Potential Removal of Klamath River Facilities 887 DETAILED PLAN FOR POTENTIAL REMOVAL OF KLAMATH RIVER HYDROELECTRIC FACILITIES

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ABSTRACT

Feasibility-level studies have been performed for removal of four hydroelectric dams on the Klamath River in Oregon and California, to provide a free flowing condition and volitional fish passage to an estimated 68 miles of coho salmon habitat and 420 miles of steelhead habitat in the upper Klamath River basin. Numerous engineering reports and environmental documents have been prepared to allow the Secretary of the Interior to determine whether the removal in 2020 of all or part of each of the hydroelectric facilities would (a) advance restoration of the salmonid fisheries of the Klamath Basin, (b) be in the public interest, and (c) not exceed \$450 million, which is the total amount to be provided by Oregon and California. This paper addresses the physical methods and timetable necessary for dam removal; plans for management, removal, and/or disposal of reservoir sediment; plans for site restoration and potential impact mitigation; and estimated project costs, as provided in the Detailed Plan (Reclamation, 2011b).

BACKGROUND

The Klamath River flows from its headwaters near Crater Lake, Oregon, to its confluence with the Pacific Ocean in northern California. The Klamath Hydroelectric Project (Project) is owned and operated by PacifiCorp, and includes four power generating developments along the mainstem of the Upper Klamath River between river mile (RM) 228 and RM 190, at J.C. Boyle, Copco No. 1, Copco No. 2, and Iron Gate Dams. The smaller East Side and West Side developments are located further upstream at the Bureau of Reclamation's (Reclamation's) Link River Dam at RM 254, and have been previously proposed by PacifiCorp for decommissioning. The Project also includes a re-regulation dam with no generation facilities at RM 233 (Keno Dam), and a small (2.2 MW) generating development on Fall Creek, a tributary to the Klamath River at RM 196.3. The installed generating capacity of the existing Project is 169 MW and, on average, the Project generates 716,800 MWh of electricity annually. PacifiCorp began relicensing proceedings before the Federal Energy Regulatory Commission (FERC) in 2000, with a proposal for continued operation of their facilities with new environmental measures. A Final Environmental Impact Statement (EIS) was issued by FERC in November 2007 which included Mandatory Conditions requiring the installation of new fish passage facilities at each dam, or the consideration of dam removal.

The Klamath Hydroelectric Settlement Agreement (KHSA) was completed in February 2010 for the express purpose of resolving the pending FERC relicensing proceedings by

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establishing a process for potential facilities removal and for operation of the Project until that time (KHSA, 2010). Under the KHSA, the Secretary of the Interior would determine by March 31, 2012 whether the removal in 2020 of all or part of each of the facilities, necessary to achieve a free-flowing condition and volitional fish passage, would (a) advance restoration of the salmonid fisheries of the Klamath Basin, (b) be in the public interest, including the potential impacts on affected local communities and Tribes, and (c) not exceed $450 million, which is the total amount to be provided by Oregon and California for facilities removal under a well-defined State Cost Cap. The KHSA describes the process for engineering and scientific studies, environmental review, and participation by the signatory parties and the public to inform the Secretarial Determination. As a part of the basis for the Secretarial Determination, a Detailed Plan to implement facilities removal was required which would include the following:

- A description of the physical methods to be undertaken to achieve facilities removal, including a timetable for decommissioning (defined as the physical disconnection of the facility from PacifiCorp's transmission grid) and removal;
- A plan for the management, removal, and/or disposal of sediment and debris;
- A plan for site remediation and restoration;
- A plan for measures to avoid or minimize adverse downstream impacts;
- A plan for compliance with all applicable laws, including anticipated permits;
- A detailed statement of the estimated costs of facilities removal;
- A statement of measures to reduce risks of cost overruns and delays; and,
- The identification, qualifications, management, and oversight of a non-federal Dam Removal Entity (DRE), in the event the Secretary does not designate a federal agency or department (such as Interior) to be the DRE.

This paper summarizes the key components of the Detailed Plan referenced above, including a description of the physical methods for removal of each dam, plans for waste material transportation and disposal, the proposed sequence and timing for draining the reservoirs to minimize downstream impacts, the preparation of cost estimates for Full and Partial Removal of the facilities, and the development of construction schedules for the work. Studies have been performed to quantify and to characterize the sediment impounded by the four dams and to evaluate the potential downstream effects of reservoir sediment release during dam removal. A reservoir management plan has been developed for the revegetation of the currently inundated lands following dam removal. Estimates for the removal of recreation facilities currently located along the reservoir shorelines and owned by PacifiCorp have been prepared. Other potential impacts to infrastructure, including necessary modifications to the Yreka water supply pipeline crossing Iron Gate Reservoir, and potential mitigation and monitoring measures, have been addressed.

PROPOSED REMOVAL CRITERIA AND TIMELINE

The proposed removal of the four hydroelectric facilities on the Klamath River must be done safely, with minimum impacts to fisheries, water quality, remaining infrastructure, local residents, and other resources. Reservoir drawdown must be controlled to ensure adequate slope stability of the embankments and reservoir rim. In order to minimize sediment release during critical fish migration periods, reservoir drawdown must be performed to the maximum possible extent between January 1 and March 15, a period of about 10 weeks. This requirement established the preferred removal timeline for Copco No. 1 Dam, a large concrete dam impounding over 7 million cubic yards of sediment, which would have to be breached during this period. Significant drawdown of the J.C. Boyle and Iron Gate reservoirs, which impound approximately 1 million and nearly 5 million cubic yards of sediment respectively, would also be performed at this time through low-level outlets; however, the large embankment sections would have to be retained until the following low-flow period (June through September) in order to minimize the risk of overtopping during a large flood event. The remaining facility, Copco No. 2 Dam, is a small concrete diversion structure with no significant sediment impoundment and would also be removed during the low-flow period. Under the terms of the KHSA, all facilities are to be removed by December 31, 2020.

