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KLAMATH RIVER RENEWAL PROJECT
GEOTECHNICAL DATA REPORT

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A	Issued in Draft	August 28, 2019
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D	Issued in Draft with Additional Laboratory Data	November 27, 2020
E	Issued in Draft with Updated Appendix H Figures	December 16, 2020

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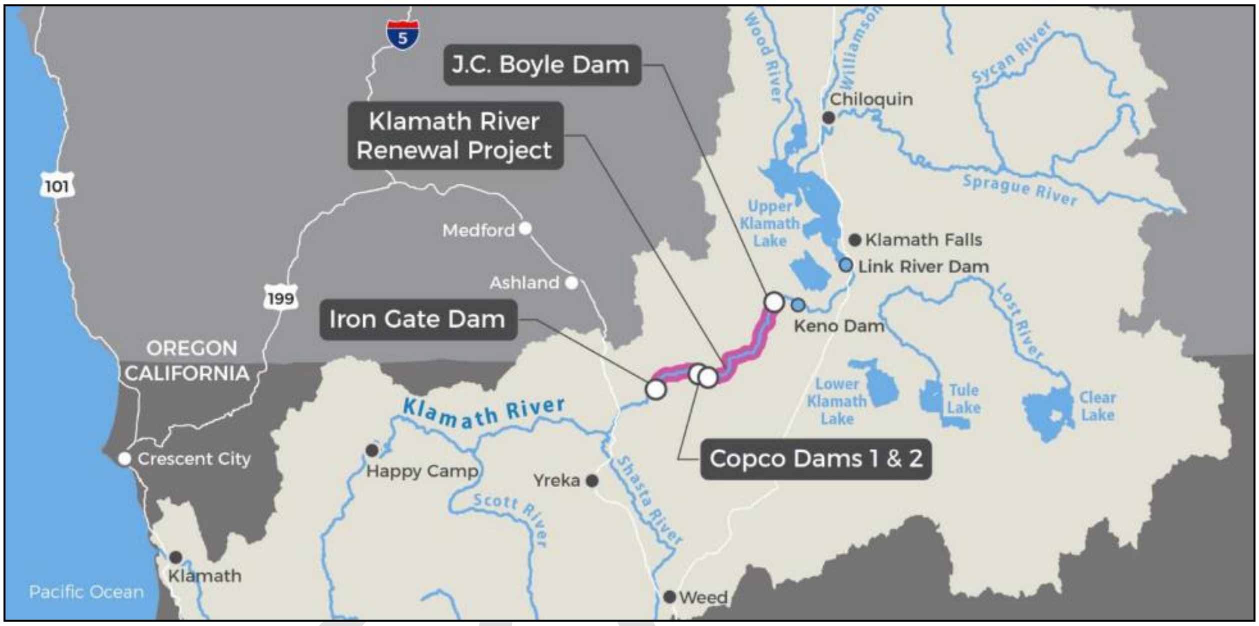
ABBREVIATIONS

ASTM	American Society for Testing and Materials
CMFS	Cedar Mountain Fault System
ID	internal diameter
ISRM	International Society for Rock Mechanics
Kleinfelder	Kleinfelder West Inc.
KP	Knight Piésold Ltd.
KRRC	Klamath River Renewal Corporation
M	magnitude
Ma	mega-annum (millions years)
NGI	Norwegian Geotechnical Institute
PanGEO	PanGEO Incorporated
USGS	United States Geological Survey
WKLZ	West Klamath Lake Fault Zone

1.0 INTRODUCTION

The Klamath River Renewal Corporation (KRRC) proposed the Klamath River Renewal Project, which involves removing four existing hydroelectric developments and appurtenant facilities on the Klamath River in southern Oregon and northern California. The four hydropower facilities to be decommissioned include J.C. Boyle, Copco No. 1, Copco No. 2, and Iron Gate. A location map of the project area is provided on Figure 1.1.



NOTES:

1. SOURCE: KRRC, 2018.

Figure 1.1 Project Location

Geotechnical site investigations were carried out in two phases. The first phase was completed for developing the Definite Plan (KRRC, 2018) and the second phase was completed for developing the dam removal scope of Preliminary Services (KP, 2020a). In addition to deconstruction, the dam removals require construction of permanent disposal fill areas, temporary work platforms, and modification of temporary and permanent access (roads, bridges, culverts).

