Submitted to
Nevada Irrigation District
1036 W. Main Street
Grass Valley, CA 95945

Submitted by
AECOM
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August 30, 2017

Nevada Irrigation District Centennial Reservoir Project Geotechnical Engineering Report - Phase III – Final

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August 30, 2017

Nevada Irrigation District
1036 W. Main Street
Grass Valley, CA 95945

Attention: Mr. Doug Roderick, P.E.

Subject: Centennial Reservoir Project
Geotechnical Engineering Report
Phase III - Final

Dear Mr. Roderick:

We are very pleased to submit this final Phase III Geotechnical Engineering Report for the Centennial Reservoir Project located near Grass Valley, California.

In accordance with the scope of work authorized under Task Orders 5 and 8, the Phase III geotechnical investigation focused on foundation characterization for roller-compacted concrete (RCC) dam design at Axis 2. Borrow investigations were carried out to confirm the nature and depth of the available rock materials for use as RCC aggregate including the amount of overburden that would need to be stripped and wasted. This Phase III Geotechnical Engineering Report builds on and incorporates the results of the previous Phase I and II reports.

This Phase III Report presents the following:

- An overview of the geologic setting and site conditions
- Seismic source characterization, historical seismicity, deterministic seismic ground motion parameters, and reservoir triggered seismicity
- Geologic characterization of soil and rock formations, rock conditions and geologic hazards.
- Field geotechnical investigation and laboratory testing results
- Characterization of dam foundation conditions
- Characterization of potential on-site rock borrow areas
- Conclusions and recommendations.

The rock characterization at Axis 2 as described in this report will be used to inform further decision making on the design of the dam foundation and its treatment. The recommended dam foundation configuration and treatment is the subject of the Conceptual Engineering Report.

Thank you for the continued opportunity to assist the NID on this very important project. We are available to discuss any questions or comments you may have on this report. Please contact me at (510) 874-3012 if you would like to schedule a time to meet.

Sincerely,
AECOM Technical Services, Inc.

M.P. Forrest

M.P. Forrest, P.E., G.E.
Project Manager

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MICHAEL PAUL FORREST
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STATE OF CALIFORNIA

Michael Paul Forrest
2/17/20

Enclosure:
Centennial Reservoir Project, Geotechnical Engineering Report
Phase III – Final

Cc: Noel Wong, Ted Feldsher, Dave Simpson (AECOM)

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List of Acronyms

ASTM	American Society for Testing and Materials
CFR	concrete-faced rockfill
CGS	California Geologic Survey
CRP	Centennial Reservoir Project
DSHA	deterministic seismic hazard analysis
DSOD	California Division of Safety of Dams
ft	feet, foot
ft/s	feet per second
g	acceleration of gravity
GIWP	Geotechnical Investigation Work Plan
GPS	global positioning system
ICOLD	International Committee on Large Dams
km	kilometer
LCI	Lettis Consultants International, Inc.
M	moment magnitude
m_b	body-wave magnitude
M_L	Richter local magnitude
NID	Nevada Irrigation District
PEER	Pacific Earthquake Engineering Research
PGA	peak ground acceleration
PSHA	probabilistic seismic hazard analysis
psi	pounds per square inch
P-wave	compressional wave
RCC	roller compacted concrete
RQD	rock quality designation
RTS	reservoir triggered seismicity
S-wave	shear wave
USBR	United States Bureau of Reclamation
UCS	unconfined compressive strength
USCOLD	United States Committee on Large Dams (now United States Society on Dams)
USGS	United States Geological Survey
WGNCEP	Working Group on Northern California Earthquake Probabilities

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1 Introduction

1.1 Background

The Nevada Irrigation District (NID) is undertaking engineering and planning studies for a proposed water storage reservoir located on the Bear River between the existing Rollins and Combie Reservoirs, which are also owned and operated by NID. In order to advance the engineering for the proposed project, called the Centennial Reservoir Project (CRP), the NID retained AECOM to perform a study of the site, including geologic mapping and geotechnical investigations, to assist in identifying preferred dam axis locations and preferred dam types for further study. The study, which is documented in this report, was carried out in several phases as authorized under the agreement between AECOM and NID dated April 15, 2015.

The proposed dam site on the Bear River was first identified and evaluated by NID in the 1920's (Tibbetts, 1926). The dam site area is located in Nevada County on the north side of the Bear River and in Placer County on the south side. The site area lies at the upstream end of Combie Reservoir and about 7 miles downstream from Rollins Dam (Figure 1-1). NID has identified a storage capacity objective of 110,000 acre-feet for the site. This corresponds to a maximum normal reservoir water surface of approximately Elevation 1855 feet. Retaining a reservoir at this elevation would require a dam height of approximately 275 feet above the Bear River, depending on the dam type, spillway design, and freeboard criteria.

Two potentially viable dam types were initially identified in the study, roller compacted concrete (RCC) and concrete faced rockfill (CFR). Two potential dam axis alignments were also identified, referred to as Axis 2 and Axis 6. The two dam types and two dam axis alignments were discussed in the Phase II Report (AECOM, 2016a).

The Phase I studies included an assessment and characterization of the foundation soil and rock conditions along the identified potential dam axis alignments, along with a discussion of the preferred axis locations and dam types considered most viable for the site. The Phase I report also presented a recommended program of subsurface investigations (AECOM, 2015).

The geotechnical site investigations were carried out under Phases II and III and are documented in this report. The Phase II investigation objectives were to further characterize and confirm the subsurface conditions along the most favorable axis locations and to assess the foundation suitability for construction of the most viable dam types. The Phase III investigations focused on one preferred dam type at one preferred axis location.

This Phase III Geotechnical Engineering Report builds on the results of the Phase I and II reports and incorporates the relevant results from those two previous phases of the study. Phase III scope was authorized under Task Order No. 5 (April 20, 2016) and Task Order No. 8 (September 19, 2016).

1.2 Summary of Previous Studies

This section summarizes the Preliminary Geotechnical Investigation, Phase II Report – Final (AECOM, 2016a) and the Conceptual-level Opinion of Probable Construction Cost (AECOM, 2016b). Those two reports provide the basis for selection of the preferred dam site and preferred dam type.

1.2.1 Phase II Preliminary Geotechnical Investigation, Phase II Report – Final

The Phase II report concluded that both Axis 2 and Axis 6 were acceptable from a geotechnical standpoint for either an RCC dam or CFR dam (AECOM, 2016a). Fatal flaws were not identified at either site. Both dam types were judged to be suitable for the site based on the observed foundation conditions. Rock materials suitable for both RCC gravity dam aggregates and a CFR dam were judged likely to be available within the reservoir area and/or from the nearby Bear River Quarry in sufficient quantities for either dam type. The main geotechnical differences between the two sites are the extent of foundation excavation and treatment that would be required, which in turn would affect construction cost.

For the same reservoir water surface Elevation 1855 feet, the reservoir capacity would be about 7,000 acre-feet less for a dam at Axis 6 than further downstream at Axis 2. Alternatively, a dam at Axis 6 would need to be about 3 feet higher in order to offer the same reservoir storage capacity as a dam at Axis 2.

1.2.2 Conceptual-level Opinion of Probable Construction Cost (OPCC)

To assist in evaluation of potential cost differences between the dam types and dam sites, OPCC's were developed for roller compacted concrete (RCC) dam and concrete faced rockfill (CFR) dam alternatives, at each of the two site locations considered (Axis 2 and Axis 6) (AECOM, 2016b). The OPCC's and conceptual-level design layouts were developed based on the available geotechnical information presented in the Phase II Report (AECOM, 2016a).

As part of preparing the OPCC's, conceptual level construction schedules were prepared for each dam type to provide a comparative assessment of the relative construction durations of the RCC and CFR alternatives. The schedules indicated that the RCC dam could potentially be constructed in about 2½ years, but the CFR dam would take about 4 years to construct.

The conclusion of the conceptual-level OPCC study was that the RCC dam at either axis is expected to have a lower estimated construction cost than the CFR dam type. The RCC dam at Axis 2 is expected to have the lowest construction cost of the alternatives considered, at about 75% to 80% of the cost of the CFR dam (AECOM, 2016b).

1.3 Preferred Dam Site and Dam Type

Based on the Phase II report and the conceptual-level OPCC, an RCC dam at Axis 2 was identified as the preferred alternative, for the following main reasons:

- Axis 2 would have a 3-foot lower reservoir elevation to store the same reservoir volume of 110,000 acre-feet. This lower elevation would reduce the level of inundation around the reservoir rim.
- The RCC dam alternative at Axis 2 has the lowest expected construction cost of the alternatives. One reason for the lower cost is that the spillway and outlet works can be incorporated into the body of the RCC dam. These costs were significant for the CFR dam alternative.
- The RCC dam could be constructed in less time than a CFR dam.
- The RCC dam would have a much smaller footprint area than a CFR dam, which is beneficial from an environmental standpoint.
- The RCC dam would be much more capable of withstanding flood overtopping during construction than would a CFR dam.

Based on the above points, an RCC dam at Axis 2 was recommended as the preferred dam type and axis location for the Centennial Reservoir Project. The Phase III investigations focused on this dam type and site location.

1.4 Purpose and Scope of Report

The original Phase III scope of work included geotechnical investigations at both Axis 2 and Axis 6. However, NID subsequently decided to focus on Axis 2 for the reasons noted above in Sections 1.2 and 1.3. The Phase III dam site geotechnical investigations, focused on Axis 2, are the subject of this geotechnical engineering report. If needed, geotechnical information on Axis 6 can be found in the prior Phase II report (AECOM, 2016a).

The geotechnical investigation at the selected dam site (Axis 2) was aimed at evaluating rock weathering depths, fracturing and hydraulic conductivities of the rock foundations. Borrow investigations were carried out to confirm the nature and depth of available rock materials in potential borrow sites, including an assessment of the amount of overburden that may need to be stripped and wasted.

The Phase III geotechnical investigations at Axis 2 and in the potential rock borrow areas were conducted in accordance with the Phase III Geotechnical Investigation Work Plan (GIWP, AECOM, 2016c). The GIWP describes the goals of the investigation, the exploration locations and depths, drill site access, procedures, drilling methods, and the instrumentation and in-situ testing methods.

The Phase III geotechnical investigation included the following tasks:

- Supplementary site reconnaissance and geologic outcrop mapping in the area of Axis 2 and the potential rock borrow areas upstream of the dam site.
- Seismic refraction surveys in the area of Axis 2 and in the potential rock borrow areas.
- Core borings drilled in the area of Axis 2 and in the potential rock borrow areas.
- Downhole testing included water pressure (packer) testing and televiewer/caliper logging in the dam foundation borings and downhole P-wave velocity measurements in the rock borrow area borings.
- Laboratory testing on selected rock core samples from the dam site and potential rock borrow areas for unconfined compression strength testing and rock core samples selected from the rock borrow borings for abrasion resistance, soundness, bulk specific gravity and moisture absorption.
- Preparation of this Geotechnical Engineering Report, to incorporate and build upon the Phase II report with the results of the Phase III investigations.

1.5 Organization of Report

After this introductory section, this report is organized into the following sections:

- Section 2 presents an overview of the geologic setting and site conditions based on a data review.
- Section 3 discusses seismic source characterization, historical seismicity, deterministic seismic ground motion parameters, and reservoir triggered seismicity.
- Section 4 discusses geologic characterization of soil and rock formations, soil conditions, rock conditions (e.g., rock units, weathering, and joints and fractures), and geologic hazards.
- Section 5 discusses the field geotechnical investigation (core drilling and geophysics) and laboratory testing programs for Phases II and III.
- Section 6 describes the dam foundation conditions as revealed by the investigations.
- Section 7 discusses potential on-site construction materials sources.
- Section 8 presents conclusions and recommendations.
- Section 9 lists the references used to prepare this report.

1.6 Acknowledgements

The following key AECOM personnel performed the work for this Phase II Report:

- Project Manager: Michael Forrest, P.E., G.E.
- Principal-in-charge: Noel Wong, P.E.
- Geologic Mapping: David Simpson, C.E.G.; Ben Kozlowicz, C.E.G; and Julien Waeber-Cohen, C.E.G.
- Logging of core borings: Sheri Janowski, C.E.G., Ben Kozlowicz, C.E.G, and Kate Zeiger.
- Seismologic Investigation: Ivan Wong, Patricia Thomas, Ph.D., and Judith Zachariasen, Ph.D.
- Geotechnical Engineering: Josh Zupan, P.E., Ph.D.
- Independent Technical Review: Theodore Feldsher, P.E., G.E.

Lettis Consultants International (LCI), of Walnut Creek, California, performed an independent evaluation of the potential for active faulting in the Centennial Reservoir study area.

Holdrege & Kull, of Nevada City, California, conducted laboratory testing on rock cores from the dam foundation and rock borrow areas.

Norcal Geophysical, of Cotati, California, performed the seismic refraction surveys and downhole geophysics (televiewer logging, caliper logging, and P- and S-wave measurements).

Ruen Drilling, of Modesto, California (main office in Clark Fork, Idaho), performed the core drilling.

The Nevada Irrigation District coordinated site access, constructed drill rig pads, cleared access routes to drill sites, and cleared the seismic refraction survey line areas.

1.7 Limitations

The professional judgments presented in this report regarding the site conditions are based on information obtained from reference data review, geologic mapping, and phased geotechnical investigations.

AECOM represents that its services were conducted in a manner consistent with the standard of care ordinarily applied as the state of practice in the profession within the limits prescribed by our client. No other warranties, either expressed or implied, are included or intended in this report.