The possible retention of selected features at each facility was studied as a potential cost-saving alternative to the Full Removal of all features, while still achieving a free flowing condition in the river. The large embankment sections at J.C. Boyle and Iron Gate Dams were considered too narrow to leave any portions in place, and the concrete spillways at J.C. Boyle, Copco No. 1, and Copco No. 2 would have to be removed for streamflow diversion during construction. The concrete spillway for Iron Gate Dam would be buried in place for either alternative. Hazardous materials would have to be removed, including hydraulic fluids, batteries, treated wood, asbestos, and contaminated soil. Coatings containing heavy metals would have to be encapsulated or removed. Unused transmission lines and poles would have to be removed, and any remaining tunnel portals and structure openings would have to be sealed against unauthorized entry. Features likely to be retained for the Partial Removal alternative include the powerhouses for each facility, selected penstocks and water conveyance features, and selected intake structures. An allowance for future maintenance would have to be included in the total cost.

Under the KHSA, power generation would continue at each facility until January 1, 2020 for collection of the necessary revenue by PacifiCorp to help fund dam removal. However, the Detailed Plan includes a requirement for an early limited reservoir drawdown at Copco No. 1 (without significant sediment release) to facilitate the breach of the large concrete dam by March 15. To more than offset this loss of power revenue, Copco No. 2 would be operated until May 1, 2020. Preparatory work prior to reservoir drawdown, including the modification of the diversion tunnels at Copco No. 1 and Iron Gate Dams under full reservoir head, and necessary improvements to local access roads and bridges, would begin in May 2019. Assumptions were made for the removal of each facility to provide a basis for the development of cost estimates.

PROPOSED REMOVAL METHODS BY FEATURE

J.C. Boyle Dam and Powerhouse

The J.C. Boyle development consists of a combination embankment and concrete dam, gated spillway, low-level diversion culvert, water conveyance system, and powerhouse located on the Klamath River between RM 228 and RM 220, in Klamath County, Oregon (Figure 1). The dam was completed in 1958 at RM 224.7 for power generation, and impounds a narrow reservoir of 420 acres (J.C. Boyle Reservoir) with approximately 2,629 acre-feet of storage capacity at reservoir water surface (RWS) elevation 3793.5. Site access is provided from Oregon Highway 66 by Topsy Grade Road and a network of unpaved project access roads. The zoned earthfill embankment is 68 feet tall at its maximum height above streambed, with a 15-foot-wide crest and a crest length of 413 feet at elevation 3800. The concrete portion is composed of a 117-foot-long spillway section, a 48-foot-long intake structure, and a 114-foot-long concrete gravity section. The spillway section contains three 36-foot-wide by 12-foot-high radial gates with an overflow crest at elevation 3781.5. A concrete box culvert with two 9.5- by 10-foot bays is located beneath the spillway and has been sealed with concrete stoplogs at the upstream end. The intake structure contains traveling fish screens and the entrance to a 14-foot-diameter steel pipeline. The water conveyance system between the dam and the powerhouse has a total length of 2.56 miles. From the intake structure, the water flows through the pipeline across the Klamath River and into an open concrete flume. A canal wasteway is provided at the forebay structure for emergency releases back to the river through a short, concrete-lined chute. Water for power generation is drawn from the forebay through a 15.5-foot-diameter, concrete-lined, horseshoe-shaped tunnel, before bifurcating into two 10.5-foot-diameter (reducing to 9-foot-diameter) steel penstocks. A conventional outdoor-type powerhouse is located on the right bank of the river at RM 220.4, and is the largest generating facility for the hydroelectric project. The two turbines are vertical-shaft, Francis-type units with a net head of 440 feet. Total generating capacity for peaking power is 98 MW.

Reservoir drawdown would be initiated on January 1 by controlled releases through the gated spillway and canal wasteway from RWS elevation 3793 to about RWS elevation 3780 for an average water year. With the reservoir at the lowest possible level (depending upon inflow), the concrete stoplogs from one bay of the diversion culvert (invert elevation 3751.5) would be removed by blasting if necessary. Releases would rapidly increase by between 2,200 and 3,000 ft^3/s and the reservoir would draw down to about RWS elevation 3770. With the reservoir stabilized at the lower level and after a sufficient hold period to ensure slope stability (assumed one week), the concrete stoplogs would be removed from the second bay of the diversion culvert. Releases would rapidly increase by between 1,000 and 2,500 ft^3/s and the reservoir would draw down to about RWS elevation 3762. This would provide the maximum reservoir drawdown possible prior to removal of the dam embankment section (about 31 feet) and should be completed by January 31 to minimize potential impacts at the downstream dam removal sites. The spillway section would be demolished to approximate elevation 3763.5, or 2 feet above the crown of the diversion culverts, by March 15 for additional discharge capacity. The embankment dam crest and left abutment wall would be retained for flood protection until after spring runoff. The downstream powerhouse could be removed (if required) anytime after decommissioning by constructing a cofferdam in the tailrace channel for removal operations in the dry.

As inflows decrease for the summer months, the reservoir level would reduce to about RWS elevation 3759 by August (regardless of water year), or below the crown of the diversion culverts. The dam embankment would be excavated in July and August to no lower than elevation 3767 (about 30 feet above the bedrock at the upstream toe) to provide an upstream cofferdam sufficient to ensure minimum 100-year flood protection in September for flows up to about 3,600 ft^3/s through the left abutment. Embankment materials would be removed downstream of the required cofferdam limits to the final channel grade, including the concrete cutoff wall. Excavated materials would be hauled to a disposal area on the right abutment. Excavated rockfill would be placed on the downstream face of the upstream cofferdam as required for a controlled breach to streambed elevation 3737, by notching below the reservoir level (expected to be below RWS elevation 3760). Final reservoir drawdown would be achieved by natural erosion of the armored cofferdam and impounded sediments to the original streambed level. The cofferdam breach at J.C. Boyle could release up to 5,000 ft^3/s and should be delayed until after the Iron Gate cofferdam has been breached, or by September 30, to minimize potential downstream impacts.