Knight Piésold Ltd. (KP) was tasked to compile the geotechnical data for both phases. This Geotechnical Data Report presents information acquired previously by others for development of the Definite Plan and includes data acquired during investigations completed by KP for Preliminary Services.

2.0 GEOLOGICAL SETTING

The geological setting summarised in this report represents a review of the following:

- Geotechnical Report Klamath River Dam Removal Project California and Oregon (PanGEO, 2008)
- Geological Map of the Weed Quadrangle, scale 1:250,000 (Wagner and Saucedo, 1987)
- Geology of the Macdoel Quadrangle, California Division of Mines Bulletin 151, scale 1:125,000 (Williams, 1949)
- Volcanic Formations Along the Klamath River Near Copco Lake (Hammond, 1983)
- U.S. Quaternary Faults, Interactive Fault Map (USGS, 2017)
- Definite Plan for the Lower Klamath Project (KRRC, 2018)

2.1 REGIONAL GEOLOGY

The Klamath River traverses multiple physiogeographic provinces starting in the Basin and Range Province of Oregon, traversing the High and Western Cascades, Klamath Mountains Province, and the Coastal Ranges of northern California, and reaching the Pacific Ocean at Requa, 16 miles south of Crescent City. The project area is predominantly contained in the Western and High Cascades. The Klamath River pre-dates the formation of the Cascade Mountain Range and maintained a relatively similar course through the mountain building events.

The bedrock of the project area comprises volcanic rocks, up to 45 million years (Ma) old, and includes basalt and andesite lava flows, tuffs, tuff-breccias and volcaniclastic sandstone. The volcanic rocks are intruded by numerous dikes and plugs of andesite, rhyolite, and basalt. Many of the volcanoes associated with the Western Cascades have since eroded, but large shield volcanoes and vents of the High Cascades remain and are still active in present times.

Large deposits of coarse alluvium were deposited along the Klamath River during the period of the last glaciation when the river had a higher discharge. Lacustrine deposits were laid down in former temporary lakes that were created at the present-day sites of the Copco No. 1 and J.C. Boyle Reservoirs when the Klamath River was temporarily dammed by volcanic activity.

2.2 J.C. BOYLE

The topography in the area of the J.C. Boyle facility is predominantly a low-gradient bowl with gently rolling terrain. The steepest topography exists in the river canyons upstream and downstream of the reservoir. All bedrock units in the area are estimated to be younger than 5 Ma and associated with the High Cascades volcanism from large stratovolcanic complexes and smaller shield volcanoes and vents; these are typically basaltic flows interlayered with volcaniclastics and hydrovolcanic deposits, leading to highly complex geology from a large variety of sources.

The surficial deposits at the reservoir comprise lacustrine deposits as well as river alluvium and local colluvial deposits. The lacustrine deposits comprise older sediments that were laid down in a former lake that was created when the river was temporarily dammed by volcanic activity and recent sediments, which were deposited within the reservoir. More details on the geological model of the reservoir are found in the Reservoir Rim Stability Report (KP, 2020b).

Faulting is very prominent in the J.C. Boyle Reservoir area and appears to be associated with extensional tectonics of the Basin and Range Province that began approximately 1.5 Ma to 2 Ma ago. The bowl topography of the reservoir area likely formed as a dropped-down basin. At least one fault splay is predicted to extend into the dam area (PanGEO, 2008).

2.3 COPCO NO. 1 AND NO. 2

The area surrounding the Copco No. 1 and Copco No. 2 reservoirs is characterized by hillsides comprised of low gradient lava flows from surrounding shield volcanoes. The Copco Basalt (0.14 Ma) makes up the vertical upper walls of the canyon in the vicinity of the dam site. The Copco Basalt was created by volcanic flows from vents on both sides of the river, which led to damming of the river and the formation of a lake in the same area as the present-day reservoir. The Western Cascades Volcanics underlie most of the slopes on the shoreline of the reservoir. This unit comprises andesite with interstratified tuff-breccia, volcaniclastic sandstone and tuffs.