2 Geologic Setting and Overview of Site Conditions

2.1 Reference Sources

This section describes the geologic setting and overview of site conditions, based on a literature review. The results of this work formed the basis for the site-specific reconnaissance, geologic mapping and geotechnical investigation that followed. Data was obtained for review from sources including NID, the California Geologic Survey (CGS), the United States Geological Survey (USGS), and others. The reviewed data included relevant mapping, published and unpublished documents, and available NID documents pertaining to the project site and other sites in the vicinity. Specific items reviewed included but were not limited to the following:

- Regional and local geologic and tectonic characterizations
- Data pertaining to material properties at and around the site
- Geologic and geotechnical evaluations of Rollins and Combie dam sites (within a 10 mile radius) and their construction records
- Available ground surface imagery and topographic data for remote characterization of the site specific geomorphology
- Available subsurface data from other sites in the region for preliminary characterization of the site-specific rock mass properties.

The reference documents reviewed for this effort included the following:

- Berlogar Geotechnical Consultants, Seismic Deformation Analysis of Rollins, Dutch Flat Forebay and Dutch Flat Afterbay Dams, March 1997.
- Chandra, D., Geology and Mineral Deposits of the Colfax and Foresthill Quadrangles California, Special Report 67, California Division of Mines, 1961.
- Civil drawings and construction records for Combie Dam, beginning 1927.
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- Cramer, C., Toppozada T., Parke D., Seismicity of the Foothills Fault System between Folsom and Oroville California, California Geology, California Division of Mines and Geology, August 1978.
- Day, H.W., Moores E., Tuminas A.V., Structure and Tectonics of the Northern Sierra Nevada, Geologic Society of America Bulletin, v. 96, p. 436-450, April 1985.
- Day, H.W. and Bickford M.E., Tectonic Setting of the Jurassic Smartville and Slate Creek Complexes, Northern Sierra Nevada California, GSA Bulletin, v. 116, p. 1515-1528, November/December 2004.
- Dupras, D., Chevreaux J. Jr., Lake Combie Specialty Sands and Gravels, Placer County, California Geology, California Division of Mines and Geology, November 1984.
- Engeo, Combie Dam Geotechnical Report, 2013.
- Geomatrix Consultants, Review of Seismic Stability of Rollins and Dutch Flat Afterbay Dams, August 1999.
- Hamilton, D. H., Seismotectonic Review and Evaluation for Nevada Irrigation District Dams, March 2007.
- James, A., Time and the Persistence of Alluvium: River Engineering, Fluvial Geomorphology, and Mining Sediment in California, Geomorphology, 31, p. 265-290, 1999.
- LiDAR Data, prepared by ECorp for NID, November 2014.
- Mark Group, Preliminary Design of Modifications to Combie Dam, May 1990.
- Marliave, C., Rollins Dam Site, Letter Report 1933.
- Nevada Irrigation District, Bear River Soil Survey Data.
- Norcal Geophysical Consultants, Seismic Refraction Investigation Combie Dam, Report, April 2013.
- Norcal Geophysical Consultants, Geophysical Investigation Rollins Reservoir Bear River Arm, August 2014.
- PG&E, Earthquake Magnitude Evaluation of Potential Seismic Sources for Rock Creek (Drum) Dam, June 1991.
- QEST Consultants, Stability Analysis of Combie Dam FERC Project No. 2981, March 1987.
- Tibbetts, F., Bear River Diversion and Storage, study for Nevada Irrigation District, February 1926.
- Tuminas, A. V., Structural and Stratigraphic Relations in the Grass Valley-Colfax Area of the Northern Sierra Nevada Foothills California, PhD Dissertation, University of California Davis, 1983.

2.2 Regional Geologic Setting

The proposed site for the CRP is located on the Bear River, Nevada and Placer Counties, California, in the Central Belt of the northern Sierra Nevada geomorphic province. An excerpt from the Geologic Map of Grass Valley-Colfax Area (Tuminas, 1983) is included on Figure 2-1. The proposed reservoir plan, dam site area and potential rock borrow areas are shown on Figure 2-2.

In the dam site area, the Central Belt is described as being "composed of diverse ultramafic, plutonic, volcanic, and sedimentary rocks that have been variably metamorphosed at low or medium grade, affected by one or more periods of isoclinal folding, disrupted by numerous faults, and intruded and metamorphosed by granitic plutons of the Late Jurassic to Early Cretaceous age" (Day, et al., 1985). The site is located on the eastern limb of the Lake of the Pines Syncline, within the upper stratigraphic section of the Lake Combie Complex. The bedrock at the site is composed of the Lake Combie Upper and Middle volcanoclastic and epiclastic units which include massive flow rock, flow breccia and sandstones, with bedding dipping slightly to the west. Regional sub-vertical fracture planes dipping to the west have also been reported (Tuminas, 1983). Based on massive granitic intrusions located less than 3 miles southwest of the site, the bedrock is also expected to be metamorphosed to varying degrees with a potential for local plutonic intrusions. Field observations confirm that the site area is located within a massive meta-volcanic unit with bedding and fracture attitudes consistent with previous reports.

The project site area is also bounded to the east and west by the Weimar Fault Zone and the Wolf Creek Fault Zone respectively, which are both part of the greater Foothills Fault System (see Section 3). The Weimar Fault zone is approximately 1.25 miles (2 km) due east of the site, while the Wolf Creek Fault Zone is approximately 3.75 miles (6 km) due west. Both fault zones trend NNW, are steeply dipping both east and west and have varying thicknesses of 300 feet to 2.5 miles. Historically, the region is likely to have experienced multiple phases of faulting, beginning with an overthrust with east directed movement, then dip-slip reverse movement, followed by right lateral strike slip movement and reverse or oblique reverse movement (Tuminas, 1983). Though the Weimar Fault Zone is not believed to have been active during the Quaternary (1.8 million years ago), the Wolf Creek Fault Zone is believed to have been active within the Late Quaternary (700,000 years ago). A seismotectonic discussion of the project area is included in Section 3.

2.3 Local Geologic and Geomorphic Setting

2.3.1 Geologic Setting

In addition to the regional geologic setting described above (Tuminas, 1983; Day, 1985 and 2004), a site-specific geologic setting was developed based on additional review of local geotechnical and geological data from nearby dam sites (Combie and Rollins Dams) and rock mass data from a quarry adjacent to the site. A quarry located approximately ½ mile south-southwest of the site provides clear exposures of rock structure. Based on surface exposures and on limited subsurface data made available by the quarry, the local bedrock is generally characterized as hard to very hard massive greenstone or meta-basalt and meta-volcanic breccia, metamorphosed to varying degrees (predominantly lightly). Structurally, the bedrock generally dips to the west with prominent sub-vertical discontinuities trending generally north-south and east-west.

Combie and Rollins Dams are both situated within a 10 mile radius from the CRP site. Combie Dam is located approximately 3 miles downstream on the Bear River and Rollins Dam is located approximately 7 miles upstream. The investigation and construction records for each dam generally confirm the regional geologic setting and similar local geologic features to those described above.

2.3.2 Geomorphic Setting

Ortho-photographic imagery and a LiDAR produced digital elevation model for the project site were reviewed. The reviewed aerial photographs are summarized in Table 2-1. A preponderance of lineaments observed in the aerial photographs and LiDAR trend north-northwest, with the longest and most prominent being located west and northwest of the dam site and spatially associated with faults of the Foothill fault system. These lineaments range in length from approximately 1 to 30 km. There are also a series of relatively short, and closely-spaced, roughly east-west-trending and northwest-southeast-trending lineaments located orthogonal to each other and at a high angle to the overall regional tectonic pattern. This pattern is readily recognizable in the multiple abrupt bends in the Bear River that appear to control, at least in part, the location of the drainage.

The valley morphology presents generally steeper east- and south-facing slopes ranging from approximately 2 horizontal:1 vertical (2H:1V) to subvertical cliffs of rock outcrops in comparison to flatter north- and west-facing slopes which are generally flatter than 2H:1V with occasional vertical cliffs formed by outcropping rocks.

In the area north of the Bear River, roughness in the terrain made apparent by the LiDAR data is indicative of shallow bedrock along a majority of the slopes. The air photos also confirm steep rock outcrops at the southern end of the site defining a prominent ridge at proposed Dam Axis 2 and extending approximately 200 feet above the Bear River. In the area south of the Bear River, smoother slopes in the LiDAR data suggest generally thicker residual soil deposits. The data also confirms a lower lying east-west trending outcrop of steep rock in the southern portion of the site near Axis 2 extending approximately 100 feet above the Bear River.

The geologic setting at the site is generally reflected by the LiDAR and aerial photograph data. Steeper east facing slopes are indicative of west-dipping bedding where west facing slopes may be flatter due to dip-slope conditions. The Bear River also makes a series of relatively orthogonal bends trending generally north-south and east-west, which are likely controlled by the bedrock structure and regional shears.

Several anomalous geomorphic features are evident from the LiDAR data. On the south side of the Bear River, upstream of the dam site, a landslide deposit is apparent above the outside bend of the river where it sharply turns west through the site. Approximately 1000 feet downstream of the slide area on the south side of the river, a topographic swale is evident, suggesting a thick colluvial deposit at the top of a natural drainage path. On the north side of the Bear River, there is a large debris deposit upstream of the dam site, which may have been man-made. Some evidence of historic mining activities exists in the site area, which may account for several of the observed geomorphic anomalies. Details on these and other geologic site features are presented in Section 4.

Table 2-1. Aerial Photographs Reviewed

Film ID	Line	Frame	Scale	Date
AV 4130	20	8/9	1:63360	09-12-91
AVP 4095	12	56/57	1:36000	07-30-91
AV 3600	20	1	1:63300	05-05-89
AV 3192	15	1	1:40000	11-15-87
GS-VFLL-C	1	4/5/6	1:24000	07-26-87
GS-VDXQ	1	9/10	1:80000	08-29-75
GS-CW	5	148/149/150	1:28400	02-22-47

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3 Seismologic Investigation

This section presents the preliminary seismologic investigation completed for the project site. The scope included the following elements: (1) seismic source characterization, (2) historical seismicity, (3) deterministic seismic ground motions, and (4) evaluation of the potential for reservoir triggered seismicity. Details of the seismologic investigation are presented in Appendix A-1 and summarized below.

3.1 Seismic Source Characterization

3.1.1 Foothills Fault System

The west-central portion of the Sierra Nevada block, which includes the proposed CRP site, contains late Cenozoic faults that have reactivated portions of the 360-km long Mesozoic Foothills fault system (Page and Sawyer, 2001). The Foothills fault system is complex and its paleoseismic history is still not well known. The faults of the Foothills fault system nearest the project site are the Wolf Creek-Big Bend fault, approximately 6 km west of the project site, and the Weimar fault, is approximately 2 km east of the project site.

3.1.2 Lineament Observations

The study included review of LiDAR data in the immediate vicinity of the project site as well as review of 1975 and 1978 U.S. Geological Survey (USGS) black and white stereo aerial photography over a wider region encompassing the breadth of the Foothills fault system and extending about 25 km north and south of the project site.

Based on the analysis of the photographs and the LiDAR, a preliminary lineament map was developed (see Appendix A). The mapped lineaments include topographic lineaments, along with vegetation and tonal lineaments. These are in places associated with linear erosion features, linear drainages, topographic steps, and range fronts. The mapped lineaments may be associated with faults, but lineaments can also be produced by other processes including fluvial and gravitational processes, differential erosion of different rock types, and jointing.

The analysis shows that many of the longer and more prominent lineaments are coincident with previously mapped faults of the Foothills fault system. In addition to these long lineaments, numerous shorter and less prominent lineaments were also observed. However, due to the short lengths of these features, and the lack of apparent continuity between them, they were concluded not to represent new (unmapped) tectonic faults in the study area. This analysis was conducted at a relatively small scale, and has a relatively high degree of confidence.

3.2 Historical Seismicity

The area of the proposed dam site has experienced very few historical earthquakes (see Figure 3-1). The only reported events of magnitude **M** 5.0 or larger within 65 km of the proposed dam site during the time period from 1855 to 2014 are the following:

- August 1, 1975: Richter local magnitude (ML) 5.7 (body-wave magnitude, mb, 5.9) Oroville earthquake that occurred about 60 km to the northwest of the proposed dam site.
- September 12, 1966: M 5.9 earthquake occurred near Boca, California, a distance of 55 km east-northeast of the proposed dam site.
- March 3 and June 23, 1909: Two M ≥ 5 events occurred 41 and 44 km northeast of the dam site. These events include a ML 5 earthquake on March 3 and an M 5.5 event (unknown magnitude scale) on June 23.

3.3 Deterministic Seismic Ground Motions

3.3.1 Earthquake Magnitude

The maximum earthquake for any fault within the Foothills fault system is considered to be M 6.5 with a surface rupture length of less than 20 km. This is consistent with the maximum magnitude considered by the Working Group on Northern California Earthquake Probabilities (WGNCEP, 1996), Schwartz et al. (1996), Page and Sawyer (2001), and the 2008 USGS National Hazard Maps (Petersen et al., 2008).

3.3.2 Deterministic Seismic Hazard Analysis and Preliminary Seismic Design Parameters

As discussed above, the closest faults to the site are the Wolf Creek-Big Bend and Weimar faults of the Foothill fault system. A deterministic seismic hazard analysis (DSHA) was performed to develop preliminary design ground motions for the proposed dam site. To carry out the DSHA, site-specific 5%-damped median, 69th and 84th percentile horizontal acceleration response spectra were developed for a maximum earthquake of **M** 6.5 on the Wolf Creek fault.