Estimated waste quantities for the Full Removal alternative include nearly 140,000 yd^3 of earthfill; 40,000 yd^3 of concrete; 2,400 tons of reinforcing steel; and 3,000 tons of mechanical and electrical items. Conventional earthmoving equipment required to remove the embankment is assumed to consist of up to eight 25 to 30 ton articulated off-road trucks with two 4 yd^3 excavators to reach the required average production rate of 400 yd^3 per hour, or 16,000 yd^3 per week (5 days per week, single shift) for removal of the dam embankment within 8 to 9 weeks. Concrete rubble would be hauled in 25 to 30 ton articulated off-road trucks to an on-site disposal area, either near the dam or forebay. Reinforcing steel, and mechanical and electrical items would be hauled in 12 to 15 ton tandem-axle highway trucks to a county landfill facility located in Klamath Falls, Oregon, approximately 20 miles away. A bulking factor of 30 percent for concrete rubble and 20 percent for earth materials has been assumed for determining the number of truck trips required for hauling loose materials.

Copco No. 1 Dam and Powerhouse

The Copco No. 1 development consists of a concrete dam, gated spillway, diversion tunnel, intake structure, and powerhouse, located on the Klamath River between RM 204 and RM 198, in Siskiyou County, California (Figure 2). The dam was completed in 1922 at RM 198.6 for power generation, and impounds a reservoir of approximately 1,000 acres (Copco Reservoir) with approximately 40,000 acre-feet of storage capacity at RWS elevation 2607.5. Site access is provided from Interstate 5 by Copco Road, and then by a steep and narrow access road to the dam and powerhouse. Ager-Beswick Road provides access to the left abutment of the dam, and is an extension of the Topsy Grade Road in

Oregon. The dam is a concrete gravity arch structure approximately 135 feet tall, with a 492-foot radius and a crest length between the rock abutments of 410 feet at elevation 2613. The downstream face is stepped, with risers generally about 6 feet in height. A 224-foot-long, ogee-type overflow spillway is located on the crest of the dam, and is divided into 13 bays controlled by 14- by 14-foot radial gates with an overflow crest at elevation 2593.5. The normal tailwater surface for operation of the powerhouse is maintained at elevation 2483 by Copco No. 2 Dam, located about 1/4 mile downstream.

A 16- by 18-foot diversion tunnel was excavated through the left abutment for streamflow diversion during construction, but was later sealed by the construction of a concrete plug approximately 200 feet upstream from the downstream portal. A gated concrete intake structure was provided upstream of the dam for flow regulation of diversion releases during construction. The penstock intakes are located at approximately elevation 2575.0 in the right abutment section of the dam. Two 10-foot-diameter (reducing to 8-foot-diameter) steel penstocks closest to the river feed Unit No. 1 in the powerhouse, while a single, 14-foot-diameter (reducing to two 8-foot-diameter) steel penstock feeds Unit No. 2. The powerhouse is located at the base of the dam, on the right bank of the river. The two turbines are horizontal-shaft, double-runner Francis-type units with a net head of 125 feet. Total generating capacity is 20 MW.

The removal of Copco No. 1 Dam is dependent upon the successful completion of modifications to restore the discharge capacity of the diversion tunnel for low-level releases. A barge-mounted crane would be mobilized to Copco Reservoir (RWS elevation 2606) in July 2019 for the underwater installation of three new slide gates on the upstream face of the diversion tunnel intake (invert elevation 2489). With the new slide gates closed, the concrete tunnel plug could be removed under dry conditions. Reservoir drawdown would begin on November 1, 2019 using the gated spillway (crest elevation 2593.5) and the modified diversion tunnel to lower the reservoir below the spillway crest. Power generation would cease at RWS elevation 2601. No significant sediment release is expected for this upper range of reservoir levels and rate of drawdown. The barge-mounted crane would be used to remove the spillway gates, piers, and bridge deck. After January 1, 2020, drawdown releases through the modified diversion tunnel would consist of streamflow plus the drawdown releases from both J.C. Boyle and Copco Reservoirs. The concurrent drawdown of both upstream reservoirs results in additional inflow to Iron Gate Reservoir at a time when the diversion release capacity at Iron Gate Dam is sufficiently high to accommodate it.

Reservoir drawdown would continue at a rate between 1.0 and 1.5 ft/day until stabilizing at about RWS elevation 2529 for an average water year (but considerably higher for a wet year). As the reservoir is drawn down, the concrete dam would be removed in 8-foot lifts between the abutments, with the concrete rubble dropped to the downstream toe of the dam and removed by truck to a disposal site on the right abutment. A large crane could be used on either abutment to deliver equipment and materials. As the reservoir head decreases and the tunnel diversion capacity becomes insufficient to pass streamflow, 16-foot-deep notches would be blasted in the concrete dam below the reservoir level for additional discharge capacity. Notching operations and weather conditions are expected to slow the demolition rate during the winter months and spring rainy season. The excavated concrete dam crest can safely accommodate overtopping flows during dam removal without concern for frequency floods, although demolition operations would have to be suspended. The top of the final notch would be at RWS elevation 2513 (regardless of water year) and would extend up to 40 feet to the final channel grade. The reservoir must be drained to RWS elevation 2483 (reservoir level at Copco No. 2 Dam) by March 15, 2020 to minimize downstream impacts due to sediment release. The remaining concrete in the dam below elevation 2513 would be removed to a level at or below elevation 2476 following the spring runoff and final drawdown at Copco No. 2.

Dam demolition would likely be performed in horizontal lifts using conventional drilling and blasting methods. High production rates with a minimum of weather delays would be required to meet the proposed construction schedule. Drilling was assumed for the construction analysis to control overall production, with up to five drill crews required for each of two 8-hour shifts, each capable of drilling 175 linear feet of production blast holes per shift, with a minimum of 9 effective working shifts per week. Production blasting is assumed to require between 3 and 6 shots per day, 6 days per week. Concrete rubble would be loaded into articulated off-road rock trucks having a haul capacity of 30 tons, using either a hydraulic track excavator with a 3.5 yd^3 bucket, or a front-end loader with a 5 to 6 yd^3 bucket. Over 700 tons of concrete rubble could be removed per day using two trucks making 12 rounds each during one 8-hour shift, with nearly 70,000 tons (or 36,000 yd^3 in-place volume) to be removed from the dam within approximately 16 weeks. Estimated total waste quantities for the Full Removal alternative include nearly 62,000 yd^3 of concrete, 900 tons of rail and reinforcing steel, and over 1,200 tons of mechanical and electrical items. A Class III sanitary landfill and medium volume transfer station is located in Yreka, California, in Siskiyou County, about 28 miles from the damsite, and is accessible by county road and federal highway (Interstate 5).

