake drains two geomorphic provinces: High Lava Plains and Modoc Plateau, composed predominantly of Miocene age basalts. The permeable volcanic rocks and subdued relief in these geomorphic provinces result in low drainage density, low stream gradients, and large internally drained areas that are typically filled with volcaniclastic sediment, alluvial fan deposits, and lake sediment (e.g., Upper Klamath, Lower Klamath, and Tule lakes). The Upper Klamath Basin also lies in the rain shadow of the Klamath and Cascade mountain ranges, and streamflow is largely from relatively steady groundwater flow. Low channel gradients, limited surface runoff, and internal drainage contribute to a muted hydrologic response to storm events and low sediment yield to the Klamath River.

The Lower Klamath Project is located in the Cascade Range Province, comprised predominantly of andesitic volcanic rocks of Cenozoic age. The Cascade Range Province is divided into the Western Cascade Sub-Province and the High Cascades Sub-Province based on the age and style of volcanism (Mertzman and Hazlett 1997, Taylor 1990). The Western Cascade Sub-Province is dominated by calc-alkaline continental margin andesites extruded about 40 million years ago (Mertzman and Hazlett

1997). The High Cascades Sub-Province is younger (Quaternary age) and is distinguished by lava flows, lava shields, pyroclastic flows, tuffs, cinder cones, and classic cone shaped stratovolcanoes.

The Mid-Klamath Basin is a subdivision of the basin located between approximately Iron Gate Dam the Trinity River confluence. The Mid-Klamath Basin occurs predominantly within the Klamath Mountains Province and is underlain by a series of geologic terranes comprised of accreted oceanic lithosphere, volcanic arcs, and mélange (Irwin 1994). The terranes were successively accreted to the convergent margin of western North America through a series of tectonic episodes. Each band of accreted material composing a terrane served as the backstop for the successive accretionary episode. Widespread metamorphism, folding, and faulting occurred in both the continental and accreted rocks during each episode. The complex geologic and geomorphic character of the Klamath Mountains reflects this tectonostratigraphic growth and subsequent plutonic intrusive, metamorphic, and volcanic activity that has occurred since the early Devonian geologic period (Irwin 1994). These rocks are more resistant to weathering and form high-relief terrain with prominent peaks and ridges.

The Lower Klamath Basin occurs farther west within the Coast Range Province and includes 40 miles of the Klamath River from approximately the Trinity River confluence to the Pacific Ocean. The Lower Klamath Basin is underlain mostly by the Eastern Belt of the Franciscan Complex and a narrow band of the Central Belt of the Franciscan Complex 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, serpentinite, graywacke, and abundant meter-size blocks of greenstone, graywacke, chert, higher-grade metamorphics, limestone, and lenses of serpentinite. The combination of tectonic deformation and shear, compositionally weak bedrock, and high precipitation rates in the Coast Ranges result in high erosion rates and sediment yields compared to other parts of the Klamath Basin (FERC 2007).

Faulting and Seismicity

The California Geological Survey (CGS) identifies seismic hazard zones according to the Alquist–Priolo Special Studies Zone Act of 1972 (Alquist-Priolo Act). Zone 4 is the highest rating requiring, compliance with the strictest building standards, while Zone 1 represents areas with the lowest probability of a seismic event. CGS has placed Siskiyou County in Seismic Zone 3 due to the presence of nearby active faults capable of surface rupture (CGS 2007).

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, Copco No. 1 Dam, Copco No. 2 Dam, or the Lower Klamath Project reservoirs. The Cedar Mountain fault is located approximately five miles east of the Klamath River in Siskiyou County (Table 3.11-1). The Hat Creek–McAuthur fault zone is located approximately 50 miles southeast of Copco No. 1 Dam. Other faults mapped by USGS, but not zoned under the Alquist–Priolo Act, include the Gillem–Big Crack fault, Pittville fault, Mayfield fault, and Rocky Ledge fault. Faults exist beneath the J.C. Boyle Dam and Reservoir; however, these faults have not moved within the past 1.5 million years and are considered inactive (Personius et al. 2003). No earthquake epicenters are mapped beneath the J.C. Boyle Reservoir, but one of the largest earthquakes recorded in Oregon occurred in 1993, with a magnitude of 6.0, in and around the Klamath Falls area approximately 15 miles north of the J.C. Boyle Reservoir. In California, the nearest active fault to the Lower Klamath Project is the Meiss Lake fault, approximately five miles east of the Klamath River near the California-Oregon State line in Siskiyou County. The next nearest California-zoned active fault in relation to the Lower Klamath Project is the Mahogany Mountain fault zone, approximately six miles east (Jennings and Bryant 2010).

Table 3.11-1. Earthquake and Fault Information.

Fault	Zoned by State of California [a]	Magnitude of Maximum Credible Earthquake (moment magnitude) [b]	Approximate Slip Rate (inches/year)	Approximate Recurrence Interval (years)
Cedar Mountain fault	Yes	6.9	0.04 [c]	3,600[c]
Hat Creek–McArthur faults	Yes	7	0.06 [c]	Unknown, possibly 1,000 to 3,000 [c]
Gillem–Big Crack faults	No	6.6	0.04 [c]	Not available
Pittville fault	No	6.7	less than 0.03 [c]	Not available
Mayfield fault	No	6.5	0.03–0.19 [c]	A few thousand years [c]
Rocky Ledge fault	No	N/A	less than 0.03 [c]	Not available

Sources:
[a] Bryant and Hart 2007
[b] Mualchin 1996
[c] USGS 2006

Based on the USGS earthquake database, the three largest earthquakes that have occurred closest to Copco No. 1, Copco No. 2, and Iron Gate dams were as follows. The first was located approximately 10 miles east of Copco No. 1 Dam and occurred with a magnitude of 3.3 on November 11, 1997. The second was located approximately 20 miles east of Copco No. 1 Dam and occurred with a magnitude of 3.0 on July 17, 1999. The third was located approximately 25 miles south of Iron Gate Dam and occurred with a magnitude of 2.5 on February 21, 2014.

Ground shaking is ground movement caused by seismic activity. Unlike surface rupture, ground shaking propagates into surrounding areas during an earthquake rather than being confined to a fault trace. A review of the CGS database indicates that the largest earthquake nearest the Lower Klamath Project, with the potential to have resulted in ground shaking near the Lower Klamath Project, occurred west of Eureka, California on November 8, 1980 (magnitude 7.3). Numerous earthquakes greater than magnitude 4.0 have occurred offshore west of Eureka (CGS 2007). The potential therefore exists for the soils and geology Area of Analysis to be affected by seismic ground shaking in the future.

Volcanism

Volcanism started in the Lower Klamath Project area approximately 40 million years ago and continued until approximately 10 and 5 million years ago. Volcanic activity shifted eastward, narrowed, and diminished in intensity over time. 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 No. 1 Reservoir, the Klamath River has incised up to half of the Western Cascade strata, exposing inter-bedded tuffs, ash, and lava flows dipping east at approximately 25 degrees. These east-dipping Western Cascades strata are overlain by nearly flat-lying High Cascades strata composed of younger Pliocene lava flows with a cumulative thickness of up to 500 feet. Zones of inter-bedded Western Cascade strata may serve as geothermal reservoirs when coupled with a heat source and sealed by overlying High Cascades lava flows (Hammond 1983).

Volcanism in the vicinity of the Lower Klamath Project includes stratovolcanoes, lava domes, and cinder cones. Quaternary volcanics, including two Pleistocene cinder cones and associated lava flows, occur in the region between the eastern edge of Iron Gate Reservoir and Copco No. 1 Dam (GEC 2006, Wagner and Saucedo 1987). Within the past 10,000 years, Mount Shasta eruptions have occurred on average every 800 years. Over the past 4,500 years, eruptions have occurred on average every 600 years. The last known eruption occurred approximately 200 years ago (Miller 1980).

There are also a series of basaltic volcanoes extending northward from California into Oregon towards Klamath Falls, which have been dissected by subsequent block faulting in the Basin and Range Province (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). Tephra hazards zones are found in association with vents that have erupted in the last 10,000 years and are thought to be likely sources for future explosive eruptions of fragmental material (Miller 1989). The closest source of potential tephra is Mount Shasta, located approximately 40 miles from Iron Gate Dam. The Klamath River, from the Oregon-California state line to approximately the confluence of Seiad Creek, is within the 85-kilometer radius of an area subject to at least two inches or more of compacted ash (Miller 1989).

Pyroclastic flows are a mixture of hot gas and rocks. During an eruption, pyroclastic flows could travel northwest from Mount Shasta toward the Klamath River (Miller 1989). The farthest potential extent of pyroclastic flows has been delineated to the bank of the Klamath River.

Rapid melting of snow and ice during a volcanic eruption can lead to local flooding. The high sediment concentrations in flood waters generated by volcanic eruptions can be more damaging than flooding from rainfall runoff. The USGS has delineated this hazard downstream of Iron Gate Reservoir (Miller 1989).

Soils

Soils within the Klamath Basin span multiple geologies, terrains, and climates. Soils in the vicinity of the Upper Klamath River surrounding J.C. Boyle Reservoir and along the river south to the Oregon-California state line 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. Soils along the Klamath River within the Hydroelectric Reach in

California are less homogenous. Soils along the Klamath River downstream of 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).

Soil types in the Area of Analysis can be grouped generally into those on steeper slopes, floodplain or terrace surfaces, or directly along the Klamath River itself. Soils on steeper slopes are shallow to moderately deep (typically 17 to 40 inches) and comprise a 7- to 8-inch surface horizon of gravelly loam; an underlying horizon of gravelly, clayey loam; and locally a very gravelly clay (FERC 2007). Floodplain or terrace surface soils comprise a deep, well-drained combination of alluvium (and in some places colluvium). These soils, as found within the canyon of the J.C. Boyle Peaking Reach, can be divided typically into a 15-inch very gravelly loam upper horizon, a transitional 6-inch gravelly clay loam layer, and a 39-inch horizon of heavy clay loam underlain by weathered bedrock to 60 inches or more below the surface (FERC 2007). The third soil type, located directly along the river, comprises unconsolidated alluvium, colluvium, and fluvial deposits. These geologically recent alluvial, low terrace, and landslide deposits consist of unconsolidated sand, silt, and gravels.

Mineral Resources

The CGS and the California Department of Conservation State Mining and Geology Board have classified Mineral Resource Zones (MRZs) in accordance with Sections 2761(a) and (b) and 2790 of the California Surface Mining and Reclamation Act of 1975 (SMARA). Lands categorized as MRZ-2 are underlain by "regionally significant" mineral resources that require that the CEQA lead agency's land use decisions be made in accordance with its mineral resource management policies, and that it consider the importance of the mineral resource to the region or the state as a whole. The primary source of information considered in this mineral resources analysis are the "mineral lands classification" maps published by the State pursuant to SMARA. Two comprehensive databases managed by the USGS (Minerals Availability System and Mineral Resource Data System) contain information regarding specific mineral locations.

Economically, the most important minerals that are extracted in the Area of Analysis for geology and soils are sand, gravel, and crushed rock (Figure 3.11-2, Table 3.11-2) (CGS/USGS 2004). Numerous small aggregate production areas are present. Other minerals that could be mined include asbestos, chromium, clay, copper, diatomite, gold, graphite, and mercury. The CGS has not prepared any reports that designate Mineral Resource Zones to be protected in Siskiyou County (Kohler 2002). The Siskiyou County General Plan does not contain a Mineral Resource Element and does not identify any specific areas of mineral resources within the county to be protected (Siskiyou County 1973).

Diatomite deposits surround much of the shoreline of Copco No. 1 Reservoir (PanGeo 2008). Diatomite is a chalk-like, very fine-grained sedimentary rock. It is used principally as a filter aid but has other commercial applications (USGS 2011). Near vertical bluffs have formed in the diatomaceous deposits as a result of undercutting due to wave erosion and failure of the weak material. Because of their location in the reservoir and existing erosion, diatomite resources are currently inaccessible for extraction purposes.

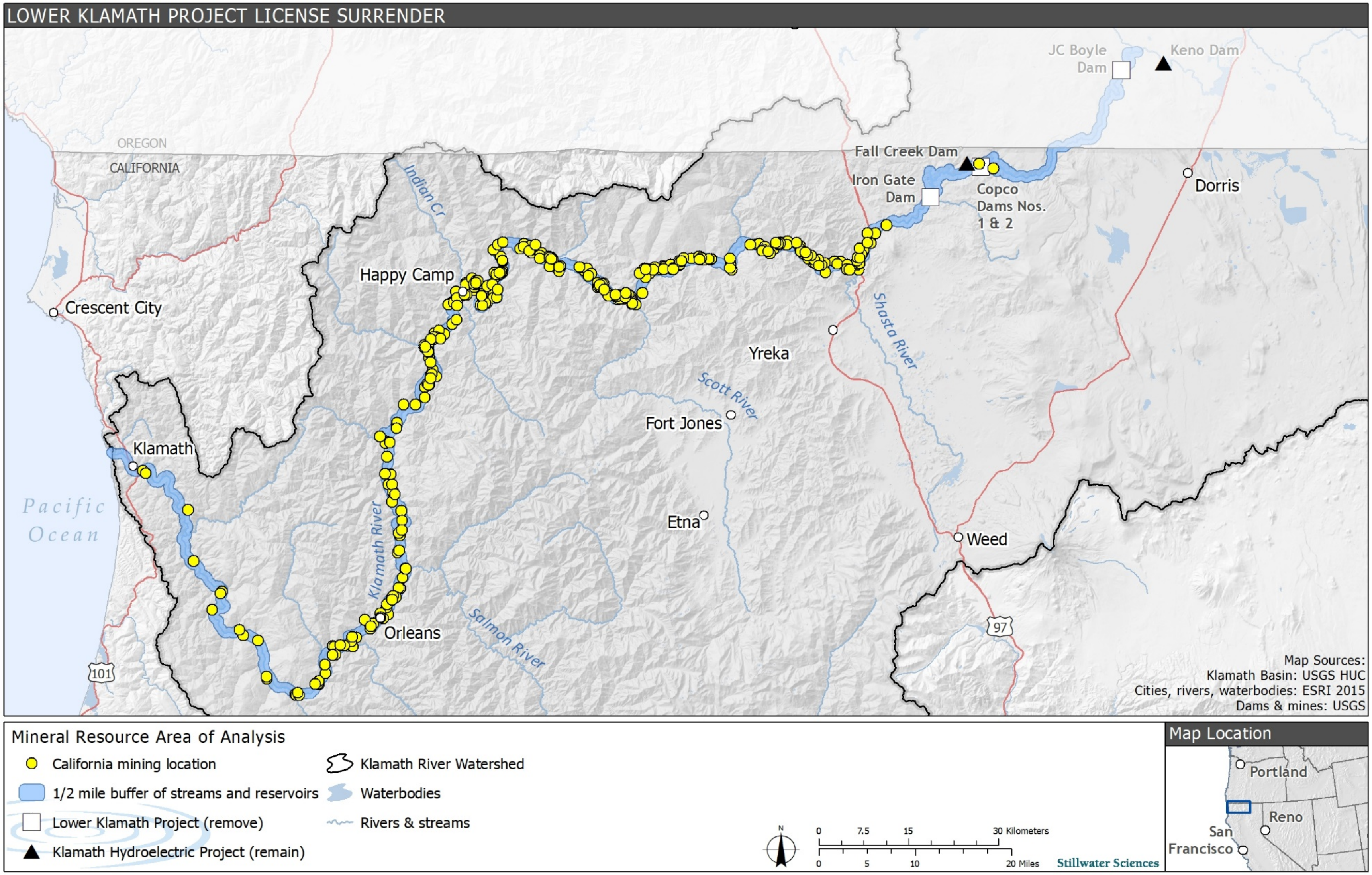

Figure 3.11-2. Mineral Resource Sites within the Area of Analysis for Geology and Soils.