The surficial deposits at the Copco No. 1 Reservoir comprise lacustrine deposits as well as river alluvium and local colluvial deposits. The lacustrine deposits mainly comprise sediments that were laid down in a former lake that was created when the river was temporarily ‘dammed’ by volcanic activity. Fine sediments, comprising silts and diatomite (siliceous skeletal remains of diatoms) were deposited in the lake. At some locations, a 3-inch to 4-inch bed of laminated black sand was found to underlie the diatomite and overlie Western Cascades tuffaceous volcaniclastic strata. The formation of the lake resulted in fluvial terraces and fans developing further still from the contemporary course of the river. Recent lacustrine deposits have accumulated within the reservoir since its construction. Colluvium occurs locally around the shoreline of the Copco No. 2 Reservoir. More details on the geological model of the reservoirs are found in the Reservoir Rim Stability Report (KP, 2020b).

Small faults that have been historically mapped around the Copco No. 1 and No. 2 facilities typically trend west to northwest south of the river. Limited structural mapping north of the river shows a northward trend.

Natural groundwater springs can be observed and typically exist in the tuffaceous layers between impermeable lava flows and along lithological contacts. The rapidly cooled more porous lava flow tops and bottoms are common aquifers in the region.

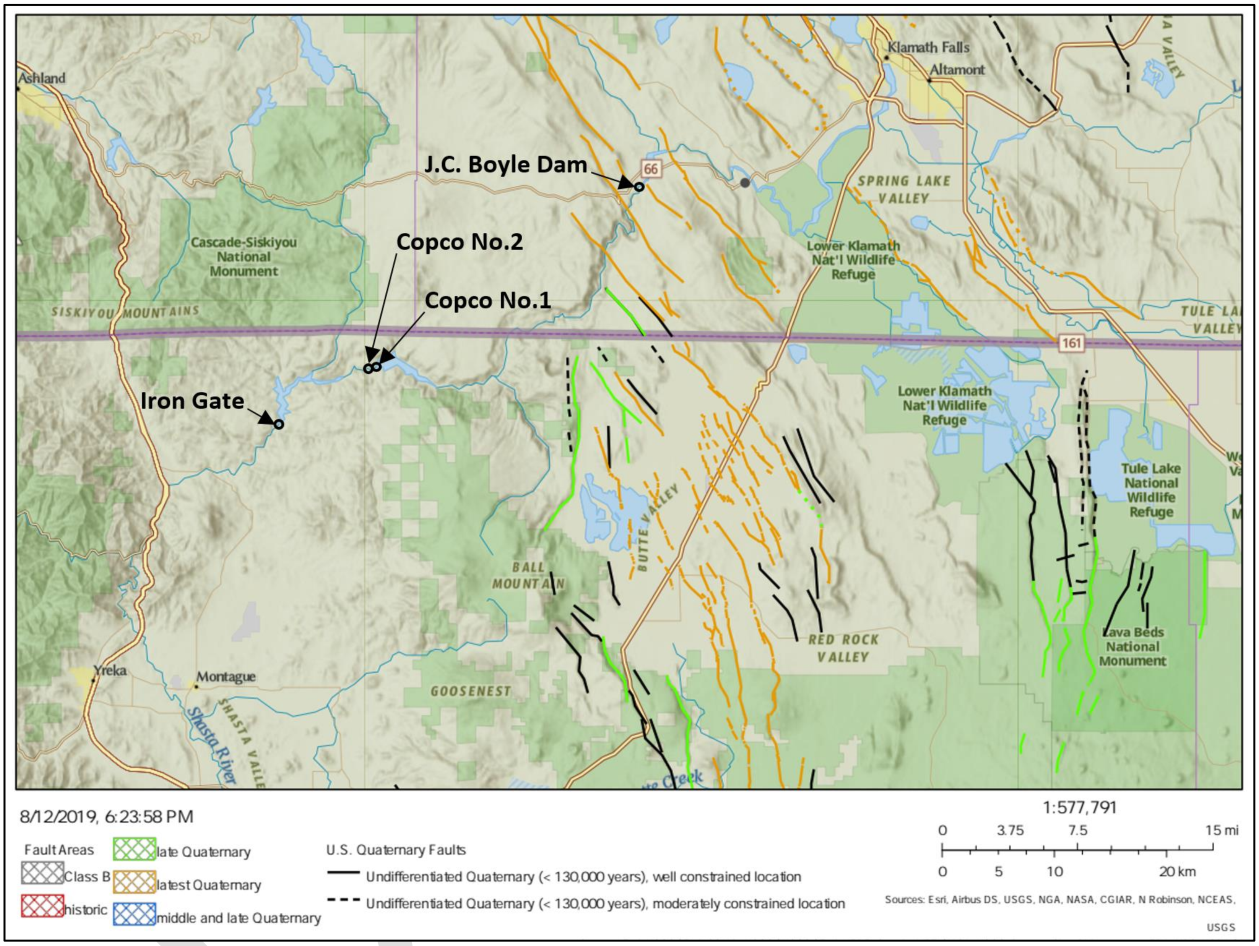
2.4 IRON GATE

The Iron Gate dam and its reservoir lie entirely within the Western Cascades Geologic Province. The bedrock around the shoreline comprises andesite and basalt with volcanic breccia, tuff, tuffaceous siltstones, and sandstones. The strata dip gently towards the east. Surficial deposits around the reservoir shoreline include colluvium and local alluvial deposits at drainage line intersections. More details on the geological model of the reservoir is found in the Reservoir Rim Stability Report (KP, 2020b).