Copco No. 2 Dam and Powerhouse

The Copco No. 2 development consists of a concrete diversion dam, embankment section, gated spillway, water conveyance system, and powerhouse, located on the Klamath River between approximately RM 199 and RM 196, in Siskiyou County, California (Figure 3). The dam was completed in 1925 at RM 198.3, approximately 1/4 mile downstream of Copco No. 1 Dam, and impounds a small reservoir of approximately 70 acre-feet at RWS elevation 2483. Site access is provided from Interstate 5 by Copco Road, and then by a steep and narrow access road to the dam, or by Daggett Mountain Road to the powerhouse, crossing the Klamath River on a single-lane bridge. The dam is a concrete gravity structure with a gated intake to a water conveyance tunnel on the left abutment, a central 145-foot-long spillway section with five 26- by 11-foot radial gates, and a 132-foot-long earthen embankment on the right abutment. The dam is 33 feet high, with an overall crest length of 335 feet and a crest width of 9 feet at elevation 2493. The concrete spillway crest is at elevation 2473, with a downstream apron at elevation 2456, between two concrete retaining walls. The water conveyance system for the powerhouse includes 3,550 feet of 16-foot-diameter concrete-lined tunnel, 1,313 feet of 16-foot-diameter wood-stave pipeline, and two 16-foot-diameter steel penstocks (reducing to 8-

foot-diameter). The powerhouse is located 1.5 miles downstream of the dam on the left bank of the river at RM 196.8. The two turbines are vertical-shaft, Francis-type units with a net head of 140 feet. Total generating capacity is 27 MW.

The dam is situated in a steep, narrow canyon. The existing access road would require significant upgrading to provide access for a large crawler-mounted crane and to handle the removal of waste materials. The access bridge across the Klamath River downstream of the powerhouse may require improvements to handle the construction equipment loads. Dam removal would begin after spring runoff, on May 1, 2020, with closure of the penstock intake gate. Releases through the gated spillway (crest elevation 2473) during the low flow period would permit initial reservoir drawdown to RWS elevation 2478 in one day. A temporary cofferdam would be constructed within the river channel to isolate the two left-hand spillway bays for structure removal to elevation 2454. Removal of the temporary cofferdam would allow the small reservoir to stabilize at approximately RWS elevation 2460 through the dam breach. Construction of a second cofferdam would permit isolation of the three remaining spillway bays on the right-hand side for removal to channel elevation 2454. Estimated total waste quantities for the Full Removal alternative include nearly 1,500 yd^3 of earthfill, over 12,000 yd^3 of concrete, 600 tons of reinforcing steel, and 2,000 tons of mechanical and electrical items. Waste disposal would use the same sites as for removal of Copco No. 1 Dam.

Iron Gate Dam and Powerhouse

The Iron Gate development consists of an embankment dam, side-channel spillway, diversion tunnel, intake structures, and powerhouse, located on the Klamath River between RM 197 and RM 190, about 20 miles northeast of Yreka, California, in Siskiyou County (Figure 4). The dam was completed in 1962 at RM 190.1 for power generation, and impounds a reservoir of 944 acres (Iron Gate Reservoir) with a total storage capacity of approximately 53,800 acre-feet at RWS elevation 2328. Site access is provided from Interstate 5 by Copco Road, and then by Lakeview Road to the dam crest and reservoir area, or by a project access road to the powerhouse. A single-lane bridge crosses the Klamath River downstream of the dam. The dam is a zoned earthfill embankment with a height of 189 feet from the rock foundation to the modified dam crest at elevation 2343. The dam crest is 20 feet wide and approximately 740 feet long, with a sheet pile wall upstream of the dam centerline extending to elevation 2348. There are fish trapping and holding facilities located on random fill at the downstream toe of the dam at elevation 2189. Cold water intakes are incorporated in the dam on the left abutment for the fish facilities and downstream hatchery. A side-channel spillway is excavated in rock on the right abutment, having a crest length of 727 feet at elevation 2328. Spillway flows enter a concrete-lined chute and flip-bucket extending approximately 2,150 feet beyond the toe of the dam. A diversion tunnel through the lower right abutment terminates in a concrete outlet structure near the downstream toe. Tunnel releases are currently controlled by the upper portion of a two-piece concrete slide gate located in a gate shaft and tower about 112 feet upstream of the dam axis. Recent modifications added a 9-foot-diameter hinged blind flange and concrete ring approximately 20 feet downstream of the concrete slide gate to prevent gate leakage during underwater inspections. The intake structure for the powerhouse is a 45-foot-high, free-standing concrete tower, located in the reservoir immediately upstream of the left abutment and accessible by footbridge from the abutment. It houses a 12- by 17-foot wheel-mounted slide gate, which controls the flow into a 12-foot-diameter penstock. The powerhouse is located at the downstream toe of the dam on the left bank, and consists of a single vertical-shaft, Francis-type turbine with a net head of 154 feet. Total generating capacity is 18 MW.

The successful removal of Iron Gate Dam is dependent upon the modification and operation of the diversion tunnel for low-level releases. The existing downstream blind flange would first be secured in place to allow replacement (under full reservoir head) of the two-piece concrete slide gate with a new 16.5- by 18-foot roller gate, using a barge-mounted crane and hard-hat divers. With the new roller gate closed, the blind flange and concrete ring would be removed. Reservoir drawdown at a rate of about 3 feet per day would begin on January 1, 2020, with controlled sediment releases through the modified diversion tunnel, lowering the reservoir 126 feet from RWS elevation 2328 to RWS elevation 2202 under average streamflow conditions. Removal of the dam embankment would begin on June 1, 2020, after spring runoff, to minimize the risk of dam overtopping. A minimum flood release capacity of 7,700 ft^3/s would be maintained in June (crest elevation 2251), 7,000 ft^3/s in July (crest elevation 2238), and 3,000 ft^3/s in August and September (crest elevation 2191) to accommodate at least a 100-year flood for that time of year. The embankment materials would include an estimated 880,000 yd^3 of earthfill, 30,000 yd^3 of riprap on the downstream face, and 80,000 yd^3 of riprap on the upstream face, and would require two shifts for excavation of 16,000 yd^3 per day (average 1,000 yd^3 per hour) with a 5-day work week. Excavated materials would be hauled about 1 mile to a proposed disposal site on the left abutment, or placed within the existing spillway chute and basin (up to 300,000 yd^3) after the embankment has been excavated below the existing spillway crest (elevation 2328).