Table 3.11-2. Mineral Resource Sites within the Area of Analysis for Geology and Soils.

Commodity	Occurrence	Past Producer	Producer	Prospect	Unknown	Total
Asbestos	1					1
Chromium	3			1	5	9
Clay	1					1
Copper	1	1			2	4
Diatomite	1					1
Gold	48	117	42	6	137	350
Graphite	2		1	1		4
Mercury	1				1	2
Sand and Gravel			3		1	4
Crushed Rock					1	1

3.11.2.2 Geomorphology

The geomorphology of the Klamath River in the Area of Analysis reflects the geology, hydrology, climate, and vegetation characteristic of the geomorphic provinces it flows through. The Klamath River within and downstream of the Hydroelectric Reach flows through steep, mountainous terrain and is generally a coarse-grained, bedrock-controlled channel with relatively short alluvial reaches and little floodplain development (Ayres Associates 1999). Channel morphology, degree of confinement, and bed surface grain size distribution are locally controlled by bedrock and by tributary flow and sediment inputs. The following sections provide a detailed description of the geology and geomorphology in channel reaches (Figure 3.11-1).

J.C. Boyle Reservoir

J.C. Boyle Reservoir (RM 229.8 to RM 233.3) transitions from a relatively wide and shallow upstream end, where the reservoir inundates a formerly low-gradient river valley, to a narrower and deeper downstream end, where the Klamath River incises into a bedrock canyon. The transition occurs at approximately RM 231. The bedrock surrounding and underlying J.C. Boyle Reservoir is principally inter-fingered volcanic deposits that are less than five million years old and are part of the High Cascade sub-province. Common lithologies include resistant basalt and basaltic andesite and less resistant volcaniclastic deposits. An outcrop of diatomite is present along the margin of the reservoir on the north side of the Klamath River by the prominent eastward bend (Appendix B: *Definite Plan*). The outcrop is at least 10 feet high and located at the foot of a rounded hill mapped as glacial material. The diatomite is underlain by black sand and is possibly interbedded with volcaniclastic material. The land surface surrounding the J.C. Boyle Reservoir is generally low gradient and underlain by competent materials. Spencer Creek enters the right bank at the upstream end of the reservoir.

J.C. Boyle Bypass and Peaking Reaches (RM 229.8 to 208.3)

The J.C. Boyle Bypass Reach begins in the Klamath Gorge downstream of J.C. Boyle Dam. Channel gradient in the bypass reach averages 1.4 to 2.3 percent. The channel through the upper portion of the bypass reach is typically composed of boulder and bedrock cascades with intermittent pools. The channel in the lower portion of the bypass reach is characterized by boulder to large cobble-bedded riffles, runs, and pools.

Rock fall from talus cones and block failures from cliff faces are the dominant sediment sources (FERC 2007).

The J.C. Boyle Peaking Reach begins as a wide, plane-bed channel just downstream of the powerhouse. The channel remains steep and boulder-dominated to the USGS gage (RM 224.4), downstream of which the steep (1.7 percent) channel is characterized by cobble-bedded riffles and runs with intermittent pools and gravel bars. Stepped terraces related to the thick lacustrine deposits occur from just downstream of J.C. Boyle Powerhouse to RM 219.1. The river is less steep (0.3 percent) in this segment, allowing for an increase in the size and frequency of finer sediment deposits (e.g., small cobble and gravel). At RM 219.1 the river becomes confined, channel gradient increases to 2 percent, and the channel bed and banks are composed of bedrock and boulders. Channel gradient decreases to approximately 0.8 percent and the river valley widens near the California state line (RM 213.8). Alternating riffles, runs, and pools characterize this section of the reach. A broad terrace within the peaking reach supports a riparian corridor, beyond which irrigated pastures occupy the floodplain. These channel conditions continue for the next five miles, where several side channels occur in conjunction with lateral bars and islands (FERC 2007). Shovel Creek, the largest tributary in this reach, enters the Klamath River from the left bank at RM 211.1.

Copco No. 1 Reservoir and Tributaries (RM 208.3 to 201.8)

Copco No. 1 Reservoir is located at a slope break in the Klamath River valley profile. The upper approximately 80 percent of the reservoir length inundates a low gradient reach of the river valley, while the lower 20 percent of the reservoir closest to the dam inundates a steeper reach. This slope break reflects base level control caused by emplacement of young volcanic deposits (e.g., Pleistocene cinder cones and associated lava flows, air fall tuff, and ash flows) that resulted in valley filling in the lower gradient upstream portion of the river valley. (FERC 2007, PanGeo 2008). Surficial deposits around Copco No.1 Reservoir include talus and rockfall debris, colluvium, alluvium and alluvial fans associated with tributary drainages, and older (likely Quaternary) fluvio-lacustrine terrace deposits (Appendix B: *Definite Plan*) (Figure 3.11-3). Fluvio-lacustrine terrace deposits surround much of the reservoir shoreline, extending to approximately 40 feet above the current reservoir level. These deposits consist of diatomite, fine-grained diatomaceous sediment and dense, coarse-grained alluvial deposits (Appendix B: *Definite Plan*). Lacustrine diatomite deposits also exist below the current range of reservoir levels, and appear as prominent benches in the bathymetry. Along the south shore, this bench is mostly continuous and ranges between 100 and 300 feet wide. Along the north shore, the bench is wider, with large peninsulas extending to the south with very steep to near vertical side slopes (Appendix B: *Definite Plan*). Multiple springs emerge from the hillside above the reservoir northeast of Copco Cove. Long Prairie Creek, Beaver Creek, Deer Creek, and Raymond Gulch drain to Copco No. 1 Reservoir.

Copco No. 2 Reservoir (RM 201.8 to 201.5)

Copco No. 2 Reservoir is a short impoundment (just over 0.25 mile) that lies immediately downstream of Copco No. 1 Dam. The narrow reservoir inundates a confined river valley deeply incised into the same young lava flows and associated volcanic rocks described above for the downstream portion of Copco No. 1 Reservoir.

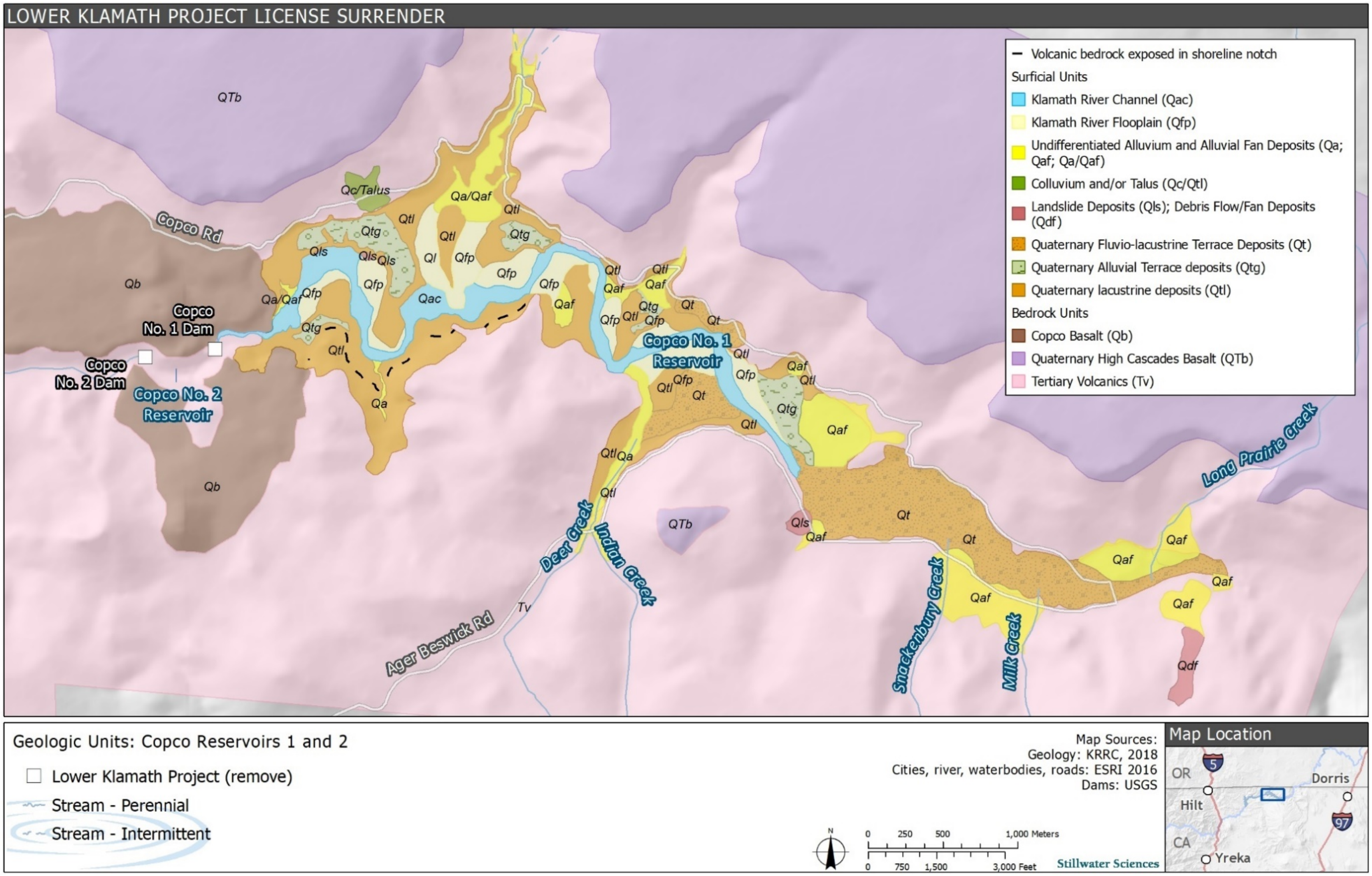

Figure 3.11-3. Surficial geology at Copco No. 1 Reservoir (Appendix B: *Definite Plan*).

Copco No. 2 Bypass Reach (RM 201.5 to 200.0)

Downstream of Copco No. 2 Dam, the Copco No. 2 Bypass Reach is a confined with minimal floodplain area. The average gradient of the bypass reach is about 1.9 percent. Bedrock channel reaches alternate with reaches where boulder-cobble deposits occupy most of the channel area. The Copco No. 2 Powerhouse returns flow to the Klamath River near RM 200.0 at the end of the reach (FERC 2007).

Iron Gate Reservoir and Tributaries (RM 200.0 to 193.1)

Iron Gate Reservoir overlies a slope break in the Klamath River valley profile, where a steeper upstream reach transitions to a lower gradient downstream reach. In this downstream reach, the valley widens and the channel is less confined by basalt flows (FERC 2007). Iron Gate Dam and its reservoir lie within Western Cascades geologic sub-province. Bedrock units include tuffaceous siltstones and sandstones, bouldery volcaniclastics and volcanic breccia, tuff and tuff breccia, and pyroxene flow rocks (Figure 3.11-4). Iron Gate Reservoir is relatively narrow and steep-sided, with numerous tributaries entering from the north (Fall Creek, Jenny Creek, Dutch Creek, Camp Creek, and Scotch Creek). Of these tributaries, Camp Creek and Jenny Creek supply the most sediment to the reservoir.

Iron Gate Dam to Hilt Mine (RM 193.1 to 184.0)

Downstream of Iron Gate Dam, the Klamath River flows through a narrow valley cut into the Western Cascade sub-province geology and sedimentary rocks of the Cretaceous Hornbrook Formation. The average gradient ranges from about 0.2 to 0.4 percent in the first five miles downstream of Iron Gate Dam. A narrow, discontinuous floodplain and extensive high terraces border the channel. The mostly single thread channel contains frequent bedrock outcrops, but the predominantly alluvial reaches have cobble-boulder bars and split flow around mid-channel bars with short side channels. Most of the bars are at least partially vegetated. The main tributaries entering 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, fine-grained alluvial fans at their confluences with the Klamath River. Cottonwood Creek forms a relatively large alluvial fan at its confluence near RM 185.1. Cottonwood Creek, Bogus Creek, and Little Bogus Creek are the first substantial sources of sediment downstream of Iron Gate Dam (Ayres Associates 1999, Buer 1981).

Hilt Mine to Indian Girl Mine (RM 184.0 to 177.2)

The Klamath River channel in this reach becomes more bedrock-dominated and confined within a narrow canyon. Alluvial bars are limited to the vicinity of the larger tributary confluences, such Williams Creek near RM 182.1 and the Shasta River near RM 179.5. The Shasta River is a source of fine gravel, sand, and finer sediment. However, the lack of substantial sedimentation in the vicinity of its confluence with the Klamath River suggests the Shasta River supplies little coarse sediment (Ayres Associates 1999).

Indian Girl Mine to Scott River (RM 177.2 to 145.1)

The channel in this reach of the Klamath River is mostly meandering and single thread, with valley width ranging from 300 feet to almost 1,200 feet. Sections with larger valley widths typically promote a lower gradient channel, more frequent alluvial features, and more

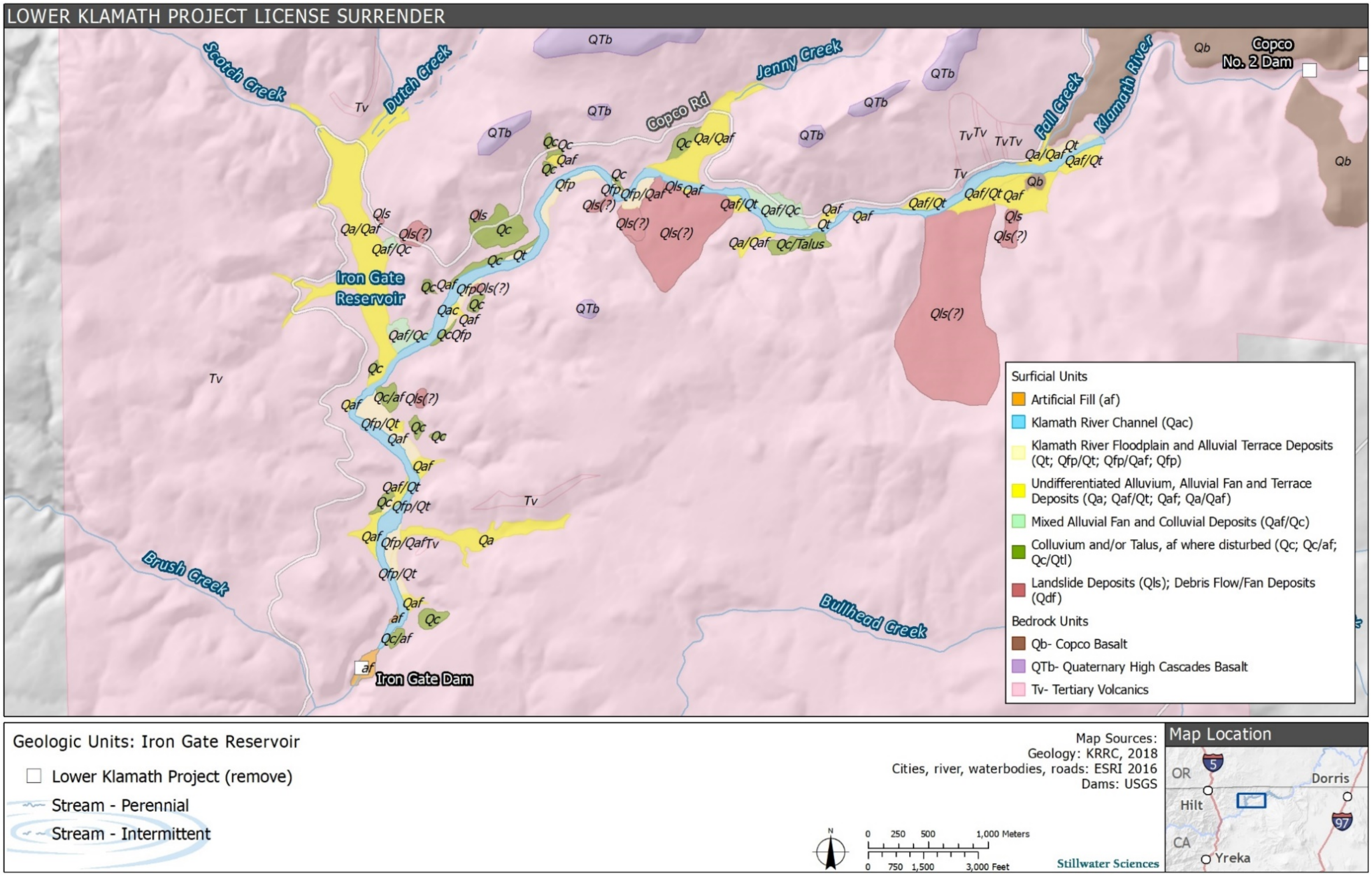

Figure 3.11-4. Surficial geology at Iron Gate Reservoir (Appendix B: *Definite Plan*).

extensive floodplains. Unvegetated point bars at the inside of channel bends, mid-channel bars, and side channel complexes are more prevalent in this reach. Alluvial features are largest in the areas immediately downstream of major tributary confluences and are typically smaller than about 17 acres per mile until after the Scott River confluence at RM 145.1. Terraces have been extensively mined throughout the reach, with tailings piles occurring in some floodplain areas.