To estimate the ground motions, recently developed ground motion prediction models appropriate for tectonically active crustal regions were used. The crustal models were developed as part of the NGA-West2 Project sponsored by Pacific Earthquake Engineering Research (PEER) Center Lifelines Program.

The 69th percentile deterministic spectra developed for each of the four ground motion prediction models along with the geometric mean are presented in Appendix A-1. The median, 69th and 84th percentile geometric mean deterministic spectra are also compared in Appendix A-1. The median, 69th and 84th percentile peak horizontal ground accelerations (PGAs) are 0.23, 0.31 and 0.42 g, respectively.

Based on DSOD guidelines (Fraser and Howard, 2002), the minimum earthquake peak ground acceleration (PGA) for new and existing dams should be 0.25 g. Considering this, AECOM recommends the use of 69th percentile deterministic ground motions for design of the proposed dam (i.e., 0.31 g). This is consistent with DSOD guidelines and recommendations by U.S. Committee on Large Dams (1985; 1998).

3.4 Reservoir Triggered Seismicity

In California, at least eight reports exist of possible reservoir triggered seismicity (RTS) (Wong and Strandberg, 1996; Knudsen *et al.*, 2009). Perhaps the most notable of these cases is Lake Oroville, which may have triggered the occurrence of the 1975 M_L 5.7 Oroville earthquake (Toppozada and Morrison, 1982). Lake Oroville is located in a setting that is geologically, tectonically and seismically similar to NID's proposed CRP, so the risk of RTS needs to be considered.

For the purposes of evaluating the risk of RTS, the proposed CRP would be classified as a shallow and small reservoir (see Appendix A for classification criteria). Although lineaments have been mapped in the proposed reservoir area, including a possible continuation of the Weimar fault, no historical seismicity has been observed in the vicinity of the proposed reservoir. Based on these factors and on previous analyses for other sites, it appears that RTS has a low probability of occurrence at the proposed reservoir site, but should nonetheless be considered for design.

The RTS earthquake recommended for design is an **M** 6.5 event, which is consistent with the maximum event assigned to faults within the Foothill fault system as described above in Section 3.3. This RTS event is also consistent with the background seismicity considered significant to the reservoir, and is therefore not expected to control the design.

4 Geologic Characterization of Soil and Rock Formations

4.1 General

The proposed Axis 2 dam site area is located on the Bear River with the right abutment on the north bank of the river and the left abutment on the south bank. The abutment slopes are moderately steep to sub-vertical, forested, and drained by steep ephemeral gullies and stream channels. Surface observations indicate that the site is primarily underlain by variably weathered and metamorphosed basaltic rock. Active faults are not mapped by CGS or USGS at the site and none have been identified during current studies at the site. Four landslide deposits were observed in the vicinity of the proposed dam site but none is within the dam footprint.

4.2 Geologic Mapping

Geologic field mapping of the project site was performed in June and July 2015 (Phase II) and in July, August and October 2016 (Phase III). The results of the geologic mapping at the dam site are presented on Figure 4-1. Mapping at the potential borrow areas, located to the northeast of Axis 2, is presented on Figure 4-2. These maps show geologic outcrops and geologic structural data overlain on a LiDAR-derived topographic map, along with the locations of the seismic refraction survey lines and exploratory core borings (discussed in Section 5).

The geologic field mapping was performed to confirm and augment the findings from the background data review and subsurface investigations. The mapping effort consisted of walking traverses across the site and visiting specific areas of interest for more detailed observation. The field mapping effort was facilitated by NID, who cleared brush to allow access along key pathways. Along each traverse, bedrock outcrops were characterized based on the rock type, degree of weathering, and discontinuity orientations. The collected data was compiled electronically using a hand-held GPS and was also recorded on a topographic base map. Compiled data are presented in Appendix B. Steep terrain, heavy brush, and the presence of water in the river limited access to significant portions of the site area and the indicated contacts between mapped units are therefore approximate.

4.3 Surficial Conditions

4.3.1 Soils and Bedrock Weathering

During the geologic mapping effort, observations of surficial soil deposits were made primarily along road cuts and deeply incised runoff channels. The soil deposits appear to thicken with increasing elevation above the Bear River, but are generally thin throughout the site, as confirmed by the presence of many bedrock outcrops. Soils exposed in road cuts varied from sandy silt to sandy clay to silty sand, with gravel and bedrock fragments throughout and increasing frequency with depth. The soils represent a typical colluvial/residual weathering profile, and are a product of weathering of the underlying rock. Photograph 1 illustrates a typical section of bedrock and shallow residual soil observed within a road cut near the CRP site.

4.3.2 Alluvium

The sands and gravels currently in Lake Combie and the Bear River channel are primarily a result of gold mining in the early 1880's (Dupras, 1984). These operations used hydraulic mining procedures to process large amounts of channel sands and gravels within 20 miles upstream of the CRP site. The deposit is naturally sorted by fluvial activity, resulting in high quartz content, hard, well-rounded sand, gravel and cobbles. The original construction drawings for Combie Dam (NID, 1928) indicate a design depth of excavation in the river channel of approximately 10 to 15 feet. "As Built" drawings for Combie Dam (NID, 1932) confirm channel deposit thicknesses of approximately 0 to 15 feet.

Alluvial deposits are present in the CRP dam site area between the abutment slopes and across the Bear River channel, which has a width of between 150 and 300 feet. The deposits consist of sandy gravel to gravelly sand and locally contain cobbles and boulders. The gravels and larger clasts include granite, quartzite, and vein quartz from rock that is present upstream to the east in the Bear River drainage basin, but not in the project site. Though none was observed during the geologic mapping effort, the alluvial deposits may also contain chert based on the mapping performed by Tuminas (1983). Alluvium is present primarily as gravel bars within the river channel, which also contains extensive rock outcrops. The approximate limits of the alluvium in the site area are shown on Figure 4-1. Bedrock outcrops in the active river channel are also shown in Figure 4-1. Photographs 2 and 3 illustrate the Bear River alluvial deposits.

4.3.3 Springs

One groundwater spring was observed above the south bank of the river at about Elevation 1700 feet near the western edge of the dam site area (Figure 4-1). This spring (seep) was present each time the site was visited from December 2014 through November 2015 and May 2016 through November 2016.

4.4 Bedrock Conditions

4.4.1 General

The project site area is located in the Central Belt of the northern Sierra Nevada geomorphic province, within the upper Lake Combie Complex. This geologic unit includes variably metamorphosed mafic volcanic formations. The more strongly metamorphosed portions are referred to as greenstone (metamorphosed basalt). Based on surficial geologic mapping, bedrock at the site is composed of basalt, some of which may be slightly metamorphosed.

4.4.2 Rock Description

The observed outcrops on both the north and south sides of the river canyon are comprised of similar rock. The rock is massive, dense, hard, strong, black to gray, fine grained, generally unweathered to slightly weathered basalt flow rock and volcaniclastic rock. The outcrops display widely spaced steep joints and gently inclined volcanic flow and depositional bedding surfaces. Rock outcrops are present in many places along the toe of the slopes near the river and in the active river channel. Near the river many of the outcrops are present as cliffs. A tall cliff on lower half of the south bank of the river near Axis 2 was too steep to safely access on foot. The lower portion of this outcrop was accessed via small boat during the Phase III investigation. Within the river channel many of the observed outcrops have been smoothed by fluvial erosion.

Surficial and structural geologic mapping performed for this investigation is shown on Figure 4-1. Bedrock mapping is depicted with two classes, based on continuity of outcrops, amount and interpreted depth of soil and degree of weathering. Areas mapped as bedrock outcrop (Class 1) are characterized by extensive, continuous rock outcrop at the surface that is generally moderately weathered to fresh, with occasional small, localized deposits of talus, soil and/or colluvium. Areas mapped as bedrock slope (Class 2) have fewer, isolated rock outcrops, typically with a greater degree of weathering. These areas may have locally thick deposits of residual soil where rock has weathered in place and may have some thin (generally less than several feet) deposits of colluvial soil. The margins of areas mapped as bedrock slopes (Class 2) are typically diffuse and gradational with adjacent bedrock outcrop or colluvial slopes. Also shown on Figure 4-1 are the locations of the observed rock outcrops where flow and clastic bedding was observed and recorded as well as the locations of observed apparent landslides. Photographs 4 and 5 illustrate the bedding and joint conditions of the bedrock. Photographs 6 and 7 illustrate the general morphology of the site.

4.4.3 Rock Structure Observed in Outcrops – Dam Site

Rock structure orientations were measured on a total of 91 joints and 25 volcanic flow and volcaniclastic bedding surfaces on rock outcrops in the Axis 2 study area. The discontinuity locations are shown on Figure 4-1 and the data are presented in Appendix B. The principal discontinuity sets from the data are summarized in Table 4-1 and plotted on Figures 4-3a (left abutment) and 4-3b (right abutment). These figures show stereonet plots displaying contoured orthogonal poles to the measured planar surfaces. Both figures show consistent south-southwest dipping flow and clastic bedding orientations, with a concentration of strikes and dips centered at N55^{o}W (125^{o} azimuth), 12^{o}SW. Remaining discontinuity features plotted on Figures 4-3a and 4-3b are clustered into distinct pole concentrations representing two prominent steeply dipping joint sets (joint sets 1 and 2 in Table 4-1) that trend roughly N-S and E-W.

Table 4-1. Discontinuity Sets from Geologic Mapping

Strike (Degrees Az.)	Dip (Degrees)	Discontinuity Type	No. of Data points
120-130	12 SW	Bedding	25
8-20	80 E	Joint Set 1	37
277-292	85 N	Joint Set 2	29

The mapped joint orientations were observed to be relatively persistent throughout the study area on both sides of the Bear River canyon. The joint surfaces observed in outcrops were generally slightly wavy, smooth to slightly rough, very narrow to tight, and with narrow bands of weathering along the joint surfaces. Geometry, roughness and weathering of the bedding and bedding-parallel joints were similar to the other joints.

4.5 Geologic Hazards

4.5.1 Landslides and Rockfalls

One active landslide was mapped on the south canyon slope adjacent to a sharp turn in the river, as shown in Figure 4-1. This landslide extends upslope 140 feet from the left bank of the river channel to approximately Elevation 1760 feet. The west side scarp is prominent and clearly visible as is the hummocky nature of the ground surface and lack of large fir and pine trees. The head scarp and east side scarp are more subdued and not as obvious. The depth of this landslide appears to be about 30 to 40 feet from surficial observations. Two other possible landslide deposits were mapped within the slopes north of the Bear River upstream and downstream of the Axis 2 dam footprint, as shown on Figure 4-1. Small rockfalls have also occurred at some of the larger rock outcrops. Rocky rubble surrounding the steep cliffs at the right abutment near the downstream edge of the site area is interpreted as rockfall debris.

4.5.2 Faults

As stated in Section 3, no faults considered active by either the CGS or USGS are mapped within the CRP dam site area. During the geologic mapping for the current phase of study, two minor inactive faults or shear zones were observed within the nearby Bear River rock quarry. Based on observations of the sheared bedrock zones, these features are about 5 to 15 feet wide in outcrop, and are very steep to vertical. One of these features strikes N10°E-N20°E, oriented towards the north-south stretch of the Bear River within the CRP dam site area. The feature is also subparallel to a large dike exposed in the north quarry wall. This feature juxtaposes volcaniclastic breccia on both sides of the shear zone. The dike margins are bounded by the shear zone, with the most prominent deformation expressed along the western margin of the dike. Deformation is characterized by a zone of anastomosing shear-fabric, grain size reduction of the volcaniclastic breccia matrix, calcite recrystallization and apparent hydrothermal alteration. The shear zone appears to be continuous up-section in the quarry walls and across upper cut benches, although careful examination of the quarry walls along projection of the shear zone to the south and southwest revealed no evidence for the continuation of this feature. The second shear zone is oriented N55°E. These features appear to coincide with a regional discontinuity fabric that follows local reaches of the Bear River. Slickensides present along shear surfaces indicate a strike slip sense of past movement. Photographs 8 and 9 illustrate the minor inactive fault or shear zone features observed in the quarry.

On the basis of (1) the lack of lateral continuity of shearing across the quarry, (2) the spatial association of deformation with dike emplacement, and (3) the absence of any geomorphic expression of faulting to the northeast, we conclude there is a very low likelihood that this shear zone represents an active surface-fault rupture hazard for the proposed Centennial Dam.

In response to a question from DSOD on active faulting in the site area, Lettis Consultants International (LCI) was retained to perform an independent evaluation of the potential for active faulting at the Axis 2 site. LCI's December 22, 2016 report is contained in Appendix A-2. LCI evaluated published and unpublished geologic reports, articles, theses, and maps. They also reviewed photographs of the rock core samples from Phase II and Phase III investigations as well as LiDAR and aerial photographs, and also performed a two-day reconnaissance including visits to the nearby quarry. Based upon the site reconnaissance, LCI identified five main volcanic rock units. They observed these units on both the north and south side of Bear River.

Conclusions from the LCI evaluation include:

- There is a lack of positive evidence to support active faulting at the proposed Centennial Dam Axis 2 site.
- The potential for active faulting at the Axis 2 site is low. The discontinuous nature of the "Quarry fault" observed in the Bear River Quarry, its association with late-stage mafic dike(s), and its lack of associated geomorphic expression all contraindicate a potential for active faulting.
- Possible linear geologic structures identified in seismic refraction surveys at the site appear to correlate with lithologic contacts and mapped slope failures rather than faulting.
- The meandering expression of the Bear River corresponds roughly to the north-south and east-west geomorphic lineaments that appear to be related to the regional orthogonal bedrock joint pattern rather than faulting.
- Volcanic stratigraphy near the Axis 2 site appears to be relatively consistent with a moderate to gentle southwest dip. The absence of vertical separation of lithologic contacts further supports the conclusion that faulting through Axis 2 is not present.