The reservoir would be drawn down to the maximum possible extent (during minimum streamflow and with no upstream drawdown releases) by September 1, 2020, to allow the placement of rockfill on the downstream face of the remaining embankment (having a crest no lower than elevation 2191) for a controlled breach above the existing bedrock surface at elevation 2154, by notching below the reservoir level (expected to be below RWS elevation 2183). Maximum breach outflow is estimated to be up to 5,000 ft^3/s, and should be performed prior to the breach of J.C. Boyle Dam to minimize potential downstream impacts.

The Iron Gate Dam production rate assessment considered the approximate lift area of the embankment by elevation, and the number of concurrent excavation operations possible at that elevation. Conventional earthmoving equipment would be used, consisting of excavators and off-road articulated or fixed-wheel haul units to reach the required average production rate of 1,000 yd^3 per hour. Key factors would be sizing the excavators to minimize the loading passes per haul unit, and selecting the maximum size haul units that can effectively negotiate the dam surface and haul route. To achieve the desired daily production rates, shift work would be required. The current assessment assumes 5 days per week and an average of 1.75 shifts per day for 8 to 9 shifts per week, and assumes an average of twenty 35-ton haul units loaded by up to four 6 to 8 yd^3 excavators, to remove the dam embankment within about 16 weeks. The potential for significant acceleration of the construction schedule may be very limited, if required, and may only be obtained by adding additional excavation time (increasing to 6 or 7 days per week, and/or longer shifts) and not by adding more equipment to the limited lift surfaces. Estimated waste quantities for the Full Removal alternative include nearly 1,100,000 yd^3 of earthfill, nearly 12,000 yd^3 of concrete, an estimated 600 tons of reinforcing steel, and nearly 1,000 tons of mechanical and electrical items at the dam and powerhouse. A Class III sanitary landfill and medium volume transfer station is located in Yreka, California, in Siskiyou County, approximately 25 miles from the damsite, and is accessible by county road and federal highway (Interstate 5).

Figure 1. J.C. Boyle Dam.

Figure 2. Copco No. 1 Dam.

Figure 3. Copco No. 2 Dam.

Figure 4. Iron Gate Dam.

(Photos courtesy of Klamath Riverkeeper, klamathriver.org)

SEDIMENT MANAGEMENT AND MONITORING

One of the major design objectives was to limit the high sediment concentrations to January 1 through March 15. That is a period when there is less biological sensitivity to high sediment loads, and when high flows can flush the fine sediment through the system. Natural erosion of the reservoir sediment was selected as the preferred alternative to reduce project costs. A mechanical dredging alternative was deemed infeasible due to the large volume of sediment, short construction window, disposal requirements, and cost.

The dredging alternative would not have reduced the sediment impacts to fish to a less than significant level and would have caused additional environmental impacts at the proposed disposal sites. Since natural erosion of sediment was selected, a detailed understanding of the potential hydrologic and sediment erosion scenarios was required. Reclamation (2011a) details the hydrologic and sediment transport analyses performed.

Streamflow Hydrology

Iron Gate Dam is located approximately 190 miles upstream from the ocean and is the most downstream dam. There are several stream gages within the Klamath River basin, including the Keno stream gage located just upstream of J.C. Boyle Reservoir; the Iron Gate stream gage located directly downstream of Iron Gate Dam; and the Seiad, Orleans, and Klamath stream gages located at RM 129, 59, and 8, respectively (Figure 5). The median stream flow for every day of the year is given in Figure 6. The stream flows are significantly lower during the months of July to October. There is also significant flow accretion from Iron Gate Dam to the mouth of the Klamath River at Klamath, California due to the multiple tributaries entering downstream.

Because the removal of the Iron Gate and J.C. Boyle dam embankments will occur primarily during the period from July 1 through November 30, a separate flood frequency analysis was performed for this time period. For example, the 100-year seasonal flood peak discharge at Iron Gate Dam is 8,390 ft^3/s from July 1 through November 30, whereas the 100-year peak discharge is 31,460 ft^3/s when the whole year is considered.

Sediment Characterization

A detailed reservoir investigation is documented in Reclamation (2010) and previous reservoir investigations have been performed by JC Headwaters, Inc. (2003), and by Shannon and Wilson (2006). The reservoir sediment was characterized based on soil properties, grain size, desiccation properties, and critical shear stress, as determined from field sampling and laboratory testing. The geologic investigations included in-reservoir drilling to collect comprehensive suites of samples of reservoir sediment behind each dam. There were three main purposes of this work:

1. To collect samples for screening-level analysis of organic and inorganic chemical compounds within the reservoir sediment and, where present, to determine the level and extent of contamination;
2. To collect samples of reservoir sediment to determine a standard suite of physical properties and to collect undisturbed samples for analyses of engineering properties; and,
3. To help determine the thickness of reservoir sediment throughout all major sections of each reservoir.