Groundwater springs are common and occur along tuff layers between impermeable lava flows or along other structures such as lava tubes, faults, joints, and lithological contacts. Aquifers in the region are commonly found in the rapidly cooled and more porous contacts of lava flows. Many tributaries along the banks of the Iron Gate reservoir are fed by these springs.

2.5 REGIONAL SEISMICITY

The facilities are located west of a series of Quaternary faults that trend north-south except for J.C. Boyle, as shown in Figure 2.1. The United States Geological Survey (USGS) defines Quaternary faults as those exhibiting movement within the last 2.58 Ma. Figure 2.1 shows the USGS search results for regional Quaternary faults located near the facilities.



NOTES:

1. SOURCE: USGS, 2017.

Figure 2.1 Regional Quaternary Faults

Seismic surveys of the hydropower facilities were completed in 2009 by Kleinfelder (2009a, 2009b, 2009c). Known Quaternary seismic sources within a 62-mile radius of the facilities were inventoried as a part of the evaluations. Twenty faults were identified, and a summary of the survey results is presented in Table 2.1.

Table 2.1 Summary of Historical Earthquakes within 62 miles of the Project Sites

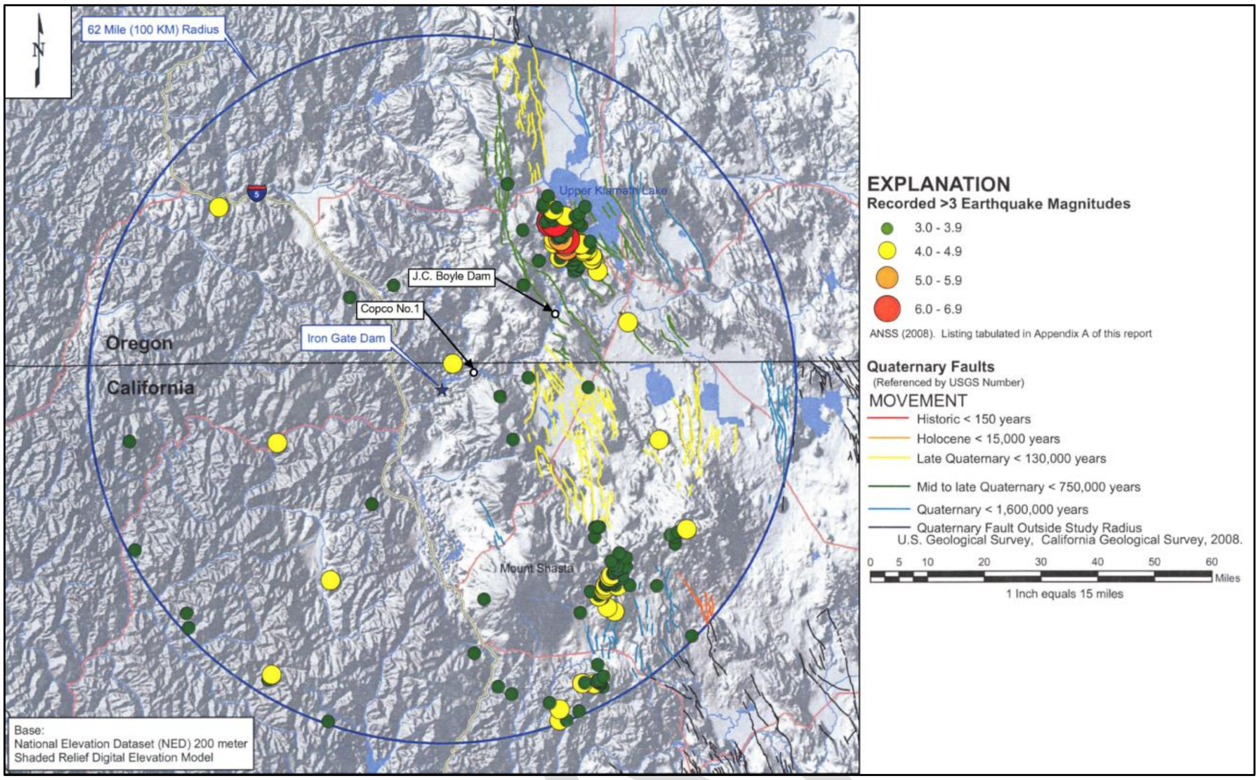
	J.C. Boyle	**Copco No. 1**	**Iron Gate**
Time Period	1906 to October 2008 (102 years)		
Maximum Magnitude	6.0		
Approximate Distance to Nearest Historical Earthquake	7.6 miles	6.6 miles	4.9 miles
Number of Events > Magnitude M3	164	180	189
Closest Quaternary Fault	Sky Lakes fault zone	Ikes Mountain-Mt. Hebron section (CMFS)	
Distance to Closest Quaternary Fault	0.25 miles	10.6 miles	15.5 miles