From Miller Gulch (RM 163.8) to Horse Creek (near RM 149.7), the river valley broadens and includes terraces and gravel bars. A narrower section from between RM 156.3 and RM 152 is confined by bedrock and by the Kohl Creek alluvial fan. From RM 152 to Horse Creek (RM 149.6), the river valley widens and has been extensively placer mined, resulting in mine tailings and other floodplain disturbance.

From Horse Creek (RM 149.6) to Scott River(RM 145.1), the river valley narrows and is confined by bedrock. Terraces and bars are restricted to the inside of meander bends. Several small tributaries enter in this reach, forming steep alluvial fans at their confluence with the Klamath River. Channel morphology is single thread with few small and unvegetated mid-channel bars and point bars (USBR 2012).

Scott River to China Point (RM 145.1 to 119.8)

The Scott River is a major source of gravel and finer sediment to the Klamath River (Ayres Associates 1999). The prevalence, size, and height of unvegetated gravel bars increases downstream of the Scott River confluence (RM 145.1 to RM 133.8), with discontinuous narrow alluvial terraces forming along the canyon margins. At Seiad Valley (approximately RM 132.8), 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 the increased tributary sediment supply results in large bars and riffles. Extensive placer mining has occurred on floodplains and terraces within the Seiad Valley area.

From RM 131.4 to 123.3, the Klamath River flows through a bedrock canyon with unvegetated bars located on the inside of meander bends. Valley terraces and bars with bedrock at shallow depth are prevalent in this reach. From RM 123.3 to China Point (RM 119.8), 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. Tributaries that contribute sediment to the river in this reach include Thompson, Fort Goff, Portuguese, Grider, Walker, O’Neil, and Macks creeks (USBR 2012).

China Point to Trinity River (RM 119.8 to 43.3)

From China Point (RM 119.8) to Deason Flat (RM 106), the channel is narrow with numerous valley terraces that have been extensively mined. Well-developed bars and riffles occur at tributary confluences and meander bends. The lower three miles of this reach contain a greater number of unvegetated bars formed by sediment inputs from Elk and Indian creeks and channel constriction beginning at RM 105.6. Tributaries in this reach deliver large quantities of sediment from landslide sources.

From Deason Flat to Dutch Creek (RM 93), the river flows through a narrow bedrock canyon with low bedrock benches capped by thin gravel deposits. Wider sections interspersed in this reach have small valley terraces that have been extensively mined and have unvegetated gravel bars. This reach also contains notable landslides along the mainstem. Independence and Clear creeks both contribute large amounts of sediment to the Klamath River in this reach.

From Dutch Creek to the Trinity River (RM 43.3), the Klamath River is confined within a narrow bedrock canyon with intermittent alluvial reaches. This reach also includes the wider alluvial valley at Orleans (RM 59). Geomorphic features include valley terraces, alluvial fans, bedrock benches, and alluvial bars. Numerous landslides occur along the Klamath River and interact with the river by delivering sediment and controlling channel position. This reach is the downstream limit of mining on the Klamath River. Tributaries that are major contributors of sediment include Ukonom Creek, Camp Creek, Bluff Creek, and the Salmon River (USBR 2012).

Trinity River to the Pacific Ocean (RM 43.3 to 0)

From the Trinity River (RM 43.3) to Cappell Flat (RM 33), the Klamath River flows through a narrow bedrock canyon with few bars and no floodplain or terraces. The channel is primarily bedrock controlled. Landslides and alluvial fans are less common. The Trinity River is a major source of sediment (Ayres Associates 1999).

From Cappell Flat to Starwein Flat (RM 10), the river flows through a narrow, confined valley with minimal floodplain and terraces. Alternate bars form in straighter reaches and point bars form at meander bends. Split flow channels, mid-channel bars, and riffles commonly form in the vicinity of tributary confluences. 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 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 (USBR 2012). The lower seven miles of the Klamath River are relatively narrow and confined, typically between 650 and 800 feet wide, with steeper gradient than in upstream reaches. The channel is up to 1,600 feet wide at large bends and in areas with active erosion and channel migration.

The mouth of the river is characterized by a delta with a large barrier bar parallel to the coastline. Landward of the barrier bar is a shallow estuary about 2,500 feet long by less than 1,000 feet wide. The Klamath River through the estuary is highly dynamic, changing positions during large flood events and transporting most of its suspended sediment load out to the ocean. The relatively small size of the estuary is maintained by ongoing deposition of medium grained sand and silty sand (USBR 2010a).

3.11.2.3 Slope Instability and Mass Wasting

Mass failures and other gravity-driven erosion processes can occur on relatively steep slopes. Such conditions within the soils and geology Area of Analysis exist only within the vicinity of the Klamath River Gorge from the California-Oregon state line to just downstream of Iron Gate Dam. Other areas of potential slope instability include all steep slopes underlain by consolidated volcanic ash (also known as tuff), as well as slopes of deep colluvium or talus that could produce slumps and debris flows. Continuous creep and rapid rockfall occur on and near talus slopes throughout the Klamath River Gorge.

Land surrounding J.C. Boyle Reservoir is generally low gradient and underlain by competent materials (Appendix B: *Definite Plan*). Rock fall from steep talus slopes is prevalent along the Klamath River between J.C. Boyle Dam and Copco No. 1 Reservoir.

Undifferentiated surficial deposits occur around much of Copco No. 1 Reservoir. These deposits include talus and rockfall debris, alluvium and alluvial fans associated with tributary drainages, and alluvial and lacustrine terrace deposits. No large-scale landslides have been identified in either the terrestrial or subaqueous slopes around Copco No. 1 Reservoir (Appendix B: *Definite Plan*), although a large alluvial fan or colluvial deposit on the north side of Copco No. 1 Reservoir may be related to an ancient inactive landslide (PanGEO 2008) (Figure 3.11-3). Wave action at the Copco No. 1 Reservoir shoreline has eroded sand and volcaniclastic tuff beneath diatomite beds, creating up to 10- to 20-ft-high vertical exposures.

PanGEO (2008) identified three possible old landslide-related features that occur on the south rim of Iron Gate Reservoir (Figure 3.11-4). KRRC identified another likely landslide along Copco Road within the peninsula between the east and west arms of Iron Gate Reservoir (Appendix B: *Definite Plan*).

Channel boundaries in the vicinity of the Lower Klamath Project are prominently composed of bedrock, boulders, and cobble, and thus subject to only minor erosion. Bank erosion is therefore not a substantial sediment source.

3.11.2.4 Sediment Load

Sediment is supplied to stream channels through mass wasting (landslides, debris flows, earthflows), sheetwash, gullying, bank failure, fluvial erosion (bank erosion, channel avulsion), dry ravel (loss of cohesion in surface materials), tree throw, wind erosion, animal action (e.g., burrowing), and soil creep. Sediment supply to the Klamath River has been estimated for portions of the Klamath Basin through various methods, including field inventory of sediment sources, interpretation of air photos and other historical information, estimation of reservoir sediment accumulation, and modeling based on empirical sediment delivery rates for specific geomorphic terrains. Primary sources of existing information about sediment delivery to the Klamath Basin include the following:

- Assessment of the quantity and characteristics of sediment stored in Iron Gate, Copco No. 1, and J.C. Boyle reservoirs (GEC 2006, USBR 2012);
- The sediment budget developed by PacifiCorp and submitted to FERC as part of the final license application for the Klamath Hydroelectric Project (FERC No. 2082) (PacifiCorp 2004);
- Sediment source inventories conducted in support of sediment TMDLs in the Scott River, Trinity River, and South Fork Trinity River sub-basins (USEPA 1998, 2001; North Coast Regional Board 2005);
- The Salmon Sub-basin Sediment Analysis (de la Fuente and Haessig 1993);
- Cumulative watershed effects analyses and watershed analyses conducted for federal lands administered by the Forest Service (UDSA Forest Service 2003, 2004, 2005; Elder 2005, 2006); and
- Sediment source inventories conducted on industrial timberlands (Simpson Resource Company 2002).

Existing information on sediment loads delivered to the Klamath River was combined with extrapolated estimates of sediment delivery from data-deficient source areas to derive estimates of cumulative average annual sediment delivery in the Klamath River from Keno Dam (RM 237) to the Pacific Ocean (RM 0) and the proportion of coarse material and fine material within the load (Stillwater Sciences 2010) (Table 3.11-3). Upper Klamath Lake traps most sediment entering the lake, and therefore little sediment is supplied to the Klamath River from the watershed upstream of Keno Dam. The average annual sediment delivery from Keno Dam to Iron Gate Dam was estimated to be approximately 150,000 tons/yr. The Scott River supplies approximately 607,000 tons/yr, the Salmon River 320,000 tons/yr, and the Trinity River 3,300,000 tons/yr. The cumulative average annual sediment delivery from the Klamath River to the ocean was estimated to be 6,237,500 tons/yr. The cumulative average annual delivery of sediment with a particle size greater than 0.063 mm (coarse sediment) was estimated to be 1,970,200 tons/yr. This estimate is within about 20 percent of Willis and Griggs (2003) estimate of average annual coarse sediment flux from the Klamath River to the Pacific Ocean (2,502,200 tons/yr). These estimates are based on various data sources encompassing different time periods and do not account for transfer of sediment to and from storage nor attrition.

Table 3.11-3. Estimated Annual Sediment Delivery to the Klamath River.

Source Area	River Mile	Cumulative delivery[1] (tons/year)		
		Total	≥0.063 mm	≤0.063 mm
Keno Dam to Iron Gate Dam	193.1	151,000	24,160	126,840
Iron Gate Dam to Cottonwood Creek	185.1	160,961	25,754	135,207
Cottonwood Creek	185.1	175,560	30,426	145,135
Cottonwood Creek to Shasta River	179.5	177,715	31,115	146,600
Shasta River	179.5	199,259	38,009	161,250
Shasta River to Beaver Creek	163.4	231,710	48,393	183,316
Beaver Creek	163.4	279,869	63,804	216,065
Beaver Creek to Scott River	145.1	373,073	93,630	279,443
Scott River	145.1	980,393	287,972	692,421
Scott River to Grider Creek	132.1	1,048,860	309,881	738,978
Grider Creek to Indian Creek	108.3	1,099,934	326,225	773,709
Indian Creek	108.3	1,173,246	349,685	823,561
Elk Creek	107.1	1,211,930	362,064	849,866
Clear Creek	100.1	1,253,972	375,517	878,454
Dillon Creek	85.4	1,282,389	384,611	897,778
Indian Creek to Dillon Creek	85.4	1,354,759	407,769	946,990
Dillon Creek to Salmon River	66.3	1,440,282	435,137	1,005,146
Salmon River	66.3	1,760,904	537,736	1,223,169
Salmon River to Camp Creek	57.3	1,785,769	545,693	1,240,077
Camp Creek	57.3	1,923,108	589,641	1,333,467

Source Area	River Mile	Cumulative delivery[1] (tons/year)		
		Total	≥0.063 mm	≤0.063 mm
Camp Creek to Red Cap Creek	52.9	1,946,606	597,160	1,349,446
Red Cap Creek	52.9	2,063,374	634,526	1,428,848
Red Cap Creek to Bluff Creek	49.7	2,079,504	639,687	1,439,816
Bluff Creek	49.7	2,417,974	747,998	1,669,976
Bluff Creek to Trinity River	43.3	2,439,210	754,793	1,684,416
Trinity River	43.3	5,756,544	1,816,340	3,940,204
Blue Creek	16.2	5,859,351	1,849,239	4,010,112
Trinity River to Mouth	0.0	6,237,471	1,970,237	4,267,234

Source: Adapted from Stillwater Sciences 2010.

[1] Cumulative sediment delivery is reported for the downstream endpoint of the corresponding source area identified in the first column. Mass is reported in US short tons and assumes a density of 1.5 tons/yd^3. Above Cottonwood Creek, assumes 16 percent of total load is ≥0.063 mm based on grain 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 mm.

The sediment load supplied from the watershed in any given year will vary from the long-term annual average load based on annual hydrologic conditions and other environmental factors (e.g., mass wasting, wildfire, land use) that control sediment supply and transport. Quantifying the potential annual variations around the estimated average annual sediment supply in the entire Klamath River basin is difficult without long-term data sets describing suspended or total sediment load. However, analyzing historical sediment discharge data from nearby locations provides a reasonable indication of the potential variation and trends in annual sediment supply. Janda and Nolan (1979) summarize sediment discharge data from a variety of USGS gaging stations in Northern California, including the Klamath River watershed. The highest annual sediment yield (Water Year [WY] 1974) in the Klamath River at Orleans was three times greater than the period average (WY 1968–1977). The highest annual sediment yield (WY 1964) in the Trinity River at Hoopa was a factor of seven greater than the period average (WY 1957–1977) and a factor of 14 greater than the estimated long-term annual average (Janda and Nolan 1979). The period of record for the Trinity River at Hoopa includes the large flood of 1964, whereas the period of record for the Klamath River at Orleans does not. Using these observed variations in annual sediment discharge as indicators for the expected range of potential variability in annual background sediment loads, the predicted sediment release from removal of dams on the Klamath River is within the typical range of background conditions at Scott River during years with average sediment delivery and as far upstream as Beaver Creek during years with high sediment delivery.

Additional insight is gained by comparing the average annual basin sediment delivery and the anticipated annual sediment load from dam removal with daily suspended sediment loads observed during large floods. The daily suspended sediment load measured in the Klamath River at Orleans exceeded the estimated cumulative average annual basin sediment delivery at the Salmon River confluence (sediment delivery node nearest Orleans) for five days during the period from WY 1968 to WY 1979. The highest daily suspended sediment load in the Klamath River at Orleans during the January 1974 flood (second largest during the 81 year period of record) was greater than the median estimate of total annual sediment load released by dam removal. Suspended sediment flux in the Trinity River at Hoopa from December 22 to 26, 1964 was approximately 25,400,000 tons, nearly eight times the high estimate of total annual sediment release from dam removal. During three of the days during the 1964 flood, the daily suspended sediment flux exceeded the high estimate of total annual sediment release from dam removal. Observations from these gaging records indicate that the predicted amount of sediment released by removal of dams on the Klamath River could be considered equal or less than the background sediment flux over a single day at the Salmon River confluence during large flood events (e.g., the January 1974 flood).