5 Geotechnical Investigation

5.1 General

This section summarizes both the Phase II and Phase III geotechnical investigations. The Phase II geotechnical investigation focused on cost-effectively obtaining the data needed to evaluate the technical feasibility of the potential dam sites (Axes 2 and 6) and dam types. The primary emphasis was on identifying significant geologic flaws or other undesirable foundation conditions present in the areas investigated. The investigations also obtained data to help evaluate foundation excavation depths, rock strengths, potential seepage conditions, and likely treatment requirements. The investigations obtained data to facilitate technical comparisons of potential dam axis locations and dam types (AECOM, 2016a).

The Phase III geotechnical investigation focused on filling in data gaps at the selected Axis 2 site and on exploring two potential rock borrow areas. No further investigations were carried out for the Axis 6 site.

Photographs 10 to 14 show drilling operations at the dam site.

5.2 Dam Foundation - Phase II Investigation

5.2.1 Seismic Refraction Surveys

A total of 12 surface seismic refraction surveys were performed by Norcal Geophysical Consultants of Cotati, California, between August 24 and 28, 2015, and on November 4, 2015. The initial 10 seismic lines performed in August were located to obtain general site coverage. Seismic refraction line 2-5 was performed to obtain data between the east end of seismic line 2-3 and the west end of seismic line 4-3. Seismic line 6-4 was performed to obtain data uphill of seismic line 6-3. The seismic refraction survey line locations are shown on Figure 4-1 in the Phase II report (AECOM, 2016a).

The surveys were performed with line lengths of 300, 600 and 900 feet. The results were used to characterize subsurface conditions in two potential dam axis areas. The survey locations were selected to help assess the depth and degree of weathering of bedrock, to evaluate the potential significance of local topographic features, and to aid in locating the core borings. Due to the steepness of the right abutment areas, the survey lines in these areas were oriented parallel to the topographic contours. However, the left abutment slopes are flatter, so two of the seismic lines (seismic line 2-4 at Axis 2 and seismic line 6-1 at Axis 6) were oriented perpendicular to the topographic contours. Seismic line 2-2 was located to check the depth of weathering in a surface drainage feature.

The seismic refraction survey methodology and results are presented in Appendix C-1.

5.2.2 Core Drilling and Water Pressure Testing

Between October 13 and November 13, 2015, eight HQ-size (2.4-inch diameter core), triple tube core barrel borings (CB-1 to CB-6, CB-8 and CB-9), were drilled in general accordance with ASTM D2113. Four borings each were drilled at Axis 2 (CB-1, -2, -3 and -4) and Axis 6 (CB-5, -6, -8 and -9). The four borings drilled at Axis 2 are shown on Figure 4-1.

The borings were drilled by Ruen Drilling of Modesto, California. Two LF-70 track-mounted drill rigs were mobilized for this investigation. The borings ranged in length from 143 to 300 feet, for a total drilled length of 1612 linear feet at Axes 2 and 6 (786 linear feet at Axis 2). All borings were located by GPS. The summary of the core borings and in situ testing is presented in Table 5-1. The core boring logs are presented in Appendix D. The cores were photographed after they were placed in wooden core boxes and also individual runs were photographed in the inner split core barrels. The core box photographs are presented in Appendix D along with the core boring logs.

The Phase II core boring locations were selected at sites suitable for track-mounted drill rigs and water truck access. The core borings and the in situ testing in the Axis 2 area are summarized in Table 5-1, including the specific objectives of each boring. Inclined borings were used due to the presence of near-vertical joint sets (see Section 4.4.3). Inclined borings were necessary in order to intersect and characterize the frequency and hydraulic conductivity of the near-vertical joints. The borings were inclined at either 60 or 75 degrees from the horizontal. Two of the borings were inclined at 75 degrees to accommodate P- and S-wave downhole velocity measurements (see Section 5.4).

Water pressure (packer) testing was performed to assess the foundation hydraulic conductivities. The testing was performed in general accordance with USBR 7310, with tests in stages (generally 20 to 30 feet long) in the borings. The test results provide data for seepage analyses and to assess foundation grouting requirements. The water pressure test data is included in Appendix E. Photographs 10 and 11 show the typical core drilling operation.

After completion, each boring was tremie cement grouted from the bottom to the ground surface. The core boxes were temporarily stored in the Bear River Quarry south of the dam site while the core logs were reviewed and point load index testing was performed (see Section 5.5). The core boxes were then moved to a large shipping container in NID's yard in Grass Valley for long-term storage.

5.2.3 Downhole Geophysics

The investigation also included downhole in-situ testing to obtain additional data to characterize the rock mass conditions. The downhole geophysical testing was performed by Norcal Geophysical Consultants during the drilling program and included televiewer logging, caliper logging and downhole seismic velocity measurements.

Televiewer logging [optical and acoustic (below water level within the borings)] was done to measure the orientation of discontinuities (e.g., joints and shears) to characterize the rock mass and foundation conditions and for use in stability analyses. Caliper logging that shows the diameter of the borehole walls was also obtained along with the televiewer logs. Televiewer and caliper logging was performed in the eight Phase II core borings and the data are presented in Appendix F-1.

Downhole geophysics (OYO suspension logging) was done to measure compression (P) and shear (S) wave velocities to characterize bedrock weathering profiles with depth and to provide data for dynamic site response analyses. P- and S-wave velocities were measured in boring CB-2 (Axis 2) and in boring CB-5 (Axis 6). The P- and S-wave measurement methodology and test results are presented in Appendix G-1.

5.2.4 Rock Strength Testing

Selected rock cores were tested by Holdrege & Kull Consultants of Nevada City, California, for unconfined compressive strength (UCS) (ASTM D7012) in the laboratory. The lengths of the cores that were selected for UCS testing were generally at least twice the diameter. Correction factors were used to correct for shorter length cores. Point load index tests (ASTM D5731) were performed on rock cores by AECOM to supplement the laboratory strength test data. These data are useful for rock strength characterization and evaluation of dam foundation suitability. The UCS test data and point load index test data are presented in Appendix H-1 and Appendix I-1, respectively.

5.3 Dam Foundation - Phase III Investigation

5.3.1 General

The Phase III Geotechnical Investigation Work Plan (AECOM, 2016c) was prepared prior to selecting the dam type and axis location. That work plan considered both Axes 2 and 6 locations and RCC and concrete faced rockfill (CFR) dam alternatives. During the Phase III investigation work, the decision was made to adopt an RCC dam constructed at Axis 2 as discussed in Section 1.3. As such, five borings (CB-10, 11, 14, 15, 19; see Figure 4-1) were drilled for the plinth (foundation slab) for the CFR dam alternative. Although these borings were located upstream of the likely RCC dam footprint, they still furnished useful geotechnical data.

5.3.2 Seismic Refraction Surveys

Seven surface seismic refraction surveys were performed in the area of Axis 2 by Norcal Geophysical Consultants between June 13 and June 16, 2016. The seismic refraction survey line locations (2-6 to 2-12) are shown on Figure 4-1.

The surveys were performed with line lengths of 300, 600 and 900 feet. The results were used to further characterize subsurface conditions in Axis 2. The survey locations were selected to help assess the depth and degree of weathering of bedrock. The survey at Line 2-12 was performed to intersect local shear zones that were observed in the Bear River Quarry that could potentially project northward toward the project site.

The seismic refraction survey methodology and results are presented in Appendix C-2.

5.3.3 Core Drilling and Water Pressure Testing

Between June 6 and August 4, 2016, ten HQ-size (2.4-inch diameter core), triple tube core barrel borings (CB-10 to CB-15 and CB-17 to CB-20), were drilled in general accordance with ASTM D2113 at the locations shown on Figure 4-1. Boring CB-16, which is located close to the Bear River, required a permit to drill (Section 401 Water Quality Certification). As such, this boring was delayed; mobilization occurred on November 12 and drilling was completed on November 16, 2016. Due to poor core recovery in the upper 29 feet of this boring, another boring, CB-16A, was angled beneath CB-16 on November 18, 2016, to retrieve core through this zone of poor recovery in CB-16. Core recovery improved using shorter core runs.

The borings were drilled by Ruen Drilling. Two LF-70 track-mounted drill rigs were mobilized for this investigation. The borings ranged in length from 42 to 210 feet, for a total drilled length of 1928 linear feet. All borings were located by GPS. The summary of the core borings and in situ testing is presented in Table 5-1. The core boring logs are presented in Appendix D. The individual core runs were photographed in the inner split core barrels and full core boxes were also photographed. The core box photographs are presented in Appendix D along with the core boring logs.

Like Phase II, the core borings and the in situ testing in the Axis 2 area are summarized in Table 5-1, including the specific objectives of each boring. Inclined borings were used due to the presence of near-vertical joint sets (see Section 4.4.3). Inclined borings were necessary in order to intersect and characterize the frequency and hydraulic conductivity of the near-vertical joints. Eight of the borings were inclined at about 60 degrees from the horizontal. In the river bottom, Boring CB-15 was inclined at 45 degrees and Boring CB-16 was inclined at 50 degrees. Borings CB-11 and CB-12 were vertical.

Water pressure (packer) testing was performed to assess the foundation hydraulic conductivity. The testing was performed in general accordance with USBR 7310, with tests in stages (generally 20 to 30 feet long) in the borings. The test results provide data for seepage analyses and to assess foundation grouting requirements. The water pressure test data is included in Appendix E. Photographs 10 and 11 show the typical core drilling operations.

After completion, five borings were tremie cement grouted from the bottom to the ground surface. Piezometer standpipes were installed in five borings as indicated in Table 5-1. The core boxes were temporarily stored on site where the core logs were reviewed and point load index testing was performed (see Section 5.5). The core boxes were then moved to a large shipping container in NID's yard in Grass Valley for long-term storage.

5.3.4 Downhole Geophysics

The investigation included downhole in-situ testing to obtain additional geologic data to characterize the rock mass conditions. Downhole televiewer logging and caliper logging was performed by Norcal Geophysical Consultants during the drilling program in all borings, except boring CB-20, which had few fractures.

Televiewer logging (optical and acoustic (below water level within the borings)) was done to measure the orientation of discontinuities (e.g., joints and shears) to characterize the rock mass and foundation conditions and for use in stability analyses. Caliper logging that shows the diameter of the borehole walls was also obtained along with the televiewer logs. The caliper logs can show where the borehole became washed out or eroded during drilling or where pieces of rock caved. Televiewer and caliper logging data are presented in Appendix F-2.

5.3.5 Rock Strength Testing

Like Phase II, selected rock cores were tested by Holdrege & Kull Consultants for UCS (ASTM D7012) in the laboratory. Point load index tests (ASTM D5731) were performed on rock cores by AECOM to supplement the laboratory strength test data. The UCS test data and point load index test data are presented in Appendix H-1 and Appendix I-1, respectively.

5.4 Potential Rock Borrow Areas - Phase III Investigation

5.4.1 Seismic Refraction Surveys

Four surface seismic refraction surveys (Lines BA-1 to Line BA-4) were performed in the South Rock Borrow Area between May 18 and May 20, 2016, as part of the Phase III investigations. In the North Rock Borrow Area, three surface seismic refraction surveys (Lines BA-5 to Line BA-7) were performed between July 6 and July 8, 2016. The seismic refraction surveys were performed by Norcal Geophysical Consultants. The seismic refraction survey line locations are shown on Figure 4-2.

The surveys were performed with line lengths of 300, 600 and 900 feet. The results were used to characterize subsurface rock conditions in the two potential rock borrow areas. The survey locations were selected to help assess the depth and degree of weathering of bedrock and to aid in locating the core borings.

The seismic refraction survey methodology and results are presented in Appendix C-2.

5.4.2 Core Drilling

As part of the Phase III investigations, five core borings (CB-B1 to CB-B5) were drilled in the South Rock Borrow Area between May 31 and June 10, 2016, at the locations shown on Figure 4-2. Three core borings (CB-B6 to CB-B8) were drilled in the North Rock Borrow Area between June 23 and June 29. The eight core borings were drilled vertically and were HQ-size (2.4-inch diameter core), triple tube equipment in general accordance with ASTM D2113. The borings were drilled to evaluate rock quality and overburden depth in the potential rock borrow areas.

The borings were drilled by Ruen Drilling. Two LF-70 track-mounted drill rigs were mobilized for this investigation. The borings ranged in length from 53 to 201 feet, for a total drilled length of 764 linear feet. All borings were located by GPS. The borrow area borings and in situ testing are summarized in Table 5-1. The core boring logs and core photographs are presented in Appendix D.

After completion, six borings were tremie cement grouted from the bottom to the ground surface. Piezometer standpipes were installed in two borings in the South Borrow Area as indicated in Table 5-1. The core boxes were temporarily stored on site where the core logs were reviewed and point load index testing was performed. The core boxes were then moved to NID's yard in Grass Valley for long-term storage.

5.4.3 Downhole Geophysics

The rock borrow area investigation also included downhole P-wave seismic velocity surveys to obtain additional data to characterize the rock mass weathering conditions and rippability in the potential rock borrow areas. The downhole geophysical testing was performed by Norcal Geophysical Consultants during the drilling program. P-wave velocities were measured in borings CB-B1 to CB-B4 (South Rock Borrow Area) and CB-B6 and CB-B7 (North Rock Borrow Area). The P-wave measurement methodology and test results are presented in Appendix G-2.