The project area is in a region defined by active faults associated with the West Klamath Lake Fault Zone (WKLZ) and the Cedar Mountain Fault System (CMFS). No Quaternary fault traces were identified beneath the dam structures at the surveyed facilities (Kleinfelder, 2009a, 2009b, 2009c). Two faults of the CMFS were mapped upstream (0.25 miles east) and downstream (0.65 miles west) of the J.C. Boyle dam (Kleinfelder, 2009a). However, Kleinfelder (2009a) indicated that seismic hazards at the J.C. Boyle site are generated by tectonic activity within the nearby WKLZ. Potential seismic hazards for the Copco No. 1 (Kleinfelder, 2009b) and Iron Gate (Kleinfelder, 2009c) dam sites are generated by earthquakes associated with the CMFS.

The Stephens Pass section of the CMFS is the only fault within the 62-mile radius of the facilities and survey period that experienced surface rupture. The occurrence was recorded in 1978 and resulted from a magnitude M4.6 earthquake (Kleinfelder, 2009a, 2009b, 2009c). The fault segment that experienced surface displacement (along approximately four miles) is located approximately 45 miles south of the J.C. Boyle dam and approximately 43 miles south of the Iron Gate dam.

The Mayfield Fault Zone experienced the highest rate of slip within the 62-mile radius and as recent as the Holocene or within the last 15,000 years (Kleinfelder, 2009a, 2009b, 2009c). The fault is located approximately 81 miles south of J.C. Boyle dam and approximately 51 miles southeast of Iron Gate dam.

Historical (1906 through October 2008) seismic events exceeding moment magnitude M3.0 were also inventoried within a 62-mile radius of the facilities as a part of the evaluations (Kleinfelder, 2009a, 2009b, 2009c). Two concentrations of recorded earthquakes are notable on the west side of Klamath Lake, approximately 15 miles north of the J.C. Boyle dam, and on the east side of Mount Shasta, approximately 43 miles southeast of Iron Gate dam. Figure 2.2 shows the search results from the Iron Gate evaluation, which also encompasses the J.C. Boyle facility.



NOTES:

1. SOURCE: KLEINFELDER, 2009c.
2. RECORD PERIOD IS 1906 THROUGH OCTOBER 2008.

Figure 2.2 Faults and Recorded Earthquakes within 62 Miles of Iron Gate Dam

3.0 DEFINITE PLAN SITE INVESTIGATIONS

The focus of the Definite Plan investigations was on rim stability of the Copco No. 1 and Iron Gate reservoirs, bridge foundations, and the City of Yreka water line. No geotechnical investigations were carried out in J.C. Boyle area.