The coarse sediment deficit resulting from sediment trapping in the Lower Klamath Project developments has resulted in coarsening of the channel bed and a reduction in the size and frequency of mobile coarse sediment deposits in a limited downstream channel extent. Because tributaries downstream of Cottonwood Creek supply most of the coarse sediment to the mainstem Klamath River under both unimpaired and current conditions, the effects of reservoir sediment trapping are most apparent in the reach between J.C. Boyle Reservoir and approximately the Scott River. Reduced coarse sediment delivery to this reach has reduced the amount and quality of spawning gravel deposits and disrupted the geomorphic processes that create and maintain aquatic habitats (Buer 1981, PacifiCorp 2004). In response to this condition, the California Department of Water Resources developed (but never implemented) gravel augmentation programs for spawning gravel downstream from Iron Gate Dam (Buer 1981). Per the interim operations of the Klamath Hydroelectric Project HCP (PacifiCorp 2012), PacifiCorp developed and implemented a plan to augment gravel immediately downstream of Iron Gate Dam beginning in 2014 (PacifiCorp 2014). Gravel augmentation occurred immediately downstream of Iron Gate Dam in 2014, 2016, and 2017, with approximately 4,600 cubic yards total placed downstream of the dam as of December 2017 (PacifiCorp 2018). The placed gravel has been moved downstream by high flows (PacifiCorp 2018), although additional details on the extent of downstream movement have not been reported. Appendix F assesses the changes to bedload sediment within the soils and geology Area of Analysis for existing conditions and for the Proposed Project.

USBR (2010b) used reach average hydraulic properties and grain size data from previous studies to estimate the flow magnitude and return period at which sediment mobilization occurs downstream of Iron Gate Dam. The representative particle diameters for all data collected downstream of Iron Gate Dam are given in Figure 3.11-5. The estimates did not include the reach from Iron Gate Dam to Bogus Creek, for which there were no grain size data. USBR (2010b) assumed this reach to be fully armored because reservoir trapping has eliminated coarse sediment supply to the reach during the past 50 years. Flows required to initiate mobilization of the median grain size (D_{50}) in reaches downstream of Bogus Creek are summarized in Figure 3.11-6.

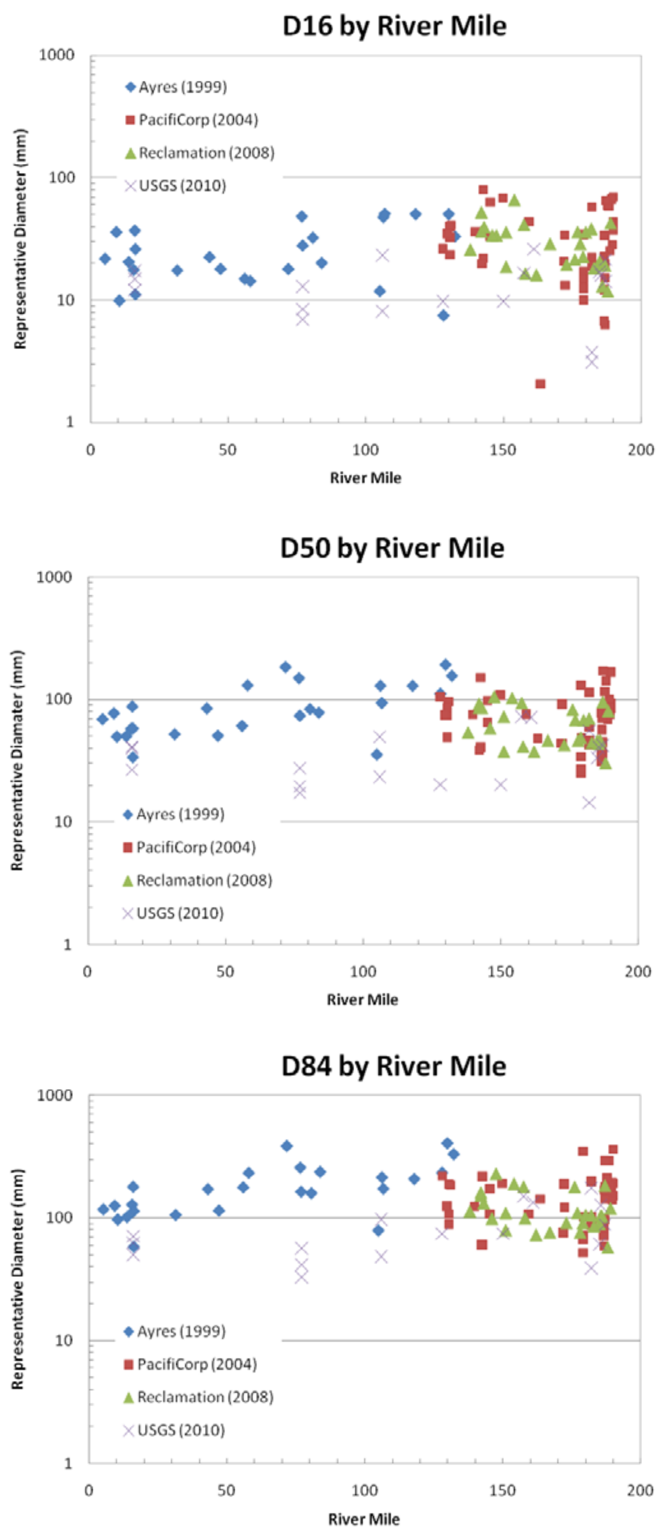

Figure 3.11-5. Particle Size Parameters (D_{16}, D_{50}, and D_{84}) from Pebble Counts of the Klamath River Bed Surface Downstream of Iron Gate Dam (USBR 2012).

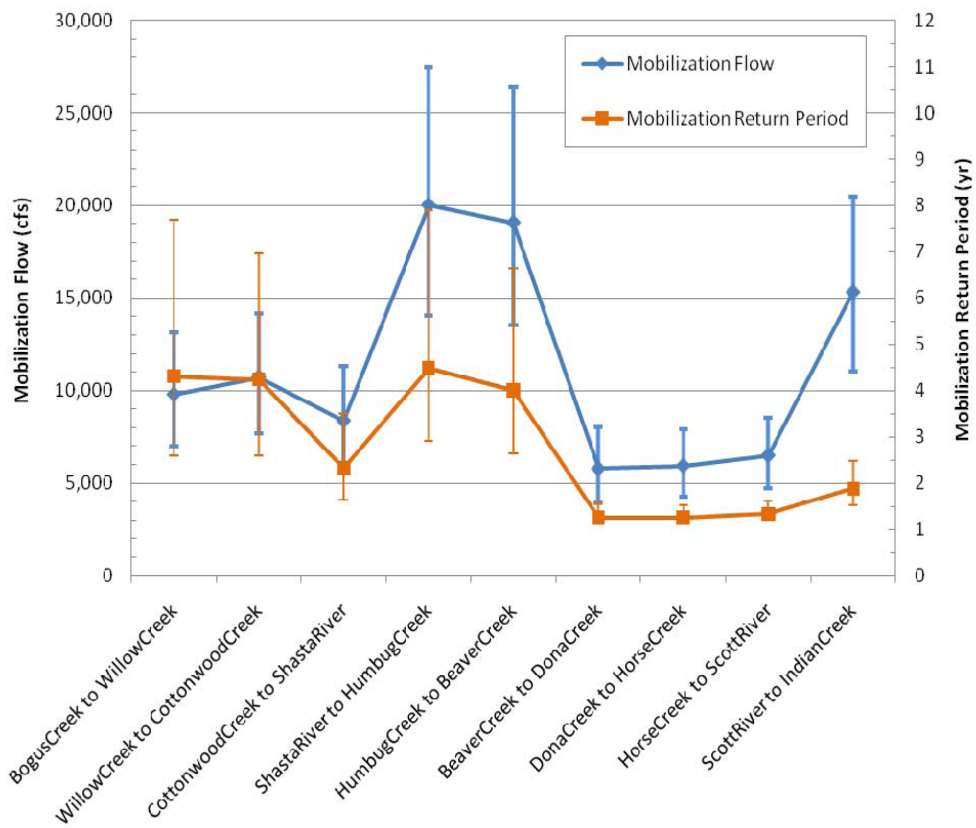

Figure 3.11-6. Flow and Corresponding Return Period at which Bed Mobilization Begins Under Existing Conditions (USBR 2012).

Suspended sediment data were collected by USGS at its gauges on the Shasta River near Yreka from 1957 to 1960, and on the Klamath River at Orleans from 1957 to 1979 and at Klamath from 1974 to 1995. The data show that suspended sediment concentrations commonly exceed 1,000 mg/L at Orleans, even at flows as low as 20,000 cfs (USBR 2012). Suspended sediment concentrations in the Klamath River upstream and downstream of Iron Gate Dam under existing conditions are summarized in Section 3.2.2.3 *Suspended Sediments* and in Appendix C.

The Scott River, mainstem Trinity River, South Fork Trinity River, and Klamath River downstream of the Trinity River confluence at Weitchpec are listed as sediment impaired under Section 303(d) of the federal CWA. Sediment source analyses, TMDL allocations for sediment, and sediment TMDL implementation plans have been completed for the Scott River, Trinity River, and South Fork Trinity River basins. A sediment source analysis and sediment TMDL have not been completed for the Klamath River downstream of the Trinity River confluence. The North Coast Regional Water Quality Control Board (North Coast Regional Board) adopted a regional sediment TMDL implementation policy for the Klamath River downstream of the Trinity River (Resolution R1-2004-0087 on 29 November 2004), and no additional sediment sources analyses are scheduled to be conducted in the basin.

3.11.2.5 Reservoir Sediment Storage and Composition

The four Lower Klamath Project reservoirs currently store approximately 13.15 million cubic yards (yd^3) of sediment (USBR 2012). The volume and weight of sediment stored in each reservoir is given in Table 3.11-4. The distribution of sediment deposits varies within each of the reservoirs. In J.C. Boyle Reservoir, sediment primarily resides in the area nearest to the dam, with thicknesses up to 20 ft (Figure 3.11-7). Both Copco No. 1 and Iron Gate reservoirs have generally even distributions of sediment with thicknesses increasing towards the dams (Figure 3.11-8 and Figure 3.11-9). The maximum thickness of the Copco No. 1 Reservoir sediment is approximately 10 ft. The maximum deposition within the thalweg of Iron Gate Reservoir is around 5 ft, with nearly 10 ft of deposition in the Jenny Creek arm of the reservoir. Copco No. 2 Reservoir inundates a small area extending to the base of Copco No. 1 Dam has no sediment sources, and does not retain appreciable amounts of sediment (see also Section 2.7.3 *Reservoir Sediment Deposits and Erosion During Drawdown*).

Table 3.11-4. Sediment stored in Lower Klamath Project reservoirs, Fall 2009.

Reservoir	Total Sediment Volume[1] (yd^3)		Total Sediment Mass[2,3] (tons)	Fine Sediment Mass[2,4] (tons)	Sand Sediment Mass[2,5] (tons)	Percent Fine Sediment by Mass[7]	Percent Sand Sediment by Mass[7]
J.C. Boyle	990,000	+/- 300,000	290,000	190,000	100,000	66 percent	34 percent
Copco No. 1[6]	7,440,000	+/- 1,500,000	1,880,000	1,630,000	260,000	86 percent	14 percent
Iron Gate[6]	4,710,000	+/- 1,300,000	1,430,000	1,210,000	230,000	84 percent	16 percent
Total[6]	13,150,000	+/- 2,000,000	3,600,000	3,020,000[6]	590,000	84 percent	16 percent
Total Copco No. 1 and Iron Gate[6]	12,150,000	+/- 2,000,000	3,320,000	2,830,000[6]	490,000	85 percent	15 percent

Source: Modified from USBR 2012a, as noted in the below footnotes.

1 Uncertainty resulted from interpolation between drill holes and is calculated as a volume with a +/- amount shown in the table (USBR 2012a).

2 Amount of sediment with a diameter greater than 2 millimeters is negligible (< 0.5 percent) for all the reservoirs and within the uncertainty of the sediment estimates. Ton is defined as equal to 2,000 pounds (dry weight).

3 Average dry densities vary between reservoirs and within the reservoir depending upon compaction and grain size distribution. The dry unit weight varies between 44.4 and 16.3 lb/ft^3 (USBR 2012a).

4 Fine sediment is sediment with a diameter less than 0.063 millimeters

5 Sand sediment is sediment with a diameter between 0.063 and 2 millimeters

6 Amounts of sediment (volumes and masses) from individual reservoirs may not equal the total amounts indicated because all volumes and masses taken from USBR (2012a) were rounded to the nearest 10,000 yd^3 (volume) or 10,000 tons, dry weight (mass). Copco No. 2 Reservoir does not retain measurable amounts of sediment and therefore is not included in the estimates of total stored sediment.

7 Percent sediments are calculated from the masses listed in the table and rounded so the percent fine sediment and the percent sand sediment sum to 100 percent.

Sediment in the Lower Klamath Project reservoirs is primarily composed of elastic silt and clay (fine sediment), including silt-size particles of organic material such as algae and diatoms, with lesser amounts of cobble and gravel (coarse sediment) (Table 3.11-5) (USBR 2012). The fine-grained sediment has low cohesion and is erodible (USBR 2010a).

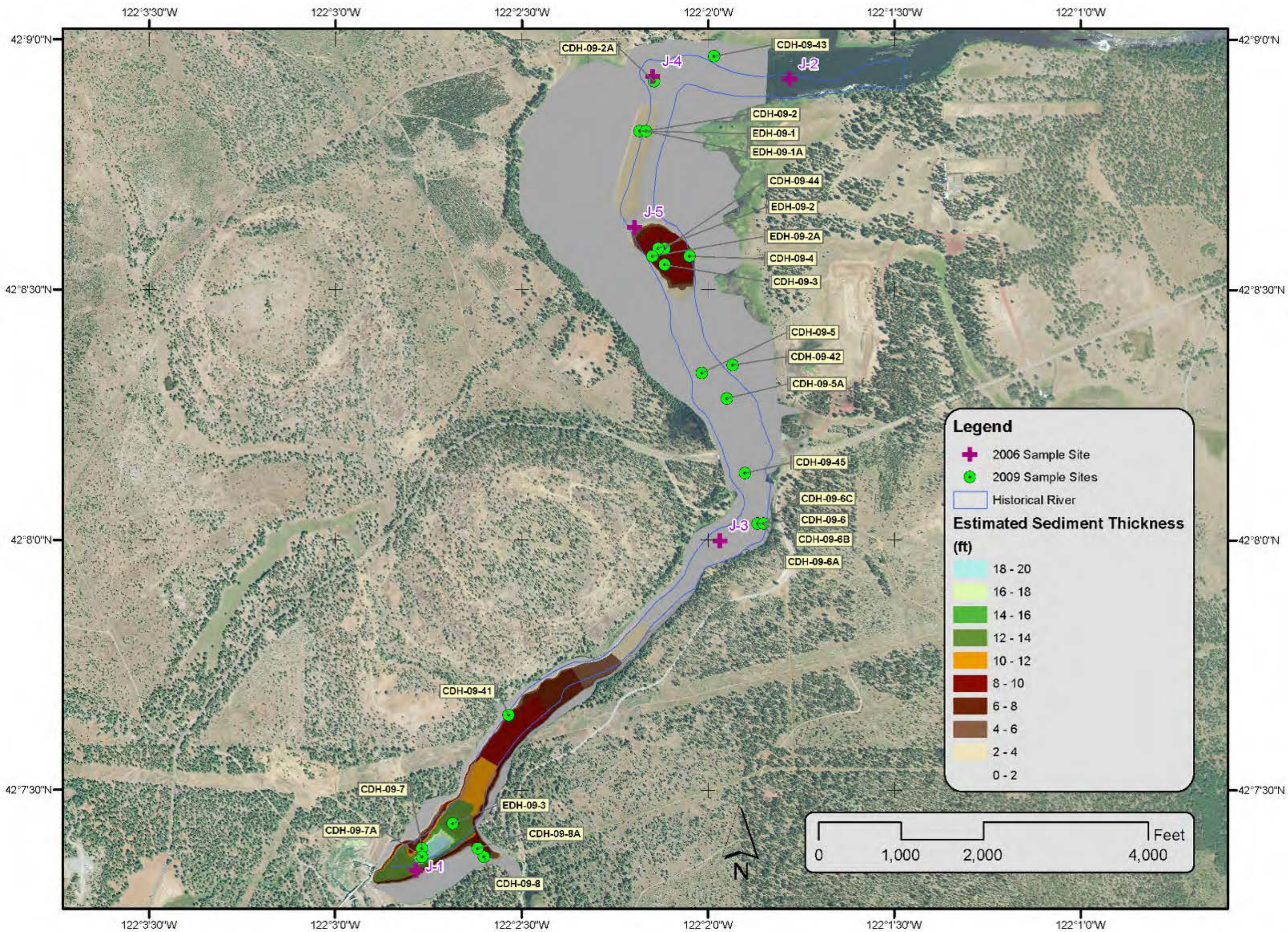

Figure 3.11-7. J.C. Boyle Reservoir Estimated Sediment Thickness and Sample Site Locations.