5.4.4 Rock Strength and Quality Testing

Selected rock cores from the potential rock borrow areas were tested by Holdrege & Kull Consultants for UCS (ASTM D7012) in the laboratory. Point load index tests (ASTM D5731) were performed on rock cores by AECOM to supplement the laboratory strength test data. The UCS test data and point load index test data are presented in Appendix H-2 and Appendix I-2, respectively.

Durability tests were performed by Holdrege & Kull Consultants on rock core samples from the potential borrow areas to evaluate suitability of the rock for RCC and concrete aggregate. These tests consisted of the following:

- Bulk specific gravity and absorption (ASTM C127)
- Abrasion (ASTM C131)
- Sodium Sulfate Soundness (ASTM C88).

The test results are included in Appendix J.

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Table 5-1. Summary of Rock Core Borings - Axis 2 and Potential Rock Borrow Areas

Boring No.	Location	Purpose	Approx. Surface Elev. (ft)	Phase II Boring Length (ft)	Phase III Boring Length (ft)	Boring Inclination		Piezometer	HC	TV/Caliper	P- & S-Wave Velocity Surveys
						Dip (Degrees)	Direction				
CB-1	Axis 2 - south	Upper abutment foundation rock quality, weathering zone depression and profile	1788	199.7		60	north		X	X	
CB-2	Axis 2 - south	Lower abutment foundation rock quality and weathering profile	1723	178.0		75	north		X	X	P&S
CB-3	Axis 2 - north	Lower abutment foundation rock quality and weathering profile	1883	254.2		60	south		X	X	
CB-4	Axis 2 - north	Upper abutment foundation rock quality, geomorphic saddle weathering zone depression and profile	1883	154.5		60	north		X	X	
CB-10	Axis 2 - south	CFRD upstream toe area	1759		202.8	60	north	X	X	X	
CB-11	Axis 2 - south	CFRD upstream toe area	1773		150.4	90		X	X	X	
CB-12	Axis 2 - south	South end of dam axis	1897		100.3	90		X	X	X	
CB-13	Axis 2 - north	Dam axis, south of CB-3, 4	1834		208.0	60	south		X	X	
CB-14	Axis 2 - north	CFRD upstream toe area	1727		202.8	60	south	X	X	X	
CB-15	Axis 2 - north, river channel	CFRD upstream toe area	1610		209.9	45	south		X	X	
CB-16	Axis 2 - north, river channel	River channel rock quality	1603		173.9	50	south		X	X	
CB-16A	Axis 2 - north, river channel	River channel rock quality	1603		42.1	57	south				
CB-17	Axis 2 - south	Lower abutment foundation	1718		152.5	60	north	X	X	X	
CB-18	Axis 2 - north	RCC dam downstream toe area	1784		200.0	60	south		X	X	
CB-19	Axis 2 - north, river channel	CFRD upstream toe area	1610		117.3	62	north		X	X	
CB-20	Axis 2 - south	RCC dam downstream toe area	1686		168.3	60	N30E				
Drilling Subtotal Axis 2				**786.4**	**1928.3**						
CB-B1	S. Borrow Area	Rock quality; overburden depth	1962		200.9	90		X			P
CB-B2	S. Borrow Area	Rock quality; overburden depth	1866		100.0	90					P
CB-B3	S. Borrow Area	Rock quality; overburden depth	1910		101.3	90		X			P
CB-B4	S. Borrow Area	Rock quality; overburden depth	1871		103.5	90					P
CB-B5	S. Borrow Area	Rock quality; overburden depth	1940		79.0	90					
CB-B6	N. Borrow Area	Rock quality; overburden depth	2016		58.0	90					P
CB-B7	N. Borrow Area	Rock quality; overburden depth	2075		53.0	90					P
CB-B8	N. Borrow Area	Rock quality; overburden depth	2092		68.1	90					
Drilling Subtotal Borrow Area					**763.8**						
Drilling Total				**786.4**	**2692.1**						

NOTES:
1. HC = hydraulic conductivity (packer) test, TV = televiewer
2. All rock core borings are HQ size
3. CB-15, 16, 16A and 19 required helicopter mobilization

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6 Dam Foundation Conditions

6.1 General

This section describes the foundation conditions at Axis 2 based on data collected from the core borings, seismic velocity surveys, rock strength testing, and discontinuity evaluation. Figure 6-1 shows a geotechnical profile along dam Axis 2. A parallel geotechnical profile located about 270 feet upstream of Axis 2 is shown on Figure 6-2. Three geotechnical sections transverse to the dam axis are shown on Figure 6-3.

6.2 Weathering and Fracturing

Weathering is a key parameter, along with rock fracture intensity and strength, that are used to establish the necessary depths of the dam foundation excavation. The recommended foundation excavation depths will be established during subsequent conceptual engineering analyses.

Table 6-1 summarizes the depths drilled, rock depths and depths to slightly weathered to fresh rock in the borings at Axis 2. The depth to rock was generally less than 20 feet in most of the dam site borings. The core boring logs show that the degree of weathering is variable. The borings often encountered significant depths of completely weathered to highly weathered rock, typically weak to very weak, and highly to intensely fractured, with RQD values from 0 to 30%. With increasing depths, all borings encountered slightly weathered to fresh rock, generally less fractured and with higher RQDs (frequently 100%). Within the slightly weathered rock zones, the fracture intensity typically decreased with increasing depth.

Table 6-1. Summary of Core Boring Results - Dam Foundation (Axis 2)

Abutment	Boring No.	Total Drilled Depth* (ft)	Approx. Drilled Depth to Rock* (ft)	Depth to Predominantly Slightly Weathered/Fresh Rock* (ft)
Left	CB-1	199.7	23	133
	CB-2	178.0	4	4
	CB-10	202.8	7	49
	CB-11	150.4	2	17
	CB-12	100.3	5	32
	CB-17	152.5	5	6
	CB-20	168.3	13	16-24
Right	CB-3	254.2	3	63
	CB-4	154.5	3	109
	CB-13	208.0	11	97-107
	CB-14	202.8	45	87
	CB-15**	209.9	9	20
	CB-16**	173.9	15	15
	CB-16A**	42.1	10	10
	CB-18	200.0	9	25-30
	CB-19**	117.3	3	17

* Depths are measured along the lengths of the angled borings.
** CB-15, 16, 16A and 19 were drilled on the right (north) side of the river channel at the toe of the right abutment.

6.3 Seismic Velocities

The seismic refraction surveys provided additional data to help evaluate the depth of weathering in the dam foundation, to supplement data from the borings. As detailed in Appendices C-1 and C-2, the seismic refraction profiles indicate seismic P-wave velocities that gradually increase from less than 1,000 ft/s near the ground surface to 14,000 ft/s within the upper 70 feet.

The surveys indicate that the depth of residual soils and highly weathered and/or highly fractured bedrock (with P-wave velocities of less than 5000 ft/s) range from less than 5 feet to more than 60 feet. Based on the data obtained from refraction lines 2-2 and 2-4, these materials appear to be thicker in the upper elevation areas of the left abutment of Axis 2. At the location of the Axis 2 crossing with seismic refraction line 2-3, low velocity materials were encountered to a depth of approximately 65 to 70 feet below the ground surface.

Beneath this low velocity layer, a zone of material with intermediate velocities (5,000 to 9,000 ft/s) is present, which is interpreted as moderately weathered and/or fractured bedrock. Similar to the trend in the thickness of low velocity materials, the thickness of intermediate velocity materials generally decreases with decreasing elevation within the left abutment of Axis 2 (seismic refraction line 2-4).

The highest velocity material (over 9,000 ft/s) is indicative of rock that is slightly weathered to fresh (unweathered). Within the left abutment, along lines seismic refraction 2-2 and 2-4, these materials were encountered at depths that generally became shallower from south to north (i.e., shallower towards the Bear River). High velocity materials were not encountered along lines seismic refraction 2-3 or 2-10 in the right abutment.

The results of downhole seismic velocity measurements in boring CB-2 show slightly weathered to fresh rock with S-wave velocities in the range of about 10,000 to 12,000 ft/s and P-wave velocities of about 20,000 ft/s (see Figure 6-1). These velocities correspond with the good quality rock at shallow depth in this boring.

6.4 Rock Strength

Unconfined compressive strength (UCS) tests were performed on selected testable core samples. Ideal test samples need to have a length-to-diameter ratio of about 2. Due to the close fracture spacing, only a few samples of moderately weathered rock were suitable for testing in unconfined compression in the laboratory. Testable samples are likely to be the better quality samples, so some degree of bias may be present in the UCS test results toward higher strength rock. Shorter cores were tested by a point load device in the field (Appendix I-1).

The UCS data (Appendix H-1) are summarized in Table 6-2 by degree of weathering.

Table 6-2. Summary of UCS Tests on Axis 2 Core Samples

Location	Predominant Degree of Weathering	Median UCS (psi)	Range of UCS (psi)	Number of Tests
Left Abutment	Moderately	2,700	N/A	1
	Slightly	9,900	1,800 – 24,100	7
	Fresh	10,950	9,350 – 12,550	2
Channel	Moderately	N/A	N/A	N/A
	Slightly	11,450	5,100 – 21,850	7
	Fresh	12,450	9,630 – 15,280	2
Right Abutment	Moderately	3,850	1,900 – 5,850	2
	Slightly	17,650	6,450 – 35,650	10
	Fresh	N/A	N/A	N/A

The point-load test data (Appendix I-1) are summarized in Table 6-3 by degree of weathering. Core test specimens that broke along existing fractures are not included in the results presented in Table 6-3. Results from tests on specimens that broke along the surface are included in the results presented in Table 6-3, although these results provide a low estimate of the UCS strength as they did not break through the entirety of the specimen.

Table 6-3. Summary of Point Load Tests on Axis 2 Core Samples

Location	Predominant Degree of Weathering	Median UCS (psi)	Range of UCS (psi)	Number of Tests
Left Abutment	Moderately	2,150	950 – 2,200	3
	Slightly	20,250	14,850 – 24,350	8
	Fresh	24,700	24,500 – 32,150	3
Channel	Moderately	N/A	N/A	N/A
	Slightly	19,050	13,800 – 22,850	8
	Fresh	N/A	N/A	N/A
Right Abutment	Moderately	3,800	2,000 – 16,950	8
	Slightly	28,950	14,350 – 39,800	12
	Fresh	N/A	N/A	N/A

As expected, both the UCS and point load strengths generally increase with decreasing degrees of weathering. The slightly weathered to fresh rock has high strengths, with values up to about 40,000 psi. A substantial range of strengths was observed for a given degree of weathering.

6.5 Discontinuity Data

Downhole televiewer logging was performed in ten of the twelve Phase III core borings. The logging obtained a total of 782 discontinuity measurements with depth, which are summarized in Appendix F. Prior to analysis, the televiewer logs were compared to the core boring logs to both verify identification and classification of discontinuities measured by the televiewer and to evaluate zones of highly weathered and/or fractured/sheared core and zones of poor recovery. The reviewed discontinuities were initially classified as significant (Class 1) to minor (Class 3). The classification process as well as the televiewer logging procedures are described in Appendix F. The discontinuities were combined with those measured in Phase II boreholes CB-1, CB-2, CB-3 and CB-4 for a total of 1116 features associated with Axis 2 borings. Lower hemisphere equal angle stereonet pole plots were prepared for discontinuity datasets compiled from boreholes located at each abutment and under the channel along Axis 2, to look for significant trends in the discontinuity data and define apparent spatial variations. Discontinuity sets were identified based on significant pole concentrations as illustrated in Figures 6-4a, 6-4b, and 6-4c and summarized in Table 6-4.

The discontinuity data shows two prevalent discontinuity sets and one less prominent set with some variance between the right and left abutments. The most consistent discontinuity set, gently dipping to the southeast to southwest, represents bedding features in volcaniclastic rock or flow fabric in basalt and basalt breccia. These bedding features are very prominent in both the right abutment (Figure 6-4b) and channel borings (sets labeled 1m) (Figure 6-4c) and are less prevalent in the left abutment borings (set 2m) (Figure 6-4a). The second prominent discontinuity set strikes roughly east-west and dips steeply south. This set is only present in the left abutment borings (set 1m) and represents joints and fractures within the rock. A third, less prominent joint set strikes N-NE and dips steeply to the E-SE. This set is present in both right and left abutments (sets 2m and 3m, respectively) but not in the channel borings.

The geometries and distribution of the discontinuity data sets described above are consistent with a geologic model of the site that has bedded volcaniclastic rocks stratigraphically lower and basalt and basalt breccia higher within a volcanic package that generally dips gently to the south-southwest. The channel and lower right abutment borings (CB-15, CB-16 and CB-19) encountered more prominent bedding and bedding parallel discontinuity sets (Figures 6-3b and 6-3c). The left abutment borings and upper right abutment borings encountered fewer shallow dipping features and more prominent, steep, orthogonal discontinuity sets consistent with cooling and weathering of basalt and basalt breccia.