Information acquired during the Definite Plan investigations were sourced from the Geotechnical Data Report produced by KRRC (2019). The investigations were conducted in February 2018 through January 2019 and included the following:

- Drilling 48 borings in and around the Copco No. 1 and Iron Gate facilities
  - 21 borings for Copco No. 1 reservoir rim stability
  - 1 boring for Iron Gate reservoir rim stability
  - 17 borings for bridge foundations
  - 9 borings for the City of Yreka water line
- Soil and rock sampling
- Standard penetration testing
- Downhole televiewer surveys
- Pneumatic packer hydraulic conductivity testing
- Vibrating wire piezometer (VWP) installations
- Laboratory testing of soil and rock samples

3.1 SOIL DRILLING

Overburden drilling was completed with the use of hollow-stem auger, solid-stem auger, and rotary wash drilling methods. Geotechnical logging of recovered materials was carried out in accordance with ASTM (American Society for Testing and Materials) D2488. In-situ penetration testing included 1.375-inch ID (internal diameter) Standard Penetration Tests, 2.5-inch ID Modified California, and 2.0-inch ID California tests. Blow counts were recorded for each six-inch interval of sampler penetration. Soil was also sampled by pitcher barrel, Osterberg, and Shelby tubes. Samples were sealed with paraffin and carefully transported to the off-site laboratory for testing (KRRC, 2019). Tube samplers were advanced by direct push or with a hydraulically activated piston sampler (Osterberg) and hydraulic gauge down pressures were recorded.

Geotechnical drilling data are compiled in Appendix A. Table A1.1 provides a summary of boring details, including the objective of each hole. Table A1.2 summarizes penetration test results. Logs of borings are found in Appendix A2.

3.2 BEDROCK DRILLING

Bedrock drilling was completed by HQ3 diamond coring. Geotechnical logging of recovered core samples was completed to collect the following:

- Lithology
- Rock mass conditions
- Rock structure, conditions, and frequency
- Drill run recovery
- Rock Quality Designation (RQD)

Bedrock core samples were also collected for off-site laboratory testing.

A note of interest was made in KRRC's report (2019) that a boring log was not created for BC-15 since drilling encountered bedrock within 1 ft of the ground surface.

Geotechnical drilling data are compiled in Appendix A. Table A1.1 provides a summary of boring details, including the objective of each hole. Logs of borings are found in Appendix A2. Photos of rock core are found in Appendix A3.

3.3 PACKER TESTING

Packer testing was completed in nine borings to estimate the hydraulic conductivity of bedrock formations for designing the tunnel alignment of the City of Yreka water line. A maximum test pressure of 1 psi per foot of depth to the center of the test section was selected to reduce the potential for hydrofracturing. Single and double pneumatic packer tests were performed, and the results are compiled in Appendix B.

Groundwater levels were measured during drilling, wherever possible, and prior to commencing each packer test. Groundwater depths are included in Table A1.1 (Appendix A).

3.4 PIEZOMETERS

Two vibrating wire piezometers were installed in two borings that were designated for the design of the City of Yreka water line. Each sensor was attached to a datalogger and KRRC (2019) indicated that groundwater level data would be reported elsewhere. Piezometer data has not been provided or requested because design of the City of Yreka water line falls outside the scope of KP.

3.5 TELEVIEWER SURVEYS

Downhole surveys were completed with an acoustic televiewer in two borings that were drilled to support the design of the City of Yreka water line. The objective of the surveys was to identify the orientation and spacing of structural features intersecting the holes. The survey data is included in Appendix C.

3.6 SOIL LABORATORY TESTING

Overburden samples from the borings were collected for the following geotechnical tests:

- Moisture Content (ASTM D2216)
- Moisture-Density-Porosity tests (ASTM D7263)
- Atterberg Limits (ASTM D4318)
- Particle-Size Distribution Analysis (ASTM D422, D1140)
- Consolidated Undrained Triaxial Compression Strength (ASTM D4767)
- Unconsolidated Undrained Triaxial Compression Strength (ASTM D2850)
- Consolidation (ASTM D2435)
- X-rays of samples
- Corrosion Testing (pH and Minimum Resistivity (CT 643), Sulfate (CT 417), and Chloride (CT 422))

Geotechnical laboratory data are compiled in Appendix D1. Table D1.1 summarizes soil index properties and strength parameters are summarized in Table D1.2. Table D1.3 summarizes the results of the corrosivity testing. Figure D1.1 summarizes the index properties and N-values for Iron Gate samples.

Figure D1.2 summarizes the index properties and N-values for Copco No. 1 samples. Laboratory data sheets are compiled in Appendix D2.

Index testing was completed for general characterization and involved samples collected from 26 borings that were drilled for rim stability, bridge foundations, and the City of Yreka water line design. Strength and consolidation testing were exclusively completed on diatomaceous samples collected for the reservoir rim stability assessment of Copco No. 1. Corrosion testing was completed exclusively for samples collected for assessing existing bridge foundations.