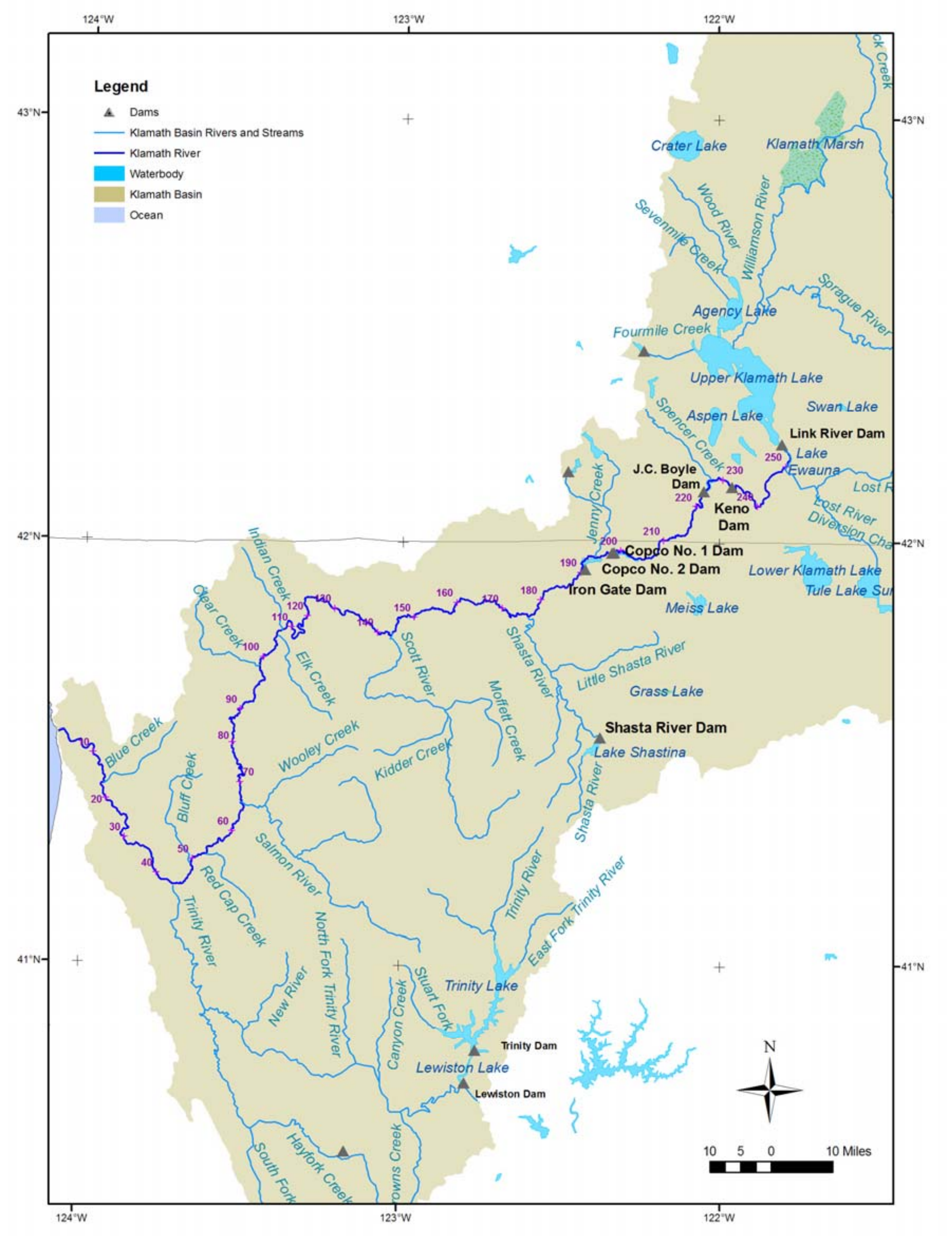

Figure 5. Klamath River Basin overview and feature location map.

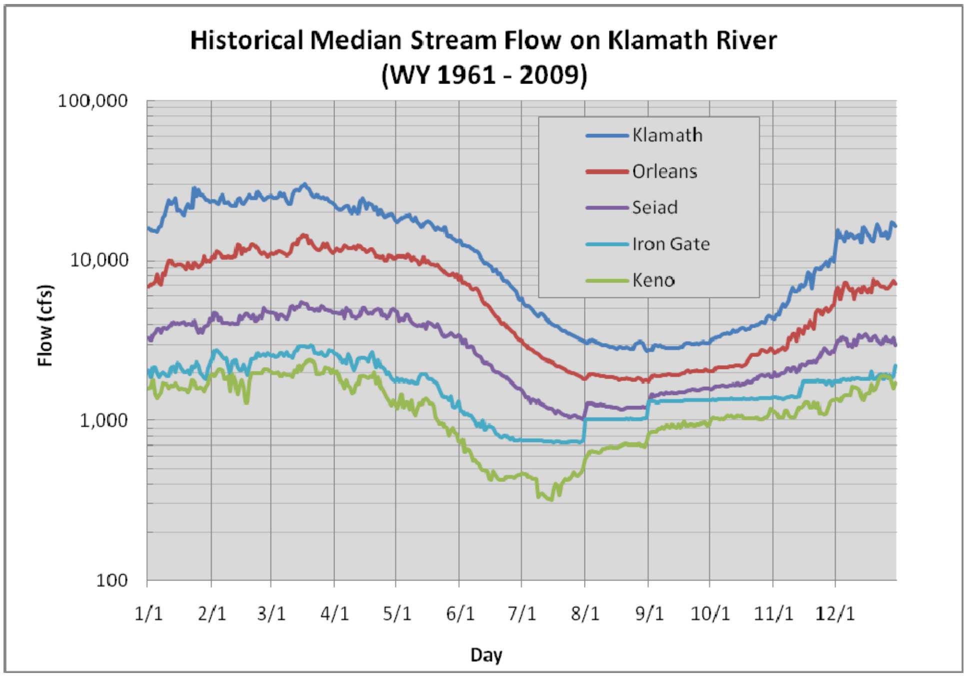

Figure 6. Median stream flows in the Klamath River at various sites.

The in-reservoir geologic investigations consisted of:

- Barge and boat platforms for auger drilling and sampling;
- Barge and boat platforms for push-tube sampling;
- A boat platform for vibracore drilling and sampling;
- A boat platform for gravity tube sampling.

The reservoir sediment is mostly an accumulation of silt-size particles of organic material such as algae and diatoms, and silt-size particles of rock loosely arranged in an open water-filled structure. Higher percentages of silt, sand, and gravel were found in the upper reaches of each reservoir. Throughout each reservoir, the fine-grained sediment has the consistency of pudding. It is generally very soft and indents with very light finger pressure. On a microscopic scale, it has an open structure that holds a very high water content. Field moistures of sediment samples were frequently 200 to 300 percent of the sample's dry weight, and ranged up to 700 percent. Due to its high water content, most of the impounded sediment not eroded during the initial stage of reservoir drawdown will likely take some time to dry out.