Table 6-4. Discontinuity Sets from Downhole Televiewer Logging

Axis/ Abutment	Strike (Degrees Az.)	Dip (Degrees)	Discontinuity Type	Plot Label
2-left	109	80 S	Joint	1m
2-left	165	9 W	Bedding	2m
2-left	28	68 E	Joint	3m
2-right	66	18 SE	Bedding	1m
2-right	59	77 SE	Joint	2m
2-channel	39	15 SE	Bedding	1m

In addition to the analysis described above, an evaluation of the potential persistence of specific significant discontinuities logged in both televiewer and core borings was performed. This process involved the identification of potential major discontinuities based on specific criteria and three-dimensional analyses of these features. The criteria used to identify these major features were:

- Features or zones logged in borings as sheared, brecciated, containing clay or clayey infill, or the presence of slickensides.
- Sets of relatively closely-spaced, parallel minor features.
- Position relative to likely dam foundation level. Features encountered near ground surface or more than approximately 20 feet above likely foundation depths were not included.
- Features with shallow dip angles. Most features dipping steeper than 30 degrees were not included as these orientations would not provide for a continuous slide plane beneath the dam.
- Features initially characterized as major (Class 1) or intermediate (Class 2) by televiewer logging.
- Certainty of orientation in televiewer log. Features with orientations that could not be confidently identified as planar were excluded.

Based on these criteria, a total of 15 features or feature sets were identified for evaluation. The persistence analysis consisted of three-dimensional projection of the planar discontinuity surfaces from the borehole where encountered toward adjacent boreholes or outcrops. The orientations (strike and dip) of these projected surfaces were varied by 5 to 10 degrees to account for possible measurement error in the televiewer analysis or structural/geologic variability of the discontinuity surface. The zones of other boreholes or ground surface where these features projected were then evaluated for possible similarly oriented discontinuities that, if interpreted to be connected, could represent a foundation defect.

The projected surfaces of three of the 15 features evaluated for spatial persistence did not intersect any other boreholes. Twelve features projected into at least one other borehole but of these, only six features projected into other boreholes where there were discontinuities with similar attitudes as the projected major feature. The projected distances were between 24 and 510 feet. The six projected major features coincided with minor features in the adjacent borings; none of the projected major features aligned with other major features.

In each case where the projection of a major feature intersected another borehole, and in particular where other minor features had similar geometries, the boring logs and core photos were carefully reviewed to evaluate if the features could be related. In each case, the likelihood that the discrete features represented single, continuous discontinuity (fracture, shear or bedding /flow plane) was judged to be very low. Data and notes describing the identified features and the results of the persistence analysis are presented in Appendix F-3.

6.6 Groundwater

Groundwater elevations were measured in the borings along Axis 2, as summarized in Table 6-5. The depth to groundwater was measured in piezometers installed in boreholes CB-10, CB-11, CB-12, CB-14, and CB-17 two or more times during the indicated date ranges in the table. Long-term groundwater level monitoring has not been performed; seasonal fluctuations in the groundwater level may occur. At other locations, the depth to groundwater was measured during or after drilling.

From the upper part to the lower part of the left abutment of the proposed dam axis, the approximate vertical depths to groundwater were observed to be 46 feet below the ground surface in boring CB-12, 111 feet in boring CB-1, 25 feet at boring CB-2, and 48 feet at boring CB-17. The relatively shallow depth to groundwater observed at boring CB-2 is generally consistent with a spring observed to the west of this boring at about Elevation 1700 feet (see Section 4.3.3 and Figure 4-1). In summary, the depth to groundwater within the left abutment varies and generally appears to decrease as the depth to moderately-fractured to massive, slightly-weathered to fresh bedrock decreases.

From the upper part to the lower part of the right abutment of the proposed dam axis, the approximate vertical depths to groundwater were observed to be 197 feet below the ground surface at boring CB-3, 154 feet at boring CB-13, and less than a foot below the surface at CB-16. This indicates the depth to groundwater is shallower toward the channel, as would be expected.

Table 6-5. Summary of Measured Groundwater Elevations in Axis 2 Borings

Abutment	Boring No.	Ground Surface Elevation (ft)	Bottom of Boring Elevation (ft.)	Bottom of Casing Elevation (ft.)	Depth to Water Level (ft.)*	Range of Observed Groundwater Elevations (ft.)	Date(s) Measured
Left	CB-1	1788	1615	NA	127.7	1677	10/30/15 (ATD)
	CB-2	1723	1551	NA	27.0	1697	10/29/15 (ATD)
	CB-10	1759	1583	1714	41.3 – 48.6	1720 – 1727	6/24/16 – 8/3/16
	CB-11	1773	1623	1668	64.3 – 65.2	1708 – 1709	6/28/16 – 8/3/16
	CB-12	1897	1797	1842	45.6 – 45.8	1851	7/12/16 – 8/3/16
	CB-17	1718	1586	1657	49.8 – 59.5	1667 – 1675	7/16/16 – 8/5/16
	CB-20	1686	1540	NA	17.6	1671	8/5/16 (ATD)
Right	CB-3	1883	1663	NA	228.3	1685	11/8/15 (ATD)
	CB-4	1883	1749	NA	N/A	N/A	N/A
	CB-13	1834	1654	NA	178.0	1680	6/14/16 (ATD)
	CB-14	1727	1551	1634	93.5 – 94.1	1648	7/7/16 – 7/16/16
	CB-15	1610	1462	NA	8	1604	7/15/16 (ATD)
	CB-16	1602.7	1469.5	NA	1.4	1602	11/15/16(ATD)
	CB-18	1784	1611	NA	145.0	1658	7/20/16 (ATD)
	CB-19	1610	1506	NA	11.0	1600	7/20/16 (ATD)

* Depths are measured along the lengths of the angled borings.
ATD = at time of drilling. Other measurements were obtained from piezometers installed in the borings.

6.7 Summary of Foundation Conditions

The geotechnical data for Axis 2 are shown graphically on Figures 6-1 to 6-3. The measured RQD values for slightly weathered to fresh rock generally range from about 40 to 100%. Typically, the upper part of the rock foundation is weathered and fractured, and the rock conditions improve with depth. The depths to slightly weathered to fresh rock are summarized in Table 6-1.

In the upper end of the proposed left abutment, at boring CB-12, predominantly slightly weathered rock was encountered at a depth of about 32 feet (approx. Elevation 1865 feet). Materials with P-wave velocities greater than 9,000 ft/s were encountered along seismic refraction line 2-11 at elevations below about 1860 feet. RQD values were typically 100% below Elevation 1845 feet.

Downhill from boring CB-12, the thickness of low-velocity, residual soils and/or highly weathered/fractured rock generally decreases with decreasing elevation (i.e., towards the channel). A similar trend in the thickness of intermediate-velocity, moderately weathered/fractured materials was also observed. These trends are consistent with the observed depths to slightly-weathered or fresh rock at borings CB-1, CB-2, and CB-17. At boring CB-1 (about 230 feet uphill from CB-2), highly to completely weathered, intensely fractured, very weak to extremely weak rock was encountered to a depth of approximately 88 feet, and there were many zones of no core recovery. Predominantly slightly weathered to fresh rock was encountered at a depth of about 133 feet (along the length of the inclined boring), which corresponds to about Elevation 1673 feet. At borings CB-2 and CB-17, predominantly slightly weathered or fresh rock was encountered at depths of only 4 feet and 6 feet, respectively. In CB-20 (about 220 feet downstream of Axis 2), the depth to slightly weathered to fresh rock was encountered at a depth of 16 to 24 feet.

Within the left abutment, the Lugeon values generally decrease with depth and range from 1 to more than 100. Although there are several exceptions, the Lugeon values are generally low (about 1 to 2) in slightly weathered to fresh bedrock within the left abutment.

Within the upper part of the right abutment, no materials with P-wave velocities greater than or equal to 10,000 ft/s were encountered in seismic lines 2-3, 2-10 and the west end of line 2-5. At the end of the right abutment, the depth to 5,000 ft/s rock is more than 65 feet, as measured in seismic line 2-3. This is consistent with the highly fractured rock conditions observed in borings CB-3 and CB-4. In boring CB-4, RQD values were generally low for the entire boring. The depth to predominantly slightly weathered to fresh rock does not decrease with decreasing elevation within the depth explored in the upper right abutment. Further downhill, the depth to predominantly slightly weathered rock at boring CB-13 is about 97 to 107 feet and about 25 to 30 feet in CB-18 (about 220 feet downstream of Axis 2).

Water pressure test data show that the hydraulic conductivities remain as high as 10 to 100 Lugeons and do not decrease consistently with depth at borings CB-3 and CB-4. This is likely due to the high degree of rock fracturing in both borings throughout the full depth of CB-3 and majority of CB-4.

In the valley bottom along Axis 2, along the Bear River, the depth to predominantly slightly weathered rock ranges from about 10 to 15 feet along the borings (about 8 to 10 feet vertical depth). The rock is highly fractured to a depth of 35 feet along boring CB-16 (27 feet vertically) as shown on Figure 6-1. The maximum measured hydraulic conductivity was about 10 Lugeons in the valley bottom.

7 Potential Rock Borrow Areas

7.1 General

The area identified in the Phase II Report for potential rock borrow areas was investigated during Phase III as discussed in Section 5.4. The areas were selected based on topographic conditions and proximity to the dam site area.

Both potential rock borrow areas that were investigated are located on hills, on the north side of the Bear River, north of the dam axis. The terrain consists of steep slopes with grass, brush and scattered tree cover. Numerous basalt outcrops were found in both rock borrow areas.

Both potential rock borrow areas, designated as the South Rock Borrow Area and the North Rock Borrow Area, were investigated to assess quantity and quality of the basalt for potential use as RCC and concrete aggregate. Core borings and seismic refraction surveys were carried out as shown on Figure 4-2. The geotechnical properties of the rock in both areas are discussed below along with the rock conditions and estimated stripping depths in these two areas.

7.2 Potential Borrow Area Rock Conditions

7.2.1 Weathering and Fracturing

The core boring logs show that the degree of weathering is variable. The borings typically encountered significant depths of completely weathered to highly weathered, weak to very weak, and highly to intensely fractured rock, with low RQD values, typically 0 to 20%. With increasing depth, the borings encountered slightly weathered to fresh rock, which was generally less fractured and had higher RQDs (frequently 100%).

Table 7-1 summarizes the borings drilled in the South and North potential rock borrow areas.

Table 7-1. Summary of Core Boring Results – Potential Rock Borrow Areas

Rock Borrow Area	Boring No.	Total Drilled Depth* (ft)	Approx. Drilled Depth to Weathered Rock (ft)	Drilled Depth to Predominantly Slightly Weathered/Fresh Rock (ft)
South	CB-B1	200.9	8	20
	CB-B2	100.0	9	45
	CB-B3	101.3	7	45-51
	CB-B4	103.5	6	45
	CB-B5	79.0	4	60
North	CB-B6	58.0	4	28
	CB-B7	53.0	2	3
	CB-B8	68.1	10	44

* Depths are measured along the lengths of the angled borings.

7.2.2 Seismic Velocities

South Rock Borrow Area

The seismic velocity profiles for the South borrow area are shown in Appendix C-2 and on Figure 7-1. The weathering profile in the south area generally follows the topography as shown on Figure 7-1. The seismic refraction surveys indicate that the depth of residual soils, colluvium, highly weathered and/or highly fractured bedrock (P-wave velocities of less than 5000 ft/s) ranges from less than 10 feet to about 40 feet. Beneath this low velocity layer, a zone of intermediate velocities (5,000 to 9,000 ft/s) is interpreted as moderately weathered and/or fractured bedrock. High velocities in seismic lines BA-2 and BA-4, in the range of 9,000 to 11,000 ft/s, indicate slightly weathered to fresh rock at depths up to about 60 feet. Velocities up to 8,000 ft/s were encountered in seismic refraction lines BA-1 and BA-3 up to 60 feet deep.

Boring CB-B5 was drilled to confirm weathering conditions in a topographic saddle. Up to 60 feet of weathering was encountered at that location.

The seismic velocity profiles from the downhole velocity surveys are plotted on Figure 7-1. The data shows P-wave velocities up to 20,000 ft/s at depths of 60 to 80 feet, indicating slightly weathered to fresh rock at those depths.

North Rock Borrow Area

The seismic velocity profiles for the North borrow area are shown in Appendix C-2 and on Figure 7-2. The weathering profile generally follows the topography as shown on Figure 7-2. The seismic refraction surveys indicate depths of residual soils, colluvium, highly weathered and/or highly fractured bedrock (P-wave velocities of less than 5,000 ft/s) range from less than 10 feet to about 50 feet. Beneath this low velocity layer, a zone of intermediate velocities (5,000 to 9,000 ft/s) is interpreted as moderately weathered and/or fractured bedrock. High velocities in seismic lines BA-5 and BA-6, in the range of 9,000 to 11,000 ft/s, indicate slightly weathered to fresh rock at depths from 10 to 38 feet on the northwest flank of the North Rock Borrow Area. Similar conditions were found more than 60 feet deep at the southwest end of line BA-6 and along BA-7.

The seismic velocity profiles from the downhole velocity surveys plotted on Figure 7-2 show P-wave velocities up to 15,000 ft/s at depths of 10 to 30 feet, indicating slightly weathered to fresh rock at those depths.

7.2.3 Rock Strength

UCS tests were performed on selected testable core samples with a length-to-diameter ratio of about 2. Shorter cores were tested by a point load device in the field.

The UCS data (Appendix H-2) are summarized in Table 7-2 for fresh to slightly weathered rock core samples.

Table 7-2. Summary of UCS Tests on Core Samples

Rock Borrow Area	Degree of Weathering	Median UCS (psi)	Range of UCS (psi)	Number of Tests
South	Fresh to Slightly	10,400	2,200-22,200	8
North	Fresh to Slightly	14,200	8,500-54,100	6

The point-load test data is presented in Appendix I-2 and summarized in Table 7-3. The data is summarized in Table 7-3 by degree of weathering.