3.7 ROCK LABORATORY TESTING

Bedrock core samples were collected for the following geotechnical tests:

- Moisture Content (ASTM D2216)
- Bulk Density (ISRM 1977)
- Brazilian Tensile Strength (ASTM D3967)
- Point Load (ASTM D5731)
- Unconfined Compressive Strength (ASTM D7012)
- Mohs Hardness
- Punch Penetration (Colorado School of Mines – 13)
- Cerchar Abrasiveness (ASTM D7625)
- Petrographic Analyses

Geotechnical laboratory data are compiled in Appendix D1. Table D1.4 summarizes the general characterization results for rock samples that were collected from borings for investigating bridge foundations and the City of Yreka water line. Table D1.5 summarizes testing results specific to tunneling for select rock samples that were collected from borings for investigating the City of Yreka water line. Figure D1.3 summarizes bedrock geotechnical properties. Laboratory data sheets are compiled in Appendix D3.

4.0 PRELIMINARY SERVICES SITE INVESTIGATIONS

Additional site investigations were completed for Preliminary Services to supplement gaps identified during review of the Definite Plan and development of designs for removal of the four hydropower facilities. The objectives of the Preliminary Services investigations were to assess existing conditions and to acquire data to assist with the design of select project components. The existing conditions assessment focused on the diversion tunnels, the Scour Hole at J.C. Boyle, select locations of reservoir rims, select rock slopes, and construction access infrastructure. Investigations for design purposes included the foundation conditions of proposed disposal sites, potential borrow source areas, and construction access infrastructure.

The following investigations were undertaken from May 2019 through July 2020:

- Inspections of the diversion tunnels at Copco No. 1 and Iron Gate Dams
- Site reconnaissance of select areas of reservoir rims at J.C. Boyle, Copco No. 1, and Iron Gate
- Inspection of the Scour Hole at the J.C. Boyle Forebay area
- Test pitting of disposal sites proposed in the Definite Plan and corresponding laboratory testing
- Site reconnaissance of select rock slopes at J.C. Boyle, Copco No. 1, and Copco No. 2
- Drilling and test pitting for potential road improvements and modifications to bridges and culverts
- Test pitting of potential on-site borrow sources and corresponding laboratory testing

4.1 DIVERSION TUNNEL INSPECTIONS

Inspections of the diversion tunnels at Copco No. 1 and Iron Gate dams were completed in July 2019. The focus of the inspections included the general condition of rock exposures inside the tunnels and at the portals, support elements (liner, bolts, etc.), seepage, structural mapping, and documenting rock mass quality parameters under the Q-System (NGI, 2015). A letter report summarizing the inspections and their findings is included in Appendix E. The inspection results are qualitative in nature due to the limited time allowed for site access.

4.2 RESERVOIR RIM RECONNAISSANCE

Site reconnaissance of select areas of the reservoir rims of the J.C. Boyle, Copco No. 1, Copco No. 2, and Iron Gate facilities was completed in July 2019. The targeted site reconnaissance was guided by and supported terrain hazard analyses completed for each reservoir rim. Data from the site reconnaissance consisted exclusively of photographs. The findings and site photo-documentation are summarized in the Reservoir Rim Stability Report (KP, 2020b).

4.3 J.C. BOYLE SCOUR HOLE

A visual inspection of the scour hole, which developed during operation of the J.C. Boyle facility, was completed in July 2019. Safety concerns restricted site access to the top of the hole, behind a security fence. Data collected from the inspection consisted of photographs and field notes that are summarized and compiled in Appendix F.

4.4 DISPOSAL AREA TEST PITTING

A test pit program was completed in January and February 2020 to characterize soil geotechnical properties in support of the design of disposal sites at the four hydropower facilities. The program also investigated potential borrow sources at Copco No. 1 and Copco No. 2.

The site investigation included excavation, hand-collected grab samples, soil logging, photo-documentation, and laboratory testing of select soil samples. Eleven test pits were excavated at the Californian facilities (Copco No. 1, Copco No. 2, Iron Gate) and seven were excavated at the Oregonian facility (J.C. Boyle). The test pits were excavated with an excavator to depths, ranging from 5 ft to 15 ft, based on pit wall stability or refusal.