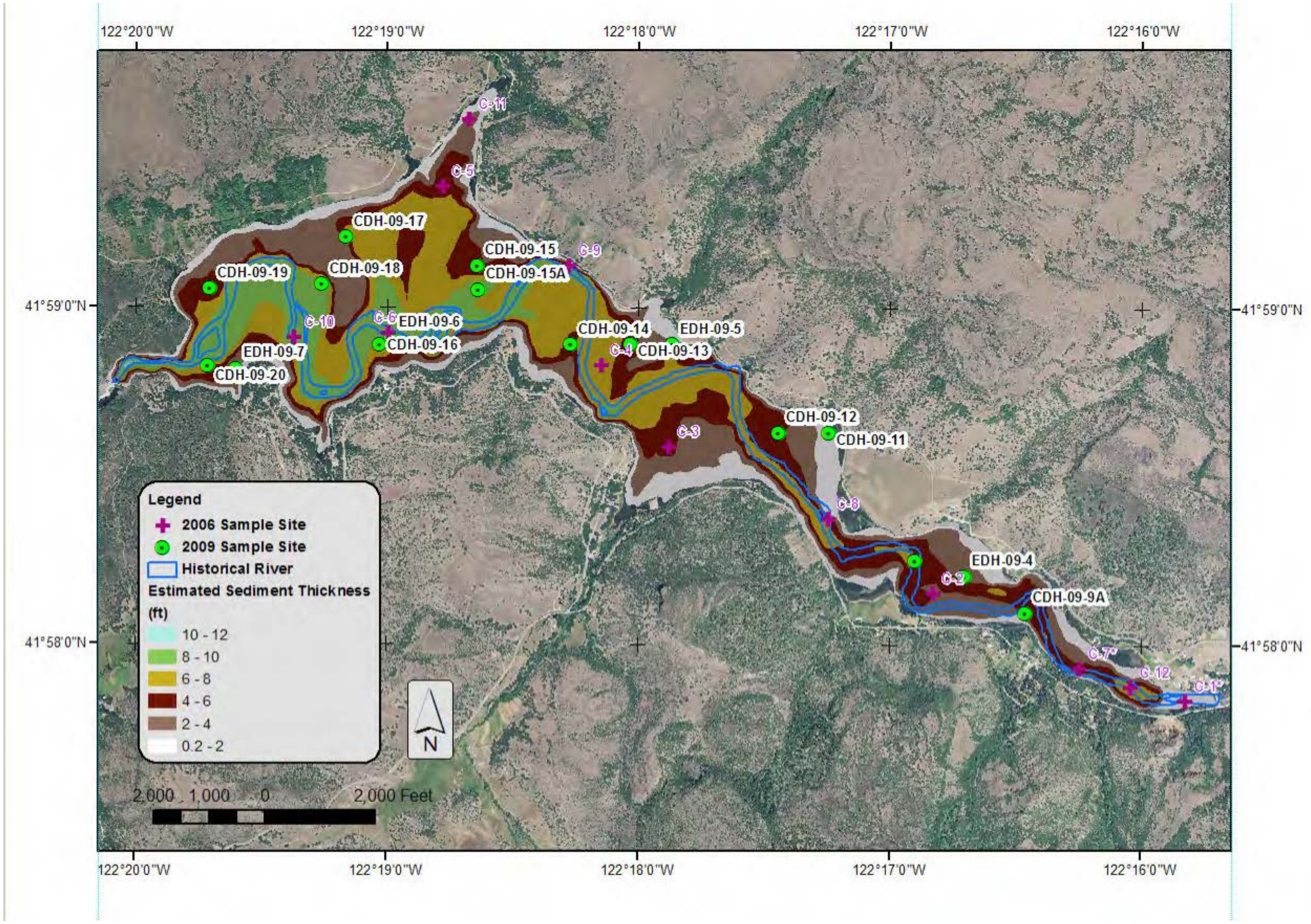

Figure 3.11-8. Copco Reservoir Estimated Sediment Thickness and Sample Site Locations.

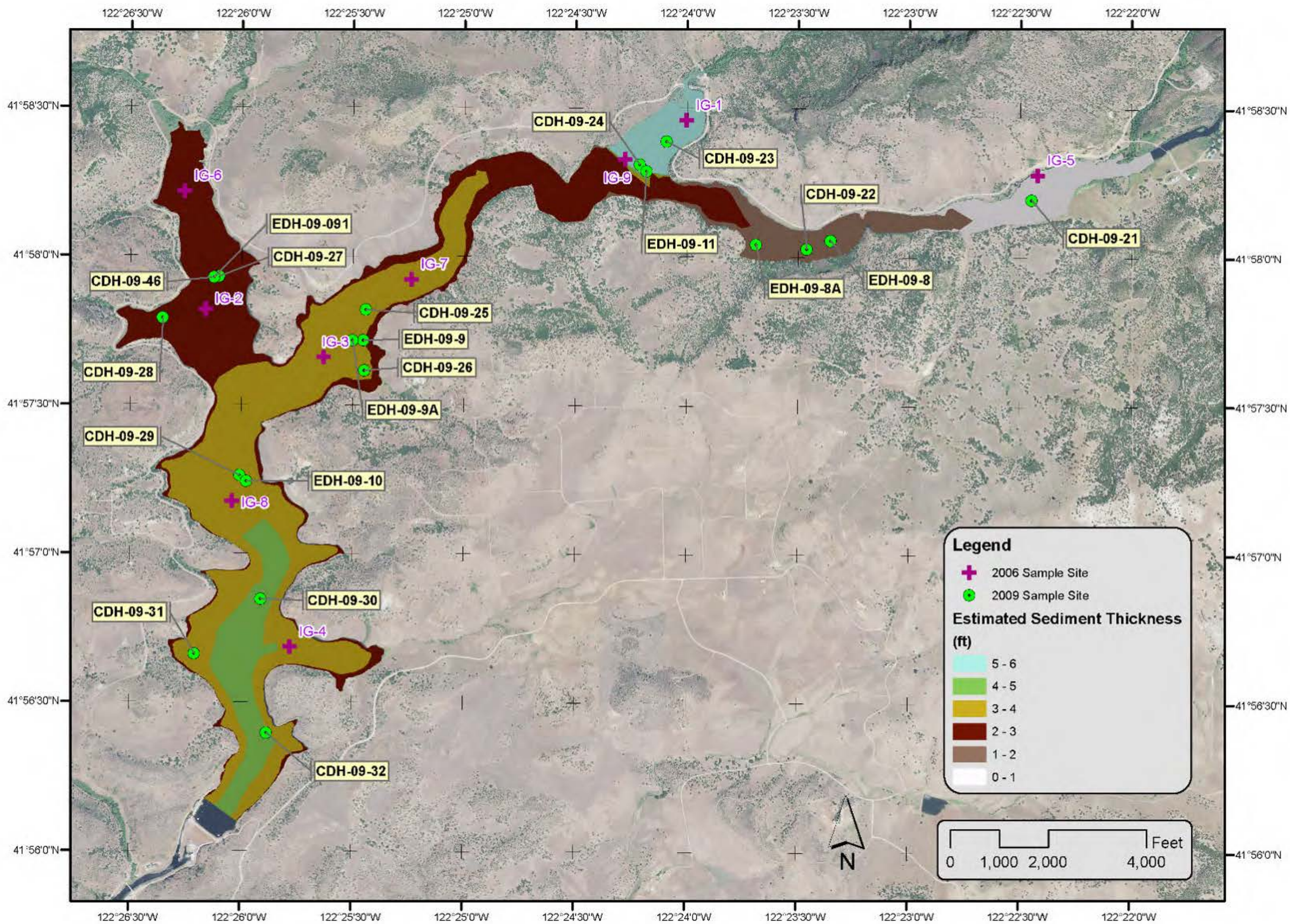

Figure 3.11-9. Iron Gate Reservoir Estimated Sediment Thickness and Sample Site Locations.

Table 3.11-5. Physical Properties of Reservoir Sediment.

Reservoir	Location	Volume yd³	percent Clay[1]	percent Silt[1]	percent Sand[1]	percent Gravel[1]	Liquid Limit (percent)	Plasticity Index (percent)	Moisture Content (percent)	Porosity (percent)	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 No. 1	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: USBR 2010a, 2012.

[1] Clay = 0 to 0.005 mm; Silt and very fine sand = 0.005 to 0.075 mm; Sand = #200 to #4 sieve; Gravel = #4 to 3 inch. Note that while organic material such as algae and diatoms would be associated with the clay and/or silt classes in the reservoir sediments, the standard method used for size separation (ASTM D22) in USBR (2012) would remove a small fraction of these during sample drying at 110ºC.

Key:
yd³: cubic yards
lb/ft: pounds per foot

3.11.3 Significance Criteria

For the Lower Klamath Project EIR, impacts to geology and soils would be considered significant if Proposed Project implementation would result in any of the following:

- Substantial soil erosion from upland areas into the reservoirs or the Klamath River due to project construction activities.
- New or exacerbated mass wasting around the rim of the reservoirs during drawdown.
- Substantial deposition of sediment in the Klamath River channel or Klamath estuary due to erosion of reservoir sediment deposits.
- Long-term removal of access to mineral resources for extraction.
- Exposure of people or structures to adverse effects resulting from rupture of a known earthquake fault, strong seismic ground shaking, volcanic activity, or large-scale slope instability.

For the purposes of this EIR, substantial is defined as "of considerable importance to public health and safety, water quality, and/or physical conditions supporting aquatic resources as these resources pertain to geology and soils." Additional criteria related to geology and soils associated effect to other resources is addressed in Section 3.2 *Water Quality*, Section 3.3 *Aquatic Resources*, and Section 3.6 *Flood Hydrology* of this EIR.

3.11.4 Impacts Analysis Approach

The assessment of the environmental impacts on geology and soils focuses on whether changes to geomorphology and sediment transport resulting from implementation of the Proposed Project would substantially increase erosion or mass wasting, or result in substantial sediment deposition which could adversely affect other associated resources within the soils and geology Area of Analysis. The soils and geology impact analysis uses results from the analyses described below to determine changes in bed elevation, substrate composition, and fine sediment deposition under the Proposed Project. Potential geomorphic changes associated with dam removal activities are described qualitatively.

Bedload transport in the area upstream of the influence of J.C. Boyle Reservoir is not anticipated to be affected by the Proposed Project (i.e., dam removal), is not within California, and is not evaluated further in this document. Link and Keno dams would remain in place and would continue to affect hydrology and sediment transport as occurs under existing conditions.

The following sources were assessed to determine the scope of existing local policies relevant to the Proposed Project:

- Del Norte County General Plan (Mintier & Associates et al. 2003):
  - Soil Resources, Policy 1.D.5
- Humboldt County General Plan for Areas Outside of the Coastal Zone (Humboldt County 2017):
  - Chapter 10.3.4, Policies BR-S8 and BR-S9
  - Chapter 11, Policies WR-P10, WR-P42, WR-P42, WR-S7, WR-IM3, WR-IM32

- Klamath County Comprehensive Plan (Klamath County 2010):
  - Goal 5 (Open Space, Scenic, and Historic Area and Natural Resources), Policy 16
- Siskiyou County General Plan (Siskiyou County 1980):
  - Geologic Hazard, Policies 1, 2, 3, 5, and 6
  - Erosion Hazard, Policy 7

Most of the aforementioned policies (and objectives) are stated in generalized terms, consistent with their overall intent to protect geologic and soil resources. By focusing on the potential for impacts to geologic and soil resources within the Area of Analysis, consideration of the more general local policies listed above is inherently addressed by the specific, individual analyses presented in Section 3.11.5 *[Geology, Soils, and Mineral Resources] Potential Impacts and Mitigation*. The more general local policies are not discussed further.

3.11.4.1 Flows

Flows under the Proposed Project were modeled assuming Klamath River hydrology defined by KBRA operations of the Klamath Irrigation Project (USBR 2012). As described in Section 3.1.6 *Summary of Available Hydrology Information for the Proposed Project*, the KBRA has expired, and hydrology under the Proposed Project would be pursuant to the 2013 BiOp (NMFS and USFWS 2013). As detailed in Section 3.1.6, the 2013 BiOp provides similar flow releases to KBRA, and does not alter the key hydrological factors that drive model results, including timing, frequency, and magnitude of flows released during winter and spring.

3.11.4.2 Suspended Sediment

USBR (2012) analyzed the potential effects of the Proposed Project on suspended sediment concentration (SSC) using output from the One Dimension Version (2.4) of the Sedimentation and River Hydraulics sediment transport model (SRH-1D). SRH-1D provided estimates of daily average SSCs at different points in the river (Huang and Greimann 2010, as summarized in USBR 2012) (see also Appendix E of this EIR). Existing conditions were also simulated using the SRH-1D model, to provide a comparison of what SSCs would be under existing conditions or under the Proposed Project in the years 2020 and 2021. Modeling assumed the Proposed Project occurred within the 48-year period beginning in 1961.

3.11.4.3 Bedload Sediment

USBR (2012) also analyzed potential changes to bedload sediment using output from the SRH-1D model (Huang and Greimann 2010, USBR 2012) (see also Appendix F of this EIR). Short-term (2-year) and long-term (5-, 10-, 25-, 50-year) changes in bedload were evaluated for a range of hydrologic conditions using representative flows taken from historical hydrology. A long-term simulation was not conducted for the Klamath River upstream of Iron Gate Dam under the assumption that short-term bedload sediment conditions (i.e., at the end of 2 years) are representative of long-term bedload sediment conditions (USBR 2012).

3.11.5 Potential Impacts and Mitigation

Potential Impact 3.11-1 Reservoir drawdown could result in changes to geologic hazards, such as seismic or volcanic activity.

As described in Section 3.11.2 *Environmental Setting*, the Lower Klamath Project is within an area that has historically been seismically active. The nearest active fault is approximately five miles from the dams proposed for removal. These faults are reported not to have moved within the past 1.5 million years and, therefore, are considered inactive (Personius et al. 2003). Under the Proposed Project, the four developments within the Lower Klamath Project would be removed as described in Section 2 *Proposed Project*. Sediment currently held behind the dams would be released during the same period. Although reservoir filling can induce seismicity, drawdown of reservoirs of this size is not expected to induce seismicity. Reservoir draining is also not expected to cause volcanic activity due to the distance from volcanic hazards (e.g., Mount Shasta). No new structures would be constructed in the Area of Analysis for geology and soils following removal of the four developments, thus there would be little to no immediate risks from changes to geologic hazards to people and infrastructure.

Significance

No significant impact

Potential Impact 3.11-2 Soil disturbance associated with heavy vehicle use, excavation, and grading could result in erosion during removal activities.