Table 7-3. Summary of Point Load Tests on Core Samples

Rock Borrow Area	Degree of Weathering	Median UCS (psi)	Range of UCS (psi)	Number of Tests
South	Moderately	N/A	17,600	1
	Slightly to Moderately	N/A	24,800	1
	Fresh to Slightly	N/A	19,700	1
North	Fresh to Slightly	22,900	10,700-26,600	3

The data is insufficient data to show a clear correlation between weathering and strength; however, the slightly weathered to fresh rock is expected to have greater strength than the more weathered rock.

7.2.4 Rock Durability

As discussed in Section 5.4.4, durability tests were performed on rock core samples from the South and North Borrow Areas to evaluate suitability for RCC and concrete aggregate. These tests consisted of abrasion, sodium sulfate soundness, bulk specific gravity, and absorption. The test results are summarized in Table 7-4, together with typical concrete aggregate acceptance criteria.

Table 7-4. Summary of Rock Durability Tests on Core Samples

Rock Borrow Area	South Rock Borrow Area	North Rock Borrow Area	Acceptance Criteria*
Abrasion – % weight loss at 100 revolutions	5.3%	5.5%	10% max.
Abrasion – % weight loss at 500 revolutions	19.4%	20.0%	40% max.
Sodium Sulfate Soundness –% weight loss at 5 cycles	1.7%	4.4%	10% max.
Bulk Specific Gravity	2.80	2.75	2.60 min.
Absorption %	0.2%	0.8%	2.0% max.

*ASTM C 33

7.3 Rock Conditions, Estimated Stripping Depths and Groundwater

Based on the investigation results presented above, the South and North potential rock borrow areas have similar geotechnical conditions (refer to Figures 7-1 and 7-2). Stripping will be required to remove soil and weathered rock to expose slightly weathered to fresh rock suitable for RCC and concrete aggregate. Based on the core boring and seismic refraction data, overburden stripping depths to expose suitable rock in the South Rock Borrow Area could range from 20 to 60 feet. Stripping depths in the North Rock Borrow Area could also be up to 60 feet. If the on-site rock borrow areas are considered further, additional investigation would be needed to lay out the rock excavations to minimize stripping volume.

The rock strengths are similar within the two potential rock borrow area locations. The slightly weathered to fresh basalt has high strengths, with measured values up to about 50,000 psi, but predominantly between 7,000 and 22,000 psi. The abrasion test data and bulk specific gravities from the two areas are similar. However, the South Rock Borrow Area samples tested had lower weight loss in the sodium sulfate test and lower absorption. The durability test data indicate that the slightly weathered to fresh basalt from both areas would satisfy ASTM C33 concrete aggregate acceptance criteria.

Groundwater levels were measured in the borings during the Phase III investigation in June and July 2016. In the South Rock Borrow Area, depths to groundwater ranged from about 58 feet (in CB-B5, in a topographic saddle) to 80 feet (in CB-B1, at the top of the hill). In the North Rock Borrow Area, groundwater was not encountered in CB-B6 and CB-B7, and was at about 26 feet in CB-B8 (soon after the boring was completed and may reflect drill water).

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8 Conclusions and Recommendations

This Phase III Geotechnical Engineering Report builds on the results of the Phase I and II reports and incorporates the relevant results of the two previous phases. The Phase III dam site geotechnical investigation focused on an RCC dam at Axis 2 with the objective of characterizing the rock foundation. Borrow investigations were carried out to confirm the nature and depth of the available rock materials for potential use as RCC aggregate including the amount of overburden that would need to be stripped and wasted.

8.1 Dam Foundation

As concluded in the Phase II study, the site at Axis 2 is acceptable for an RCC dam (AECOM, 2016a). The current Phase III geotechnical investigation confirms this conclusion.

The upper part of the rock foundation at Axis 2 is weathered and fractured, and the rock conditions improve with depth. The degree of fracturing and weathering decreases with depth, and generally hydraulic conductivities also tend to decrease with depth, with the exception of the upper part of the right abutment. As stated in the Conceptual Design Criteria Technical Memorandum (AECOM, 2016d), the foundation objective is to found the RCC dam mainly on slightly weathered to fresh, hard rock. It is expected that some localized areas of moderately weathered rock will be present in the foundation. In the upper abutments, where the dam will be low, slightly to moderately weathered rock will be evaluated to confirm its acceptability to satisfy stability criteria. The depth of excavation is expected to extend to 100 feet in some locations of the foundation (e.g., at boring CB-1 in the left abutment and in CB-13 in the right abutment). The discontinuity analysis indicates that the more prominent features observed in borings and borehole televiewer surveys are not likely to persist as discrete, continuous foundation defects.

The rock characterization at Axis 2 as described in this report will be used to inform further decision making on the configuration of the dam foundation and the depth and extent of the grout curtain. The rock characterization will also be used to assess the strength properties of the dam foundation to confirm that necessary stability criteria are met. The recommended dam foundation configuration, including the grout curtain layout, is the subject of the Conceptual Engineering Report.

8.2 Rock Borrow Materials

The geotechnical investigation results indicate that sufficient quantities of suitable quality rock are available on site for RCC aggregate. The durability test data indicate that the slightly weathered to fresh basalt from the two potential borrow areas investigated would satisfy both RCC and concrete aggregate acceptance criteria.

Based on the investigation results, the South and North rock borrow areas have similar geotechnical conditions. Stripping will be required to remove soil and weathered rock to expose slightly weathered to fresh basalt suitable to produce RCC and concrete aggregate. Based on the core boring and seismic refraction data, overburden stripping depths to expose suitable rock in the South and North Rock Borrow Areas could extend to as deep as 60 feet.

If the on-site rock borrow areas are considered further, additional investigation would be needed to locate the rock excavations to minimize stripping volume. Another rock borrow source under consideration is the existing Bear River Quarry, south of the dam site.

Subsequent to the geotechnical investigation, a future bridge over the Bear River was located close to the North Rock Borrow Area. It is planned that the bridge will be constructed prior to rock borrow excavation operations and, therefore, this area will be precluded from use.

8.3 Recommendations for Geotechnical Investigation for Design

The geotechnical investigations to date have been carried out in three phases, in 2015 (Phases I and II) and 2016 (Phase III). A fourth phase of geotechnical investigations is recommended to obtain additional data needed to develop the project design and reduce uncertainty.

As for the previous phases, the fourth phase of investigations in the dam foundation should include seismic refraction surveys, core borings, water pressure (packer) testing, and televiewer/caliper logging to fill in data gaps. Laboratory testing should include strength of rock foundation materials. In addition, in situ testing of the rock mass strength and stiffness (using a downhole dilatometer device) may be appropriate in fractured zones of selected borings, to help establish and verify the minimum excavation depths.

If the on-site rock borrow areas are considered further, additional investigation would be needed to further characterize the subsurface conditions and to locate the rock excavations to minimize stripping volume. Borrow investigations should be carried out to confirm the depth of useable rock materials. The investigation should assess the amount of overburden that would need to be stripped and wasted. These investigations should include additional seismic refraction surveys, core borings, and laboratory testing. The testing should include strength of the rock materials, abrasion resistance, soundness and bulk specific gravity. Petrographic examination of the rock should also be performed to verify the minerology and the absence of potentially deleterious constituents. The potential for alkali reactivity of the rock to be used for RCC aggregate should be evaluated.

9 References

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Figures

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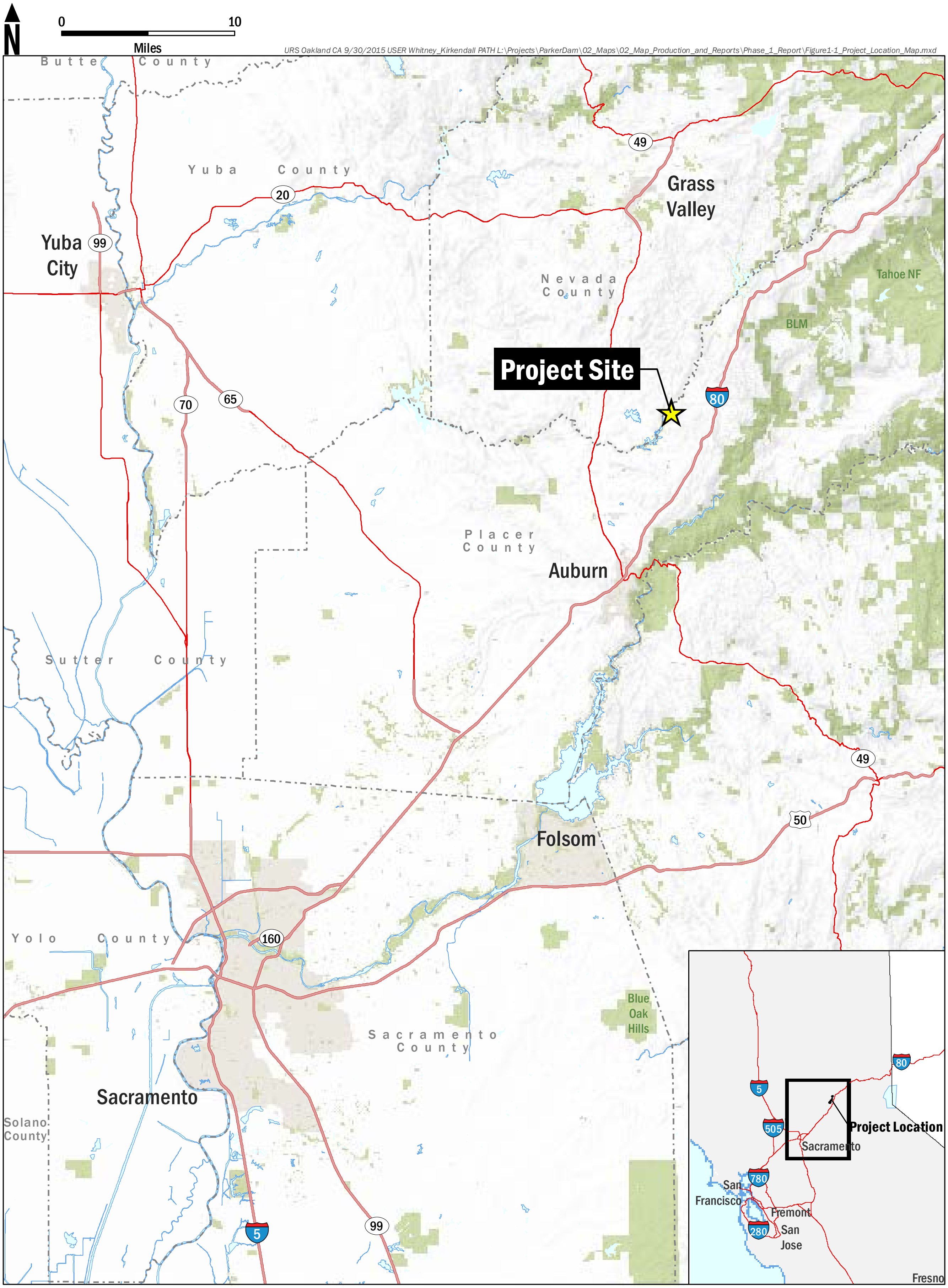


AECOM

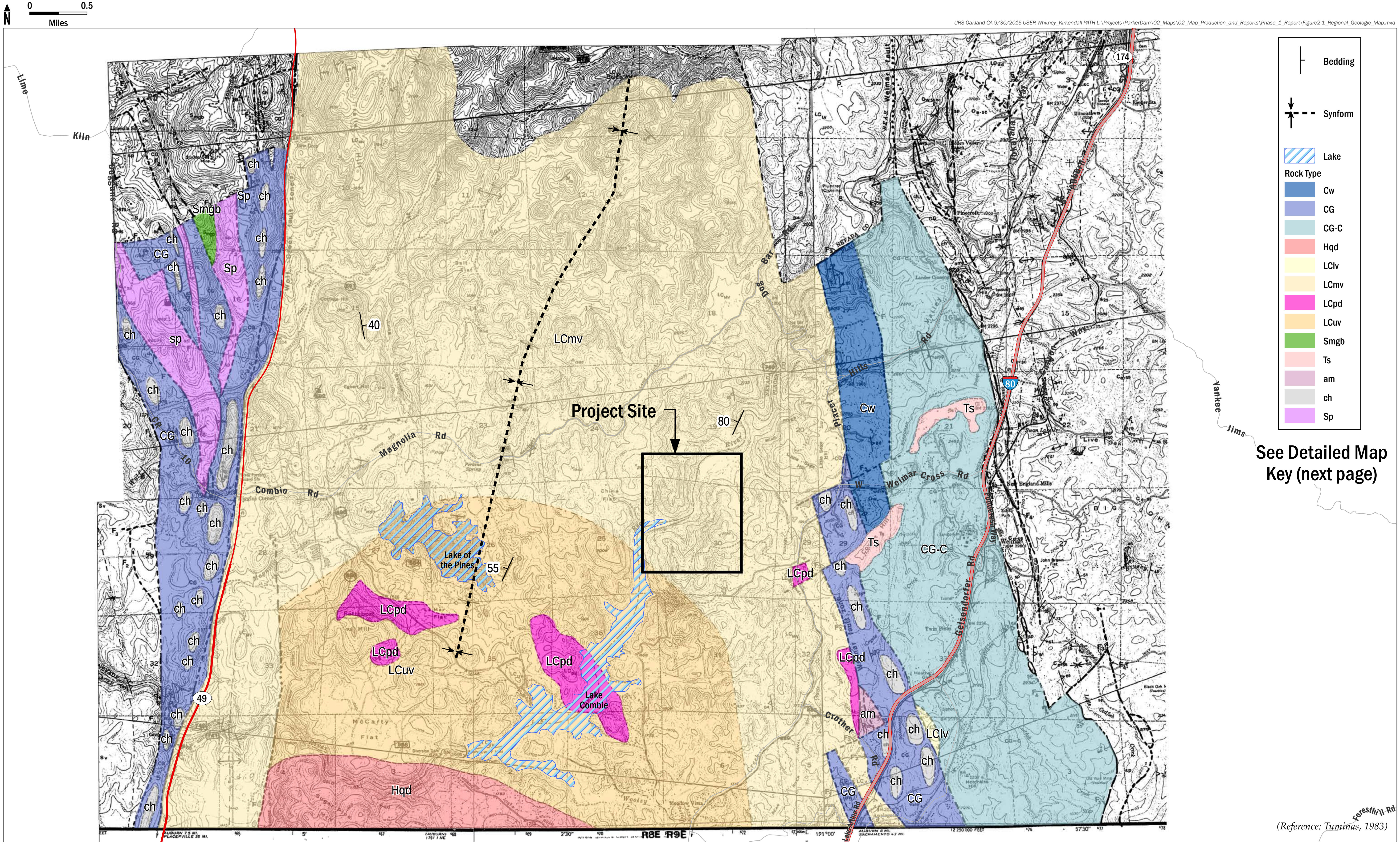
Nevada Irrigation District

Centennial Reservoir Project

60503855

FIGURE 1-1

Project Location Map



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Centennial Reservoir Project