The fine-grained sediment also has low cohesion and is highly erosive. In each reservoir, fine-grained sediment deposits were thinnest in the upstream portion of the reservoir and thickest near the dam, and were thin to nonexistent in narrow channels of the reservoirs where flow velocities exceed an estimated 2 to 4 miles per hour. This was attributed to the sediment either remaining in suspension or eroding from the active channel, or both.

Sediment Routing Results

The short term release of fine sediment will occur as the reservoirs are drawn down. The rate of reservoir drawdown and response to high flows is largely determined by the low-level outlet capacity at Iron Gate and J.C. Boyle Dams and by the notching rate at Copco No. 1 Dam. Hydrologic routing during dam removal was performed using the RiverWare model. Simulations were performed for two-year time periods. Every water year between 1961 and 2008 was simulated. A dry year, median year, and wet year was also identified based upon the total volume of flow during the period from March to June. A one-dimensional hydraulic and sediment transport model, SRH-1D (Huang and Greimann, 2010) was used to simulate the erosion of the reservoir sediment and downstream transport. Reservoir drawdown was predicted to release approximately 1/3 to 2/3 of the estimated 15 million yd^3 of sediment that will be stored in the reservoirs by year 2020. More material will be eroded during a wet year than during a dry year. The river channel will return to its pre-dam alignment at each reservoir and have a width similar to pre-dam conditions. The sediment that is left behind in the reservoirs will raise the floodplain terraces above the pre-dam conditions so that the new terraces would be inundated less frequently than typical floodplains in the basin. High flows will gradually erode into the new terraces, but this process would occur slowly over several decades.

Most of the eroded fine sediment will be transported to the ocean during the period of initial reservoir drawdown between January 1 and March 15, 2020. The maximum sediment concentrations during this period may be more than 10,000 mg/l downstream of Iron Gate Dam. The tributaries entering the Klamath River will significantly reduce these concentrations to less than 2,000 mg/l at the mouth of the Klamath River. An example of the sediment concentrations expected as the result of dam removal downstream of Iron Gate Dam is shown in Figure 7.

If there is a wet year, it may take longer to drain Iron Gate Reservoir because of its limited outlet capacity and sediment concentrations in the river could exceed 1,000 mg/l as late as June. If there is a dry year, the sediment concentrations will be higher during the drawdown period because of less dilution of sediment by the flow. Sediment concentrations are expected to return to background levels by September 2020 regardless of the stream flow. One reason for the rapid decrease in sediment loads is the plan for aggressive hydroseeding of the exposed sediment surfaces immediately following dam removal, which will stabilize the sediment from erosion due to rainfall. The reservoir sediment resistance to erosion also dramatically increases once it dries out.

The bed material within the reservoirs and along the Klamath River between Iron Gate Dam and Cottonwood Creek is expected to have a high sand content (30 to 50 percent) immediately following reservoir drawdown until a flushing flow moves the sand-sized material out of the reach. The minimum flushing flow is expected to be at least 6,000 ft^3/s and to last several days to weeks in order to return the bed to a condition dominated by cobble and gravel and with a sand content less than 20 percent. After the flushing flow, the bed is expected to maintain fractions of sand, gravel, and cobble similar to natural conditions. The mobility of the river bed downstream of Iron Gate Dam to Cottonwood Creek will also be increased by the removal of the dams. The return of the natural gravel supply to this reach will increase the frequency of gravel mobilization from once every four years to once every other year.

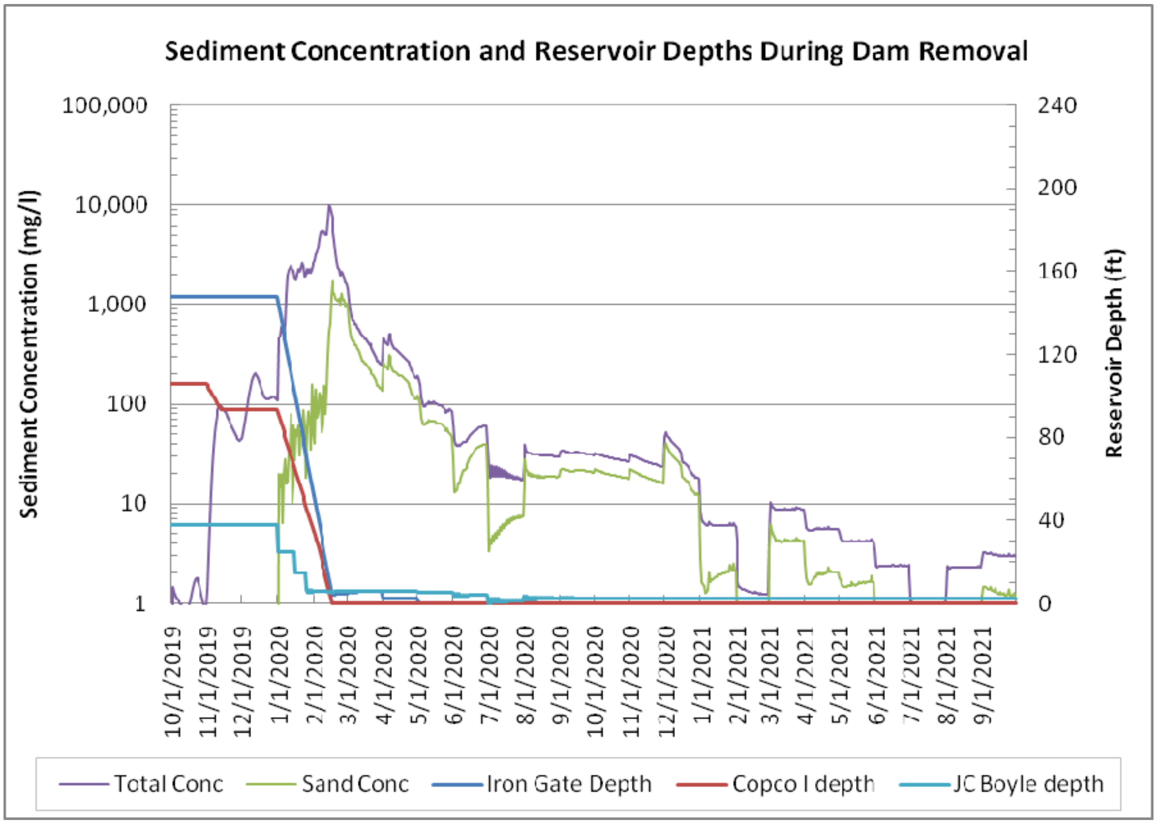

Figure 7. Simulated sediment concentrations downstream of Iron Gate Dam resulting from concurrent drawdown of J.C. Boyle, Copco, and Iron Gate Reservoirs during a median water year.