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 No. 1 Reservoir. Prior to demolition, coverage under the General Stormwater National Pollution Discharge Elimination System 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 Control Plan prior to deconstruction that describes BMPs to prevent erosion during demolition activities. These BMPs would be implemented in accordance with the approved Storm Water Pollution Prevention Plan (SWPPP) and Erosion Control Plan (Appendix B: *Definite Plan*). Implementation of these BMPs under the Proposed Project would minimize the potential for erosion and sediment delivery into the reservoir areas.

Significance

No significant impact

Potential Impact 3.11-3 Reservoir drawdown could result in hillslope instability in reservoir rim areas.

The KRRC proposes drawdown of J.C. Boyle, Copco No. 1, and Iron Gate reservoirs would take place between November 1 of dam removal year 1 and March 15 of dam removal year 2 as detailed in the proposed Reservoir Drawdown and Diversion Plan (Appendix B: *Definite Plan*). For all reservoirs, the minimum drawdown rate would be 2 feet per day and the maximum drawdown rate would be 5 feet per day, until drained. Although the new gates at Copco No. 1 and Iron Gate dams would be able to accommodate higher drawdown rates, the maximum drawdown rate of 5 feet per day is recommended by KRRC as a conservative value based upon slope stability analyses conducted for each of the Lower Klamath Project reservoirs.

The area surrounding J.C. Boyle Reservoir is generally low gradient and underlain by competent materials. Review of topographic data and reconnaissance of the reservoir slopes indicate that no landslides occur adjacent to the reservoir. For these reasons, the stability of the J.C. Boyle Reservoir slopes would be unaffected by the reservoir drawdown and there would be no impact due to the Proposed Project.

No large scale landslides have been identified in the terrestrial or subaqueous slopes around Copco No. 1 Reservoir. Diatomaceous deposits along the rim and below the reservoir water level present the greatest potential for slope instability during drawdown (Appendix B: *Definite Plan*). Where the toe of the diatomite deposit lies above the current high lake level, slope response to rapid drawdown is determined by the properties and geometry of the underlying volcanic and volcaniclastic strata. Where the toe of the diatomite deposit lies below the current high lake level, slope response to rapid reservoir drawdown is determined by the properties and thickness of the diatomite deposits and the underlying material. Based on the low diatomite permeability, the proposed drawdown rate (2 to 5 feet per day) would have minimal effect on its stability. KRRC is therefore not proposing to limit the drawdown rate of Copco No. 1 Reservoir.

The geologic assessment and slope stability analysis conducted by KRRC (Appendix B: *Definite Plan*) indicated that certain segments along the Copco No. 1 Reservoir rim have a potential for slope failure that could impact existing roads and/or private property (Figure 3.11-10). These areas include approximately 3,700 linear feet of slopes along Copco Road and approximately 2,800 linear feet of slope adjacent to private property (Appendix B: *Definite Plan*). Up to eight parcels in these areas have existing habitable structures that could potentially be impacted. KRRC has proposed to complete additional field geologic investigation and laboratory testing of material properties to better understand the potential for slope instability in these areas.

As part of the Proposed Project, KRRC would consider the following actions to offset potential impacts in reservoir rim areas where there is a high probability of slope failure (Appendix B: *Definite Plan*):

1. For segments along Copco Road:
   a. Re-align road segment away from rim slope
   b. Engineer structural slope improvements (e.g., drilled shafts or other structural elements that could be installed to resist slope movement)
2. For segments adjacent to property or structure:
   a. Move structure or purchase property
   b. Engineer structural slope improvements (e.g., drilled shafts or other structural elements that could be installed to resist slope movement)

While the proposed actions is designed to reduce the potential for new or exacerbated mass wasting around the rim of the reservoirs associated with drawdown, the proposed actions do not explicitly address potential impacts resulting from hillslope instability outside of those areas currently identified as having a high probability of slope failure or commit KRRC to implementation of their aforementioned proposed actions. Therefore, the impact of the project on hillslope instability in reservoir rim areas would be significant.

Implementation of Mitigation Measure GEO-1 would reduce the impact of slope failure in reservoir areas to less than significant. If instability of these deposits exposes cultural resources, then the impact may be significant and mitigation may be required (see Section 3.12.5 *[Historical Resources and Tribal Cultural Resources] Potential Impacts and Mitigation*).

The extent and morphology of bedrock outcrops and general lack of surficial deposits around Iron Gate Reservoir suggest stable reservoir slopes under rapid drawdown conditions (Appendix B: *Definite Plan*). There may be potential for drawdown to induce block sliding where hard, strong volcanic flow rocks are underlain by saturated tuffaceous beds and bedding dips into the valley (PanGEO 2008). Hammond (1983) reports several low to moderate dip angles of volcaniclastic beds into the valley, but there is no evidence of previous slope instability at these locations. Historical aerial photographs indicate that the three possible old landslide-related features that occur on the south rim of Iron Gate Reservoir have been stable and unaffected by historical reservoir drawdowns and have a low risk of instability during future drawdown (Appendix B: *Definite Plan*). Shallower slides are likely to occur in the shallow surficial deposits around the reservoir rim and on the reservoir slopes that are currently below the reservoir surface (Appendix B: *Definite Plan*). Small, shallow soil failures in the more deeply weathered volcaniclastic beds and in colluvial deposits present a minor hazard to Copco Road where the road is immediately adjacent to the shore (Appendix B: *Definite Plan*). These slope failures are likely to be shallow and local and therefore, if they were to occur, would constitute a less than significant impact.

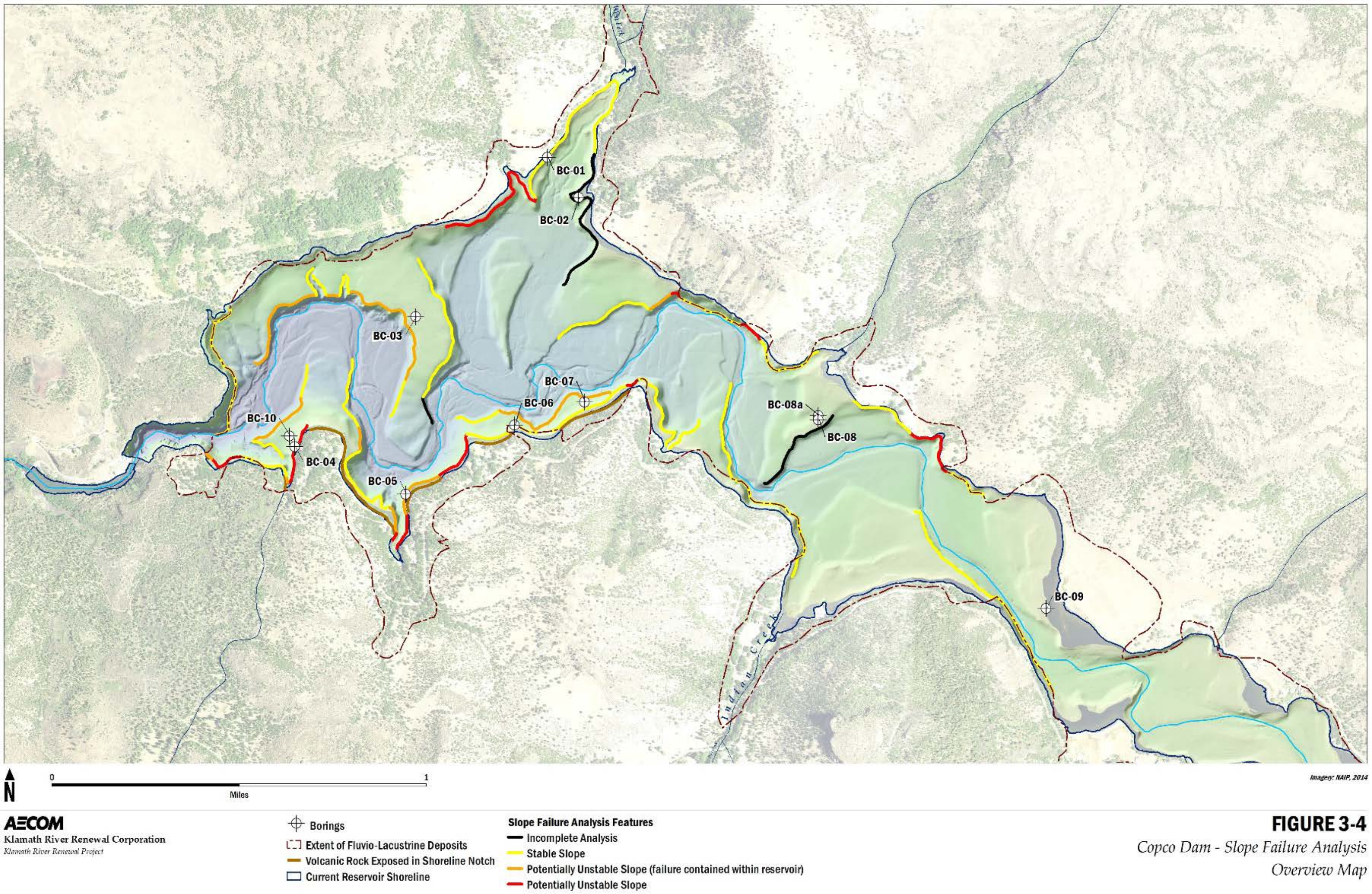

Figure 3.11-10. Results of slope failure analysis at Copco No. 1 Reservoir (Appendix B: *Definite Plan*).

Mitigation Measure GEO-1 – Slope Stabilization.
KRRC will visually monitor large, potentially unstable areas within the Copco No. 1 Reservoir footprint for the duration of reservoir drawdown and for two weeks following drawdown. Depending on the location, monitoring may involve tribal monitors (see also Mitigation Measures TCR-1, TCR-2, and TCR-3). If slope failure is observed, an exclusion zone will be established around the unstable area and the KRRC will monitor the unstable area.

Following drawdown activities, and once the areas are safe to inspect, the KRRC shall inspect any slope failures and implement slope stabilization measures, as appropriate. For any large slope failure that occurs during drawdown or the year following drawdown, KRRC will offset potential impacts by implementing the following actions:

1. Move affected structures or purchase affected property,
2. Re-align affected road segments,
3. Engineer structural slope improvements (e.g., drilled shafts or other structural elements that could be installed to resist slope movement), and
4. Revegetate affected areas.

Significance
No significant impact at Iron Gate Reservoir and J.C. Boyle Reservoir

No significant impact with mitigation for diatomaceous deposits along the rim and below the Copco No. 1 Reservoir water level

Potential Impact 3.11-4 Reservoir drawdown could result in short-term instability of embankments at the earthen dams (Iron Gate and J.C. Boyle).
Analyses of embankment stability during drawdown at the earthen dams (i.e., Iron Gate Dam and J.C. Boyle Dam) indicate factors of safety greater than the selected minimum factor of safety of 1.3. The analyses indicate that the proposed reservoir drawdown rates would not result in substantial embankment instability (Appendix B: *Definite Plan*). While there is a potential for small, shallow slumping along the upstream embankment slopes due to the potential strength loss of surficial materials during drawdown, this degree of slumping would not threaten the structural integrity of the embankments or deliver a substantial amount of sediment. The impact would be a less than significant in the short term (less than two years following dam removal). Copco No. 1 and No. 2 dams are concrete structures that would be unaffected by reservoir drawdown rate.

Significance
No significant impact

Potential Impact 3.11-5 Reservoir drawdown could result in substantial short-term sediment deposition in the Klamath River downstream of Iron Gate Dam due to erosion of reservoir sediment deposits and a long-term change in sediment supply and transport due to dam removal.
Based on average annual sediment deposition rates, approximately 15.1 million yd3 (4.16 million tons) of sediment would be deposited behind the dams by 2020 (USBR 2012) (Table 3.11-6). Between 2020 and 2021 (i.e., dam removal year 2 when drawdown would primarily occur), the sediment volume present behind the dams would increase by approximately 81,300 cubic yards in Copco No. 1 Reservoir and approximately 100,000 cubic yards in Iron Gate Reservoir based on estimates of annual

sedimentation rates for each reservoir (USBR 2012). The increase in sediment volume between 2020 and 2021 would be an order of magnitude less than the uncertainty of the 2020 total sediment volume estimates, so model results using the 2020 sediment volumes would still be applicable to the Proposed Project.

Table 3.11-6. Estimated Amount of Sediment in the Lower Klamath Project Reservoirs in 2020 (Source: USBR 2012).

Reservoir	Estimated 2020 Total			
	Total Volume (yd^3)	Total Sediment (tons)[1]	Fine Sediment[2] (tons)	Sand[3] (tons)
J.C. Boyle	1,190,000	340,000	220,000	120,000
Copco No. 1	8,250,000	2,090,000	1,800,000	290,000
Iron Gate	5,690,000	1,730,000	1,460,000	280,000
Total[4]	**15,130,000**	**4,160,000**	**3,480,000**	**680,000**
Total Copco No. 1 and Iron Gate	**13,940,000**	**3,820,000**	**3,260,000**	**560,000**

[1] Ton is defined as equal to 2,000 pounds (dry weight).
[2] Fine sediment is sediment with a diameter less than 0.063 millimeters.
[3] Sand is sediment with a diameter between 0.063 and 2 millimeters.
[4] Sediment volumes and weights from individual reservoirs from USBR (2012) were rounded to the nearest 10,000th unit. Copco No. 2 Reservoir does not retain measurable amounts of sediment and therefore is not included in the estimates of total stored sediment.

Reservoir sediment consists primarily of silts and clays that would be easily eroded during drawdown. Approximately 36 to 57 percent of the total sediment stored in J.C. Boyle, Copco No. 1, and Iron Gate reservoirs by 2021 would be eroded and transported downstream during the drawdown period and the year following dam removal (i.e., short-term), or an estimated 5.4 to 8.6 million yd^3 (1.2 to 2.3 million tons) (Table 3.11-7, Figure 3.11-11). Approximately 15 percent of this sediment eroded from reservoir areas during the first year following dam removal would be transported farther downstream as bedload.

The rate of reservoir drawdown would affect the amount of erosion of the sediment deposit. A faster drawdown rate would reduce the time of interaction between the flow and reservoir sediment deposits, thus reducing the overall amount of sediment erosion, whereas a slower drawdown rate would increase the time of interaction between the flow and reservoir sediment deposits, thus increasing the overall amount of sediment erosion. It is expected that increasing the previously modeled maximum drawdown rate of 2.25 to 3 feet per day (USBR 2012b) to the Proposed Project maximum drawdown rate of 5 feet per day (Appendix B: *Definite Plan – Appendix P*) would slightly decrease the total amount of sediment erosion that occurs during drawdown. The previously modeled maximum drawdown rate would result in erosion of 36 to 57 percent of the reservoir sediment deposits (Table 2.7-11). Increasing the drawdown rate to 5 feet per day would most likely result in less erosion than previously modeled.

Erosion and transport of sediment deposits within Copco No. 1 and Iron Gate reservoirs during drawdown would be assisted by using barge-mounted pressure sprayers to jet water onto newly exposed reservoir sediment deposits as the water level drops (a process referred to as sediment jetting). Sediment jetting would maximize erosion of reservoir sediment deposits in historical floodplain areas (especially the historical two-year floodplain) during drawdown and minimize the potential for future erosion of reservoir sediment deposits after the drawdown period. Additionally, removal of reservoir sediment deposits with sediment jetting would promote riparian bank and floodplain connectivity by increasing river inundation on the historical floodplain during high flow events and minimize manual excavation and grading of sediments from proposed restoration sites after completing drawdown. Sediment jetting would be focused in the six areas where restoration actions are proposed within the Copco No. 1 Reservoir footprint (Figure 2.7-9) and the three areas where restoration actions are proposed within the Iron Gate Reservoir footprint (Figure 2.7-10).