The objectives of the laboratory testing were to determine index properties and to assess the chemical composition and durability of the proposed borrow areas. The following tests were completed:

- Particle Size Distribution Analysis (ASTM D6913, D7928)
- Atterberg Limits (ASTM D4318)
- Moisture Content (ASTM D2216)
- Modified Proctor (ASTM D1557)
- Specific Gravity (ASTM D854, C127)
- Los Angeles Abrasion (ASTM C131)
- Slake Durability (ASTM D4644)
- Modified Acid Base Accounting
- Synthetic Precipitate Leaching Procedure (EPA 1312)

Details of the test pit program, location maps, test pit logs, photographs, and laboratory results are included in Appendix G.

4.5 SELECT ROCK SLOPES

Rock slopes adjacent to various components of the J.C. Boyle, Copco No. 1, and Copco No. 2 facilities were inspected in July and December 2019. These include slopes that were excavated to construct the facilities and roads as well as natural terrain slopes upslope from the facilities and roads. The following areas were evaluated:

- J.C. Boyle power canal
- J.C. Boyle access road to penstocks
- Copco No. 1 and Copco No. 2 dam access roads at the right abutments
- Copco No. 2 Dam access road to left abutment and wood-stave penstock
- Copco No. 2 Dam left abutment slope (remnant timber-cribbed rock fall protection)

Data collected from the inspection consisted exclusively of photographs. Findings of the site reconnaissance and preliminary terrain hazard assessments are summarized in Appendix H.

4.6 CONSTRUCTION ACCESS INFRASTRUCTURE

Two site investigations were completed for assessing the proposed construction access infrastructure. The first investigation was completed in December 2019 and evaluated the surface asphalt and subgrade condition of Copco Road. The second investigation was completed in June 2020 and evaluated the ground conditions at various bridges and culverts at Copco No. 1 and Iron Gate. Laboratory testing was also completed as a part of the second site investigation.

Approximately 18 miles of Copco Road, from the Klamath Bridge to the intersection of the Copco No. 1 Dam access road, was investigated by drilling 18 borings and surveying both traffic lanes with ground penetrating radar. Asphalt was drilled with a 6-inch diamond coring bit and the subgrade was drilled using a 6-inch hollow stem auger. Boring depths ranged from less than 1 ft to 8 ft below ground surface. Standard penetration tests (ASTM 1586) were performed at regular intervals in each drillhole. The site investigation details and results are summarized in Appendix I1.

Ground conditions near bridge and culvert crossings at seven locations at Iron Gate were investigated January through April 2020. Drilling of 18 borings (depths of 2 ft to 35 ft) was completed with a 6-inch hollow stem auger. Standard penetration tests (were performed and bulk samples were collected from each boring. The following lab tests were conducted:

- Particle Size Analysis (ASTM D6913)
- Proctor Compaction Testing (ASTM D1557)
- Atterberg Limits (ASTM D4318)
- Direct Shear (ASTM D3080)

These site investigation details and results are summarized in Appendix I2.

4.7 BORROW SOURCES FOR RIPRAP AND GRANULAR FILL

A site investigation was completed in May 2020 to identify possible onsite borrow sources for riprap (erosion protection) and granular fill (riverbed and bedding materials) at each of the four facilities. The investigation was limited to surficial inspections (no subsurface excavations) and laboratory testing of select grab samples. The objectives were to determine material type, particle size and distribution, durability, and geochemical characteristics.

The following lab tests were proposed:

- Particle Size Analysis (ASTM D6913)
- Point Load (ASTM D5731)
- Micro-Deval (ASTM D6928)
- Magnesium Sulphate Soundness (ASTM C88)
- Specific Gravity and Absorption (ASTM D6473)
- Modified Acid Base Accounting
- Synthetic Precipitate Leaching Procedure (EPA 1312)
- X-Ray Diffraction (XRD)

Details of the site investigation, location figures, photographs, field assessment results, and laboratory results are included in Appendix J.

5.0 LIMITATIONS

This geotechnical data report consists of a summary of all geotechnical work completed and data collected for the Klamath River Renewal Project that was made available to and acquired by KP. This report is factual in nature based on the information received and collected on the respective dates and is presented with no to little interpretation. The data collected were and the information presented are consistent with industry practice and a standard of care that is ordinarily exercised by the respective professions based on the scope of work prescribed by the client.

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7.0 CERTIFICATION

This report was prepared and reviewed by the undersigned.

Prepared: ______________________________
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Approval that this document adheres to the Knight Piésold Quality System: CN