RESERVOIR RESTORATION

A significant reservoir restoration effort is planned and has the following main objectives (Reclamation, 2011c):

- Weed management around the reservoir areas prior to dam removal.
- Active revegetation of reservoir areas with native grasses immediately after reservoir drawdown.
- Application of herbicides to further limit invasive species.
- Planting of woody riparian species along the river banks in the reservoir areas.
- Monitoring of vegetation growth to ensure objectives are accomplished.

The revegetation of the reservoir areas presents many challenges and there are many uncertainties related to the dynamics of vegetation establishment after reservoir drawdown. Ideally, native grasses and riparian species on exposed sediment deposits will establish immediately following reservoir drawdown. This will minimize the time the exposed sediments are vulnerable to invasive species, discourage erosion, take advantage of residual moisture for desirable species, and provide valuable habitat in a timely manner. Current scenarios require the initiation of reservoir drawdown by January 1 and the reservoirs should be nearly empty by April 1 under median hydrologic conditions. Under wet conditions, J.C. Boyle and Iron Gate Reservoirs may partially refill, and the actual dates for revegetation will be subject to weather conditions and flow forecasts.

A combination of aerial, barge-mounted, and truck-mounted hydroseeding and hydromulching will be used immediately after reservoir drawdown in the spring of 2020. Once grasses are established, spot treatments of post-emergent herbicides will be applied for invasive species within the revegetation areas and may be re-applied the following year if further treatments are found necessary. This will be followed by fall reseeding in the areas where establishment did not occur. Continued monitoring and reseeding as necessary will be continued for 5 years following dam removal to ensure adequate vegetation restablishment.

MITIGATION MEASURES

A public draft Environmental Impact Statement and Environmental Impact Report (EIS/EIR) has been prepared in compliance with the National Environmental Policy Act (NEPA) and the California Environmental Quality Act (CEQA) to analyze the impacts of four action alternatives (DOI, 2011). Mitigation measures to reduce negative impacts were identified for the following: Aquatic Resources (fish impacts), Terrestrial Resources (wildlife impacts), Surface Water Hydrology (downstream flood impacts), Groundwater (upstream well impacts), Water Supply/Water Rights (downstream intake impacts), Cultural and Historic Resources (submerged cultural sites), Recreation (replacement of facilities), Transportation (protection of bridges and culverts), and Monitoring Plans (for sediment, water quality, and aquatic resources). An allowance for all potential mitigation costs was included in the construction cost estimates for both dam removal alternatives, based on estimated costs for each mitigation measure identified.

COST ESTIMATES

Feasibility-level cost estimates were prepared for both Full and Partial dam removal alternatives based on the information obtained during the design investigations relative to structure layouts and removal limits, and streamflow diversion and demolition plans, from which approximate quantities for each kind, type, or class of material, equipment, or labor were obtained. These estimates were intended to capture the most current pricing for materials, wages and salaries, accepted productivity standards, and typical construction practices, procurement methods, current construction economic conditions, and site conditions for the current level of design, and are suitable for use in the selection of a preferred project alternative and to determine the economic feasibility of the project. The Partial Removal alternative would require additional facilities maintenance over the life of the project, for which a Life Cycle Cost (LCC) was determined using a planning interest rate of 4.125 percent. A summary of the Most Probable cost estimates for each alternative, representing the Designer's and Cost Estimator's best opinion and assessment of the scope of work and cost for the project, is provided in Table 1.

Table 1. – Most Probable Cost Estimates, Dam Removal Alternatives

Line Items	Full Removal Alternative	Partial Removal Alternative
Dam Facilities Removal	76,618,994	52,096,172
Recreation Facilities Removal	797,305	797,305
Reservoir Restoration	21,728,000	21,728,000
Yreka Water Supply Mods	1,765,910	1,765,910
Mobilization and Contingencies	50,728,393 38,8	30,385
Escalation to Jan 2020	36,461,398	27,582,228
TOTAL FIELD COST	188,100,000	142,800,000
Engineering	37,600,000	28,400,000
Mitigation	65,900,000	63,400,000
TOTAL CONST. COST	**291,600,000**	**234,600,000**
LIFE CYCLE COST	**0**	**12,350,000**

Some degree of cost risk and uncertainty is associated with each component in the cost estimates prepared for the Detailed Plan. Because of these uncertainties, cost risk modeling methods were used to help quantify these uncertainties and their potential impacts on the total project costs. Potential risks and the associated costs were identified and evaluated using a Monte Carlo-based simulation process. Monte Carlo simulations furnish the decision maker with a range of possible outcomes and the probabilities with which they would occur. The Monte Carlo simulation was run for 10,000 iterations to model the forecast values for Contract Cost, Field Cost, and Total Construction Cost for each feature. For this analysis, the non-contract costs (including engineering and mitigation), escalation from current price level to year 2020, and contingency allowances were driving factors for variation in the Total Construction Cost forecast values, which ranged from $238,000,000 to $493,100,000 for the Full Removal alternative, and from $185,100,000 to $403,600,000 for the Partial Removal alternative, with a range from $9,000,000 to $26,800,000 for Life Cycle Costs.

CONCLUSIONS

A Detailed Plan for the removal of four hydroelectric dams on the Klamath River in Oregon and California has been prepared to develop the physical methods and timetable necessary for dam removal; plans for management, removal, and/or disposal of reservoir sediment; plans for site restoration and potential impact mitigation; and estimated project costs, in accordance with the Klamath Hydroelectric Settlement Agreement. The feasibility-level cost estimates confirm that the four dams can be removed in year 2020 in order to meet the project requirements for a free-flowing river and for volitional fish passage without exceeding the State Cost Cap of $450 million.

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