While the anticipated amount of sediment that will be eroded varies by reservoir, approximately 36 to 57 percent (5.4 to 8.6 million yd^3 [1.2 to 2.3 million tons]) of the total 2020 reservoir sediment volume is expected to erode and be transported downstream during the drawdown period (Table 2.7-1). Large quantities of sediment would remain in place after dam removal in each of the former reservoirs, primarily in areas above the active channel. The remaining sediments would consolidate (dry out and decrease in thickness). Studies of the existing sediments in J.C. Boyle Reservoir show an anticipated change in sediment depth of up to 61 percent of original depth (USBR 2012a). A higher degree of shrinkage of the sediment layers is expected in Copco No. 1 and Iron Gate reservoirs due to the increased organic matter content in these sediment deposits.

The range in the estimated volume of sediment eroded from each reservoir is primarily dependent upon whether the prevailing hydrology during reservoir drawdown corresponds to a dry hydrologic year or a wet hydrologic year. The majority of the erosion would occur during the reservoir drawdown process and would be a combination of direct erosion of sediment by moving water, slumping of the fine sediment along the reservoir sides toward the river, and sediment jetting of some areas of reservoir-deposited sediments during drawdown. In a dry hydrologic year, reservoir pool levels can be drawn down steadily and relatively quickly, resulting in a shorter period of interaction between the flow and sediment deposits, and thus less overall sediment erosion. In a wet hydrologic year, the reservoir pool may experience cycles of drawdown followed by periods of refilling during high flow events, resulting in longer period of interaction between the flow and the sediment deposits, and thus more overall sediment erosion.

Table 3.11-7. Estimated Amount of Sediment Erodible with Dam Removal (Source: USBR 2012).

Reservoir	Percent Erosion[1]		Fine Sediment Erosion		Sand Erosion	
	Minimum Erosion (percent)	Maximum Erosion (percent)	Minimum (tons)	Maximum (tons)	Minimum (tons)	Maximum (tons)
J.C. Boyle	27	51	60,000	110,000	30,000	60,000
Copco No. 1	45	76	820,000	1,370,000	130,000	220,000
Iron Gate	24	32	350,000	460,000	70,000	90,000
Total	36	57	1,230,000	1,950,000	230,000	370,000
Total Copco No. 1 and Iron Gate	36	56	1,170,000	1,830,000	200,000	300,000

[1] The erosion rates are based on hydrologic conditions recorded for the March to June flow volume at Keno gage on the Klamath River from water year 2001(90 percent exceedance) and 1984 (10 percent exceedance). Erosion would primarily occur during the drawdown period. Additional erosion and sediment transport could occur in the following year that would be indistinguishable from the background sediment regime.

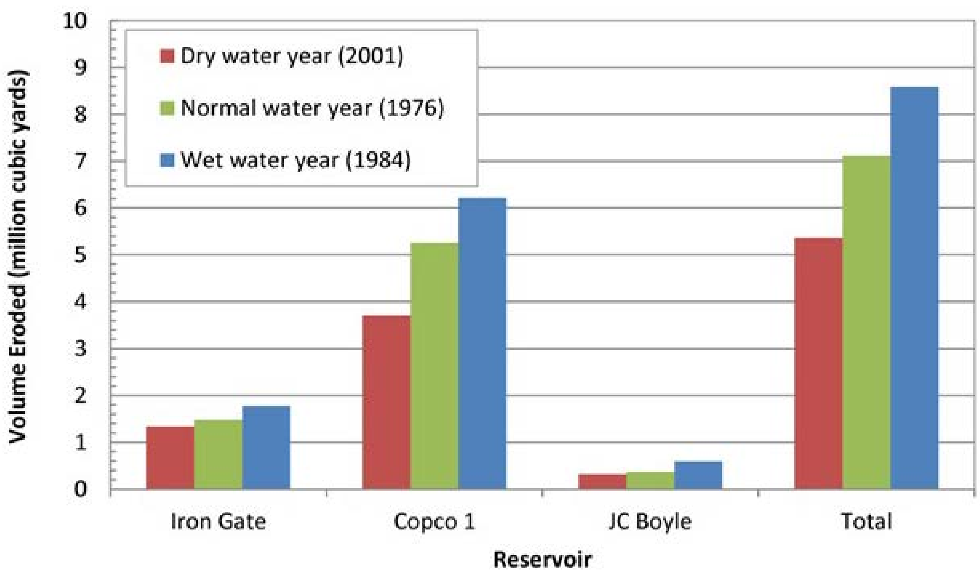

Figure 3.11-11. Volume of Sediment Eroded from Reservoirs in the Hydroelectric Reach During 2020 Drawdown Beginning in January (USBR 2012).

Model simulations indicate that 43 percent to 64 percent of the sediment stored in the reservoirs would remain in place following the year after dam removal (i.e., long-term), primarily as a relatively thin wedge in areas above the active channel. The remaining sediment would consolidate (i.e., harden, dry, shrink in volume, and decrease in thickness) following reservoir drawdown (USBR 2012). Studies of the existing sediment in Lower Klamath Project reservoirs indicate an anticipated change in sediment thickness in J.C. Boyle Reservoir of up to 61 percent due to consolidation (USBR 2012). A higher degree of shrinkage of the sediment layers is expected for Copco No. 1 and Iron Gate reservoirs due to the increased organic matter content in the sediment deposits contained within these reservoirs. Sediment deposits remaining in the reservoir footprints following reservoir drawdown would erode slowly, or potentially not at all due to consolidation. Secondary erosion of residual reservoir deposits would be affected by increases in shear strength with desiccation, the prevalence of cracks, and disintegration in response to wetting and drying cycles. The prevalence of cracking would encourage gully erosion as lower infiltration rates intensify surface runoff and concentrate flow in cracks. Gullies would incise and widen with time. The availability of coarse sediment (i.e., sand and larger) to abrade fine-grained deposits may be an important factor encouraging gully erosion. Gullies closer to coarse sediment sources (e.g., near the steep hillslopes at Copco No. 1 and Iron Gate reservoirs) may have more effective secondary erosion than areas lacking those sediment sources (e.g., Upstream Reach of J.C. Boyle Reservoir) (Appendix B: *Definite Plan*). As riverine conditions return within the reservoir footprints, any additional erosion and transport of reservoir sediment farther downstream would be indistinguishable from background rates within the watershed. Overall, this degree of long-term erosion would be a less than significant impact. Future construction activities (e.g., access road construction, recreation facilities) would need to consider the potential instability and erodibility of sediment remaining within the reservoir footprints.

Anticipated erosion volume due to dam removal into the context of annual basin-wide sediment discharge are estimated to average an annual total sediment supply from the Klamath River to the Pacific Ocean of approximately 5.8 million tons (4 million tons/yr of fine sediment and 1.8 million tons/yr of sand and larger sediment (Stillwater Sciences (2010). Farnsworth and Warrick (2007) estimate that the average annual silt and clay discharge is 1.2 million tons/yr. The considerable uncertainty in the annual average sediment load estimates is related to the different approaches to estimation, the large variation in the measurement of SSCs, the lack of a unique relationship between flow and SSC, and the large annual variation in sediment loads. In dry years the supply of sediment to the ocean could be less than 1 million tons/yr (Figure 3.11-12). Given these estimates, it is expected that the amount of sediment released during the year of drawdown and dam removal would be similar to that transported by the Klamath River to the Pacific Ocean in a year with average flow, much less than that transported by the Klamath River in a wet year, and greater than that transported by the Klamath River in a dry year.

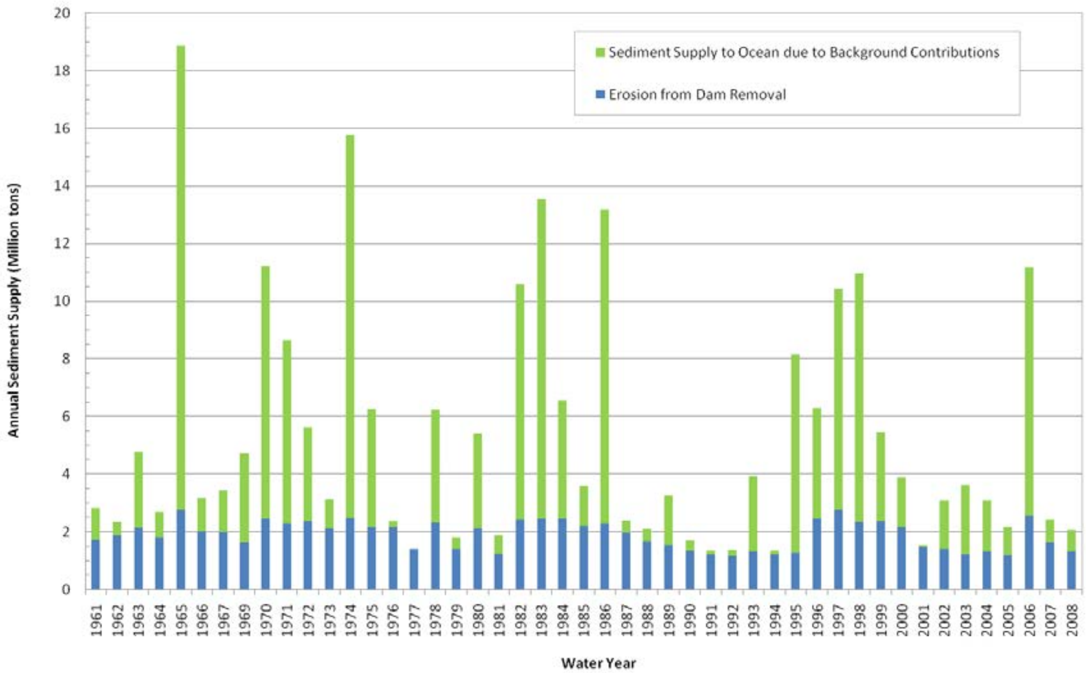

Figure 3.11-12. Annual predicted sediment delivery to the Pacific Ocean under the Proposed Project and existing conditions ("Background Contributions") by water year. Model results are only valid for the year of dam removal, and no significant increase in sediment loads is predicted in years following dam removal (Source: USBR 2012).

Channel Response in the Hydroelectric Reach

SRH-1D modeling results indicate channel bed elevations would decrease and median channel substrate size would increase within the reservoir reaches during drawdown (January to May of the drawdown year) (Figure 3.11-13, Figure 3.11-14). The proportion of fine sediment would decrease to near zero within two months after drawdown; the proportion of sand would initially increase to 30 to 50 percent then decrease to 10 to 25 percent; the proportion of gravel would change (mostly increase) to 20 to 35 percent; and the proportion of cobble would increase to 50 to 70 percent. The estimated changes depend on the reservoir and simulation water year type (i.e., wet, median, or dry). These changes would stabilize within six months as the bed within the historical river channel reaches pre-dam elevations (USBR 2012). After dam removal, channels currently inundated by reservoirs would likely vary from narrow, single-threaded to wide and sinuous with the potential to form complex features, such as meander cut-offs and vegetated islands (USBR 2012).

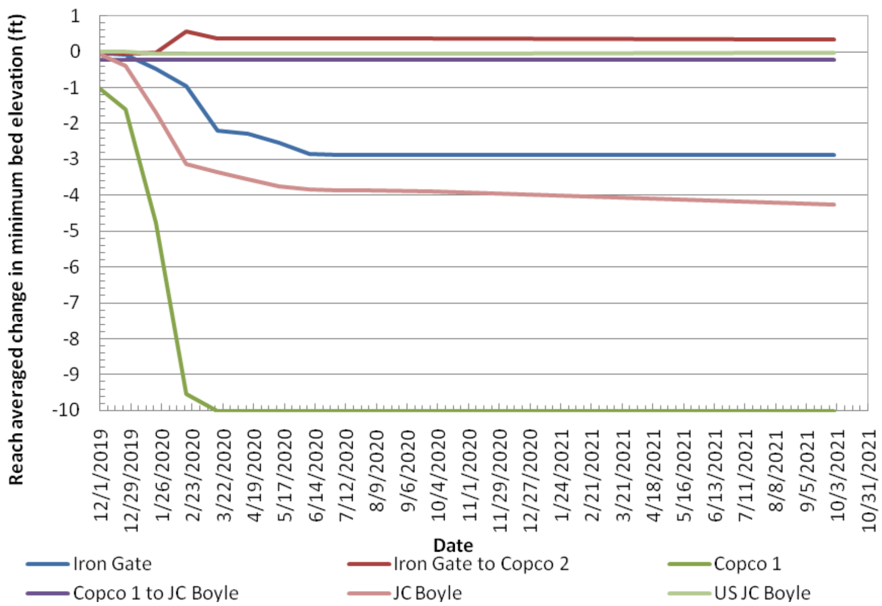

Figure 3.11-13. Reach-Averaged Erosion in the Hydroelectric Reach during a Representative Wet Water Year (USBR 2012).

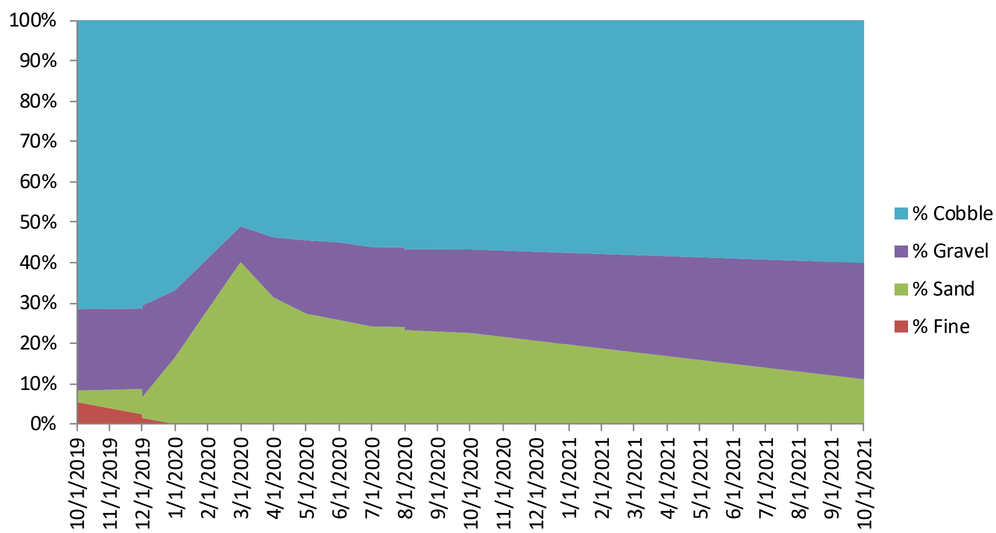

Figure 3.11-14. Simulated Bed Composition from Copco No. 2 to Iron Gate Reservoirs during Two Successive Representative Dry Water Years During and After Drawdown (Based on simulation results provided by USBR, March 2012).

The river reaches upstream of J.C. Boyle Reservoir and from Copco No. 1 Reservoir to J.C. Boyle Dam would experience little change in bed composition or median substrate size during drawdown (USBR 2012). Currently, these reaches are predominantly cobble (90 percent) with small fractions of gravel and sand. Modeling of the Copco No. 2 Dam to Iron Gate Reservoir reach shows decreases in the combined proportion of sand and fines, with the dry simulations showing decreases to approximately 35 percent of sand and fines two years after drawdown.

Channel Response in the Klamath River Downstream of Iron Gate Dam

The short-term (i.e., two years following dam removal) effects of the Proposed Project on dam-released sediment and sediment resupply would likely extend from Iron Gate Dam to approximately Cottonwood Creek (USBR 2012). Because approximately 85 percent of the sediment stored within the reservoirs is fine (silt and clay), most sediment eroded from the reservoirs would be fine. Fine sediment transport rates would increase downstream of Iron Gate Dam during the short-term, but a large portion of this fine sediment would be transported to the ocean as suspended sediment shortly after being eroded (Stillwater Sciences 2010, USBR 2012). Coarse sediment (i.e., sand and larger) transport would occur more slowly depending on the frequency and magnitude of mobilization flows and attenuation by channel storage.

Short-term (2-year) SRH-1D model simulations indicate up to about 0.9 feet of reach-averaged deposition between Bogus Creek and Willow Creek (RM 188.0), and up to about 0.4 feet of deposition from Willow Creek to Cottonwood Creek (USBR 2012) (Figure 3.11-15). Model simulations indicate that reaches located farther downstream will change little (< 0.5 ft). Eight miles of the Klamath River mainstem channel could potentially be affected by sediment release and resupply, representing 4 percent of the total mainstem channel length downstream of Iron Gate Dam (190 miles).

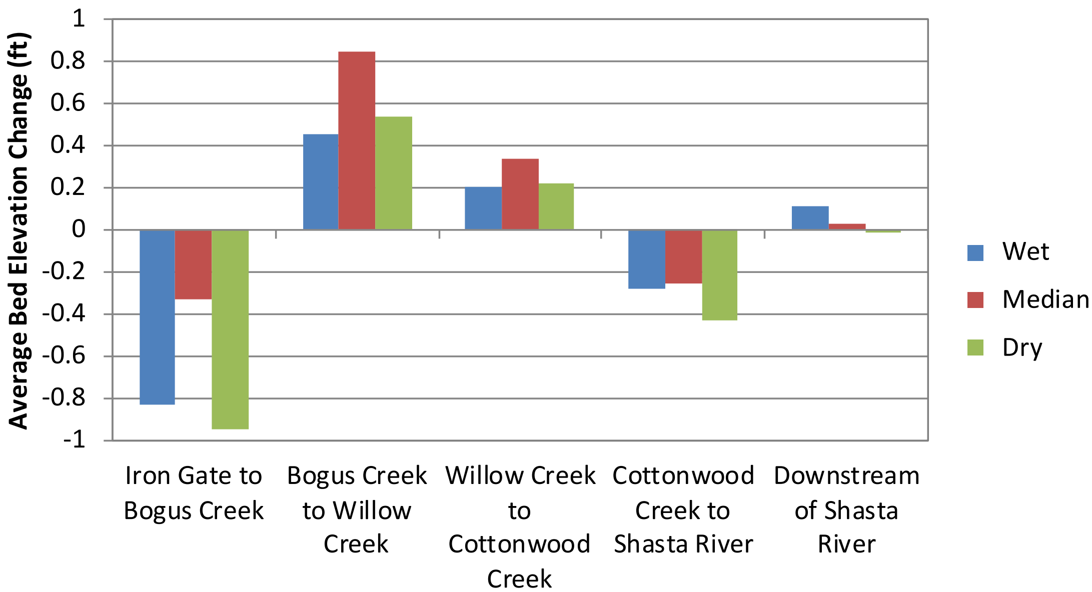

Figure 3.11-15. Reach Averaged Bed Elevation Change for Two Successive Wet, Median, or Dry Water Years Following Reservoir Drawdown (Based on simulation results provided by USBR, March 2012).

It is not possible to accurately predict short-term deposition patterns in the mainstem river channel at a fine spatial scale (e.g., individual pools or other slack-water areas) under the Proposed Project using 1D sediment transport models. However, the general short-term sediment transport and depositional patterns can be reasonably surmised based on patterns observed in the Klamath River and other analogous river channels. Dam-released sediment may temporarily deposit in pools and other slack water areas (e.g., eddies) and at tributary confluences in the reach from Iron Gate Dam to Cottonwood Creek. These transient sediment deposits would be highly erodible during subsequent flow events, leading to a short residence time (i.e., likely one year or less except during dry years). KRRC proposes a channel survey to document pool depths in the Klamath River from Iron Gate Dam to Humbug Creek prior to dam removal, and every year after dam removal for the first 3 years

In the short term, SRH-1D model simulations indicate that dam-released sediment and sediment resupply under the Proposed Project would increase the proportion of sand in the channel bed and decrease median bed substrate size (Figure 3.11-16 and Figure 3.11-17) (USBR 2012). Under wet, median and dry simulations, sand within the bed in the reach from Iron Gate to Bogus Creek would increase to 30 to 35 percent by March to June of the drawdown year, gradually decreasing to 10 to 20 percent by September two years later. Median substrate size (D_{50}) would fluctuate slightly before stabilizing to approximately existing conditions with a D_{50} of 100 mm (Appendix F). Short-term model simulations also indicate a decrease in median grain size (from an initial value of approximately 80 mm down to 40 to 65 mm) and an increase in the proportion of sand (up to 40 percent) in the reach from Bogus Creek to Willow Creek, and an increase in the proportion of sand (up to 35 percent) and a decrease in median grain size (from an initial value of approximately 65 mm down to 38 to 45 mm) in the reach from Willow Creek to Cottonwood Creek (Appendix F).

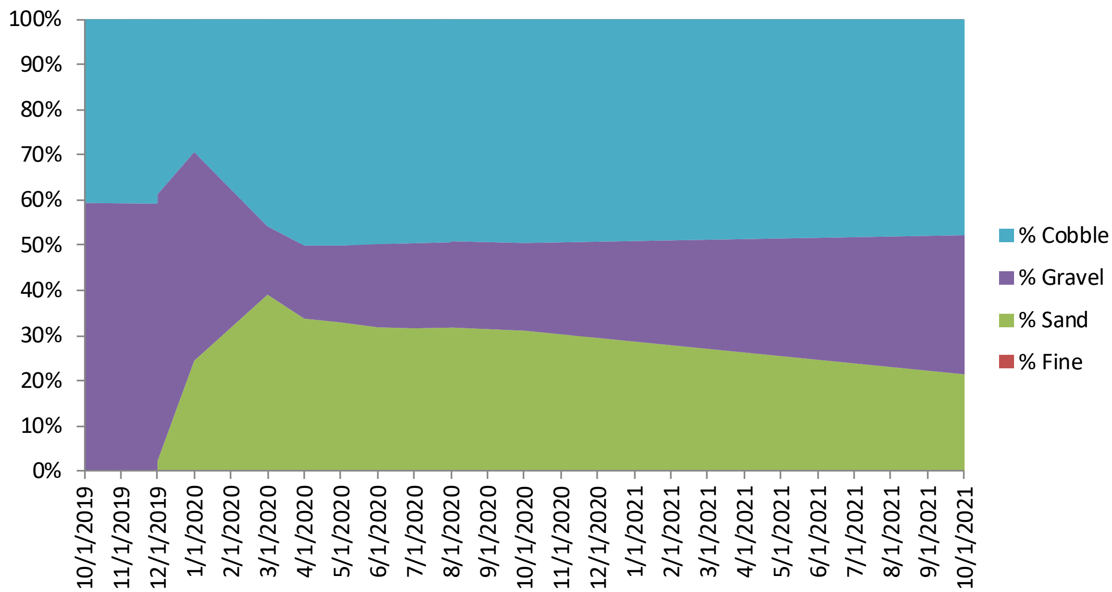

Figure 3.11-16. Simulated Bed Composition from Iron Gate Dam to Bogus Creek during Two Successive Dry Water Years Following Reservoir Drawdown (Based on simulation results provided by USBR, March 2012).

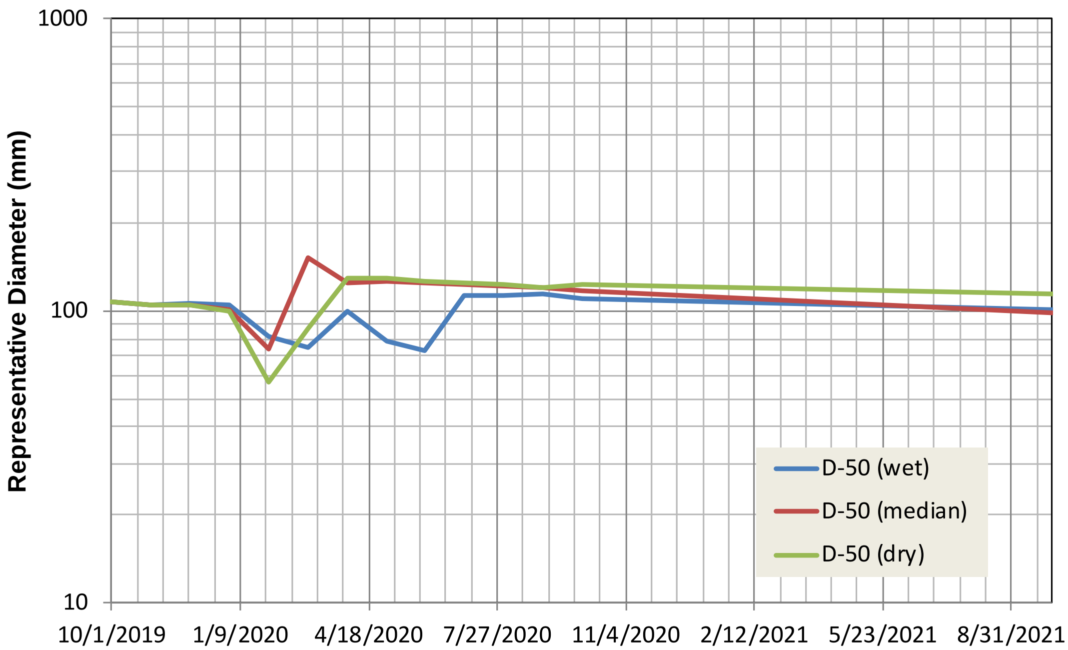

Figure 3.11-17. Simulated D50 (mm) from Iron Gate Dam to Bogus Creek during Successive Wet, Median, and Dry Water Years Following Reservoir Drawdown (Based on simulation results provided by USBR, March 2012).

In general, the Proposed Project would have the beneficial long-term (i.e., 50 years) effects of increasing sediment supply and transport and creating a more dynamic and mobile bed downstream of Iron Gate Dam. During the 50 years following the initial release of sediment by the Proposed Project, bed elevations would adjust to a new equilibrium in response to sediment supplied by upstream tributaries within the Hydroelectric Reach. While 0.8 to 1.7 feet of aggradation could result from the Proposed Project between Iron Gate Dam and Cottonwood Creek (i.e., simulations based on a median start year), no long-term sediment deposition is expected downstream of Cottonwood Creek (USBR 2012). Long-term (5 to 50 year) simulations indicate that after 5 years, the Proposed Project would increase the proportion of sand in the bed to 5 to 22 percent and decrease the D_{50} to approximately 50 to 55 mm (Appendix F). These changes would stabilize and continue through to Year 50. Fining of the bed surface would reduce the flow required to mobilize the channel bed from approximately 10,000 cfs to 6,000 cfs in the reach from Bogus Creek to Willow Creek (RM 192.6 to RM 188) and from 11,000 cfs to 6,000 cfs in the reach from Willow Creek to Cottonwood Creek (RM 188 to RM 185.1) (USBR 2012). The corresponding return period for a bed-mobilizing flow in the reach from Iron Gate Dam to Cottonwood Creek (USGS RM 193.1 to RM 185.1) would decrease from 4 years to approximately 2 years.

Channel Response in the Klamath River Estuary

The majority of the fine sediment (silts, clays, and organics) released by dam removal would be transported to the ocean. The fine material is unlikely to deposit in significant quantities in the estuary, evidenced by the lack of a large sandbar within the mouth of the Klamath River under existing conditions. There are currently high concentrations of silt and clay transported through the estuary, and sediment sampling by USBR (2010) documented the absence of fine material in the estuary except in the backwater and vegetated areas. If dam removal occurs during a low flow year, there may be relatively small volumes of sediment deposited in these areas.

Pacific Ocean Nearshore Environment

Because of the complexities of the transport processes, the area and depth of fine sediment deposition in the Pacific Ocean nearshore environment resulting from the Proposed Project cannot be precisely predicted. A considerable amount of fine sediment is anticipated to initially deposit on the seafloor shoreward of the 196-feet isobath along the coast, with greater quantities depositing in close proximity to the mouth of the Klamath River. After fine sediment loading onto the continental shelf during river floods, fluid-mud gravity flows typically transport fine sediment offshore. Summer coastal upwelling naturally re-suspends some of the river sediments that are transported to the nearshore environment and deposited on the continental shelf, especially those from the previous winter (Ryan et al. 2005; Chase et al. 2007; see Potential Impact 3.2-7). Along with the background river sediments transported annually by the Klamath River and deposited on the continental shelf, a portion of the sediment deposited on the continental shelf following dam removal would also have the potential to be re-suspended during the summer coastal upwelling. Any sedimentation of the nearshore seafloor resulting from the Proposed Project would likely be transported farther offshore to the mid-shelf and into deeper water depths off-shelf. The short-term (less than two years following dam removal) and long-term (2–50 years following dam removal) effects of the Proposed Project on sediment delivery to the Pacific Ocean would be less-than-significant, given the relatively small amount of total sediment input from reservoir sediment release in comparison to the total annual naturally occurring sediment inputs to the nearshore environment.

Bedload sediment effects related to coarse sediment released by the Proposed Project or sediment re-supply likely would not extend downstream of the Cottonwood Creek confluence (RM 185.1). Therefore, there would be no bedload-related effects in the Klamath River Estuary or Pacific Ocean nearshore environment under the Proposed Project.

Significance

Significant and unavoidable in Middle Klamath River from Iron Gate Dam to Cottonwood Creek in the short term

No significant impact in the Middle Klamath River downstream of Cottonwood Creek, Lower Klamath River, and Klamath River Estuary in the short term

Beneficial for Hydroelectric Reach, Middle and Lower Klamath River, and Klamath River Estuary in the long term

No significant impact in Pacific Ocean nearshore environment in the short term and long term.

Potential Impact 3.11-6 Reservoir drawdown could result in increased bank erosion in the Klamath River downstream of Iron Gate Dam.

Reservoir drawdown could increase bank erosion in downstream reaches if, as a result of the Proposed Project, river discharge increases such that higher stages exert more force on erodible banks over a longer period of time. Under the Proposed Project, drawdown of the four reservoirs would occur simultaneously beginning in January of the drawdown year (Copco No. 1 Reservoir would also experience early drawdown starting November of the year prior to drawdown, at a lower rate [maximum of 2 feet per day]), see also Section 2.7.2 *Reservoir Drawdown*). Section 3.6 *Flood Hydrology* discusses historical flow rates and discharge statistics for each of the reservoirs. The proposed drawdown rates are consistent with the historical discharge rates from the reservoirs and would be adjusted depending on the water year; therefore, flow rates downstream of the dams are not anticipated to increase substantially above median historical rates, if at all (discharges from the reservoirs would be similar to, or less than, seasonal 10-year flood flows from the reservoirs).

Although some erodible banks have been identified in the Lower Klamath River, based on expected drawdown flow rates which are similar to existing flow rates, substantial amounts of additional bank erosion are not expected to occur downstream of any of the dams during reservoir drawdown. Therefore, bank erosion in downstream reaches due to reservoir drawdown would be a less than significant impact.

Significance
No significant impact

Potential Impact 3.11-7 Reservoir removal could reduce or eliminate the availability of a known mineral resource or a locally-important mineral resource recovery site.
Diatomite deposits near the southern downstream shore of Copco No. 1 Reservoir are currently inaccessible for extraction purposes due to their location in the reservoir and existing erosion. Under the Proposed Project, land ownership within the reservoir areas would be transferred to the KRRC and then to California, or to a designated third-party transferee, in the case of Copco No. 1 Reservoir (Section 2.7.10 *Land Disposition and Transfer*). The lands would thereafter be managed for public interest purposes, which could include open space, active wetland and riverine restoration, river-based recreation, grazing, and potentially others. While it is possible that the diatomite deposits would become more available than under the existing condition, it is also possible that they would continue to be inaccessible in the short and long term. Thus, this EIR does not consider the accessibility of diatomite deposits to be a beneficial effect, but rather a continuation of the existing condition.

Significance
No significant impact

3.11.6 References

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