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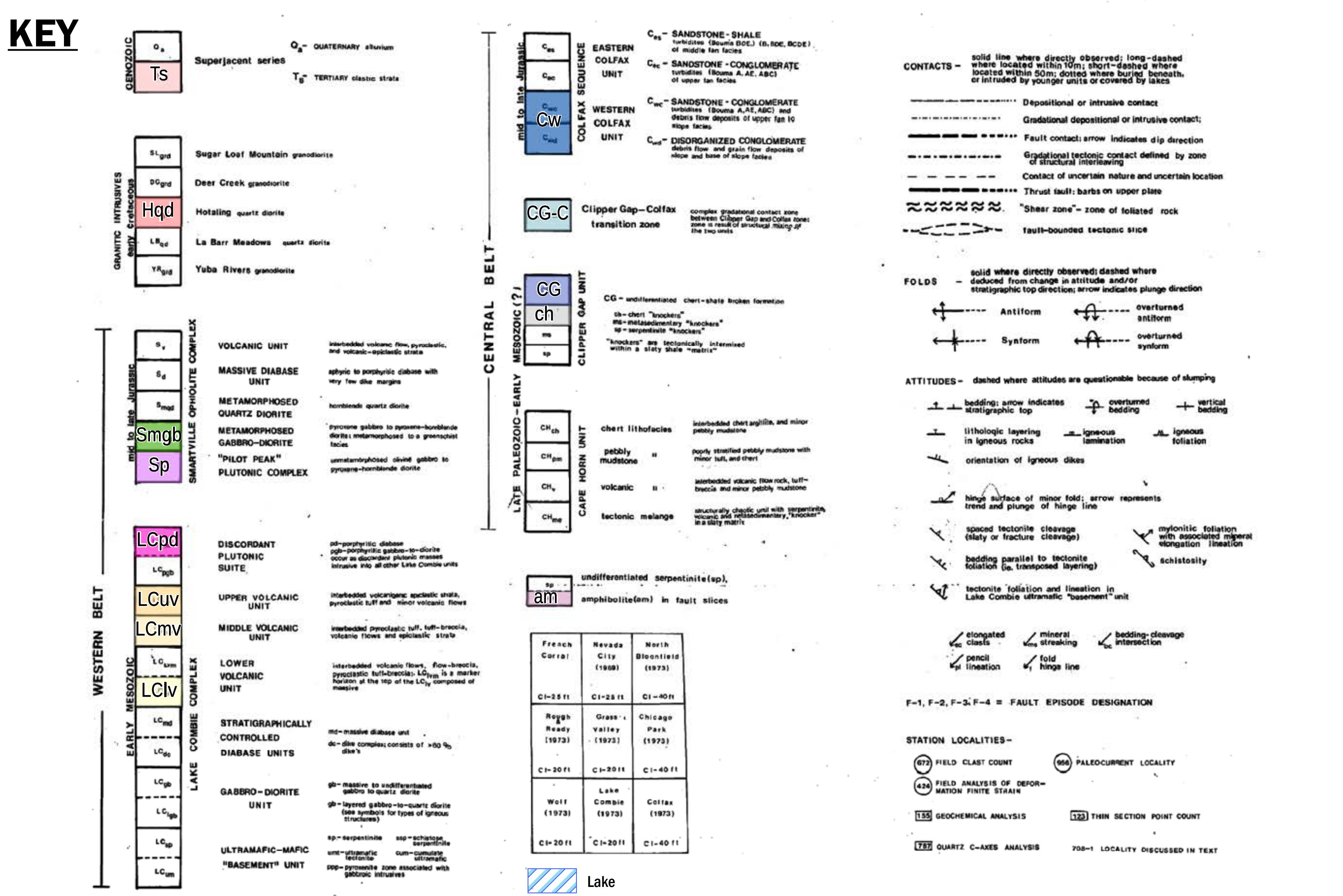
FIGURE 2-1

Regional Geologic Map



(Reference: Tuminas, 1983)

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Nevada Irrigation District

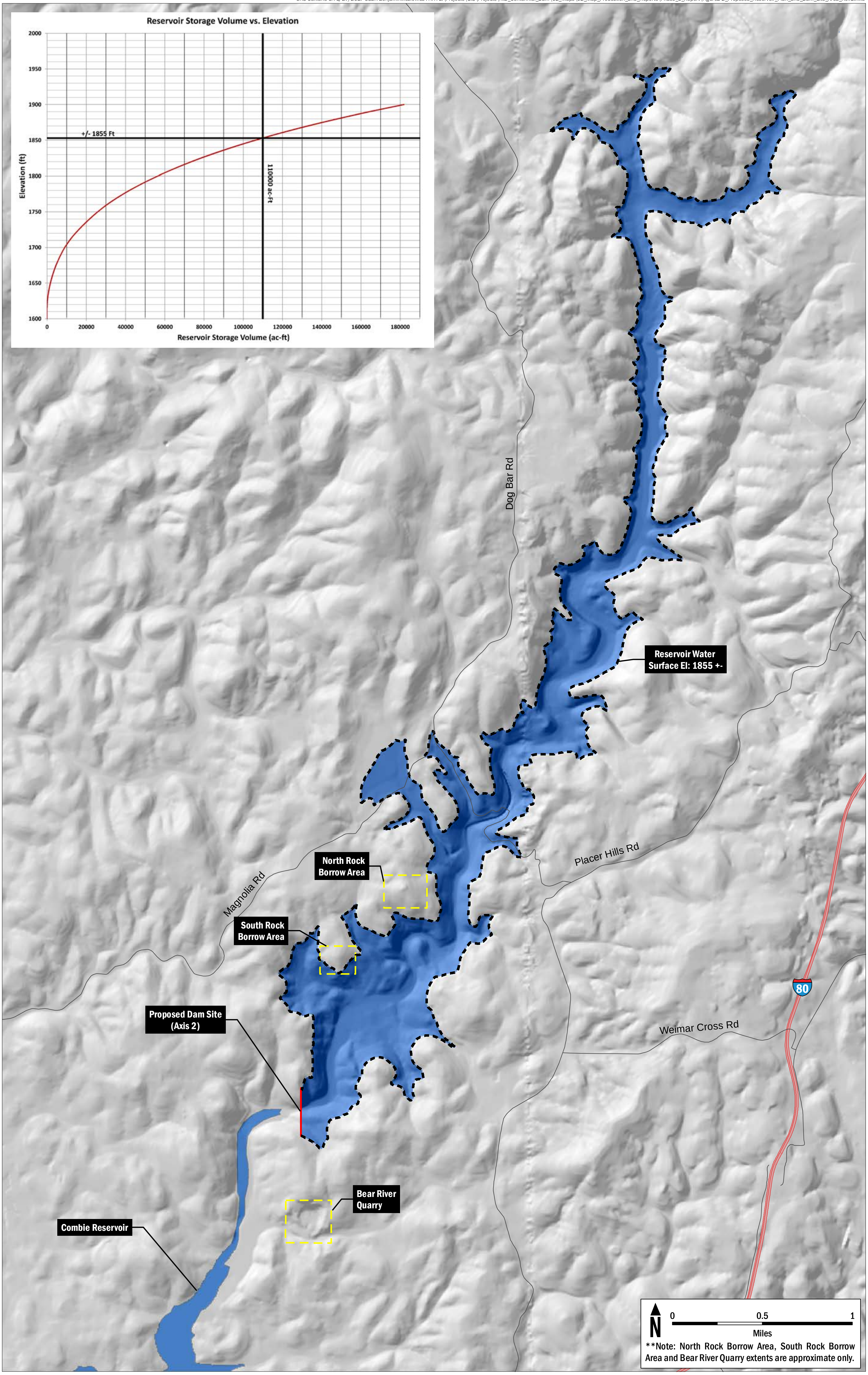
Centennial Reservoir Project

60503855

FIGURE 2-1 (CONT'D)

Regional Geologic Map

URS Oakland CA 1/27/2017 USER Benjamin.kozlowicz PATH L:\Projects\GIS\Projects\NID_Centennial_Dam\02_Maps\02_Map_Production_and_Reports\Phase_3_Report\Figure2-2_Proposed_Reservoir_Plan_and_Dam_Site_Area_Rev1.mxd



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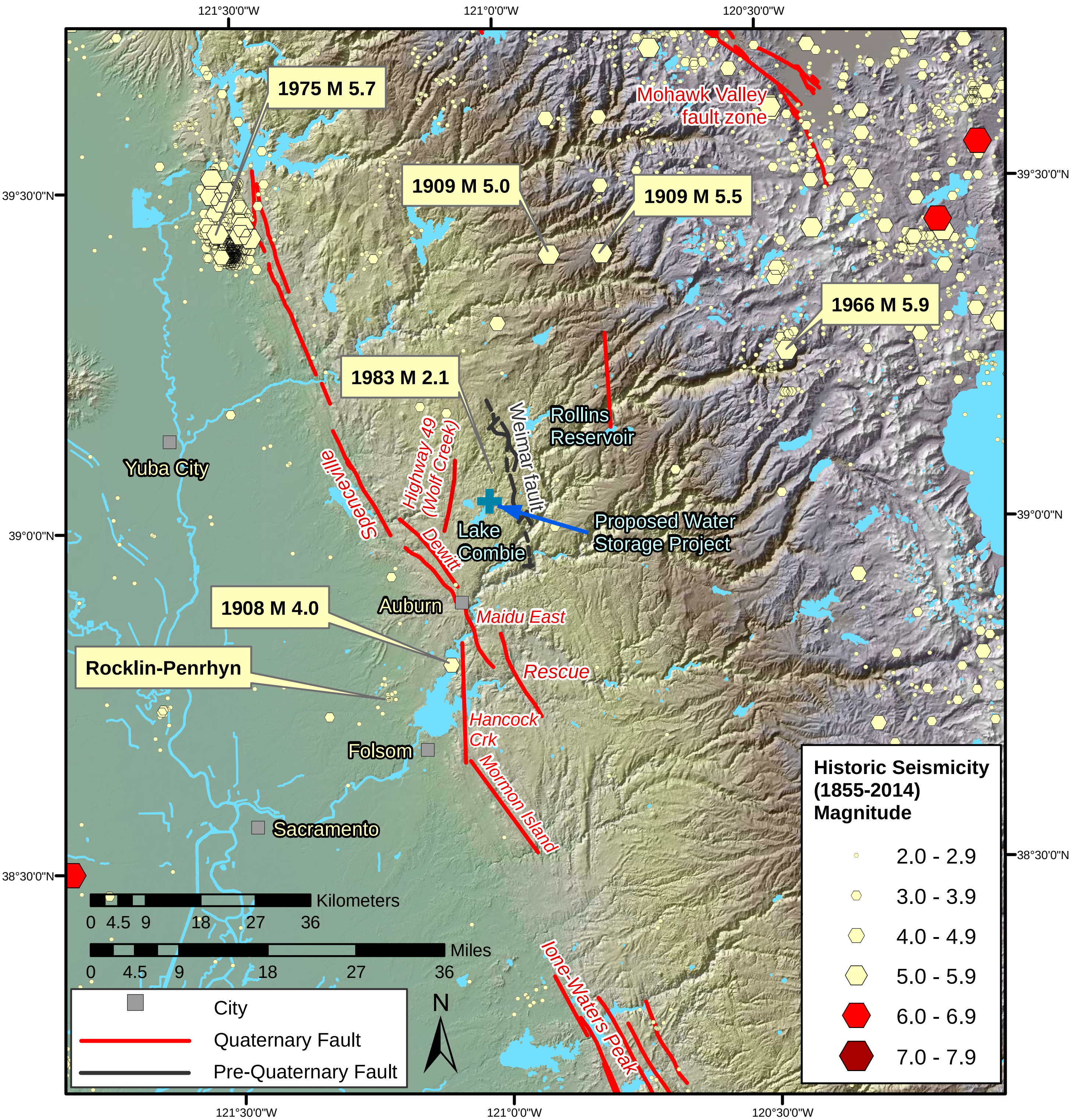
Nevada Irrigation District

Centennial Reservoir Project

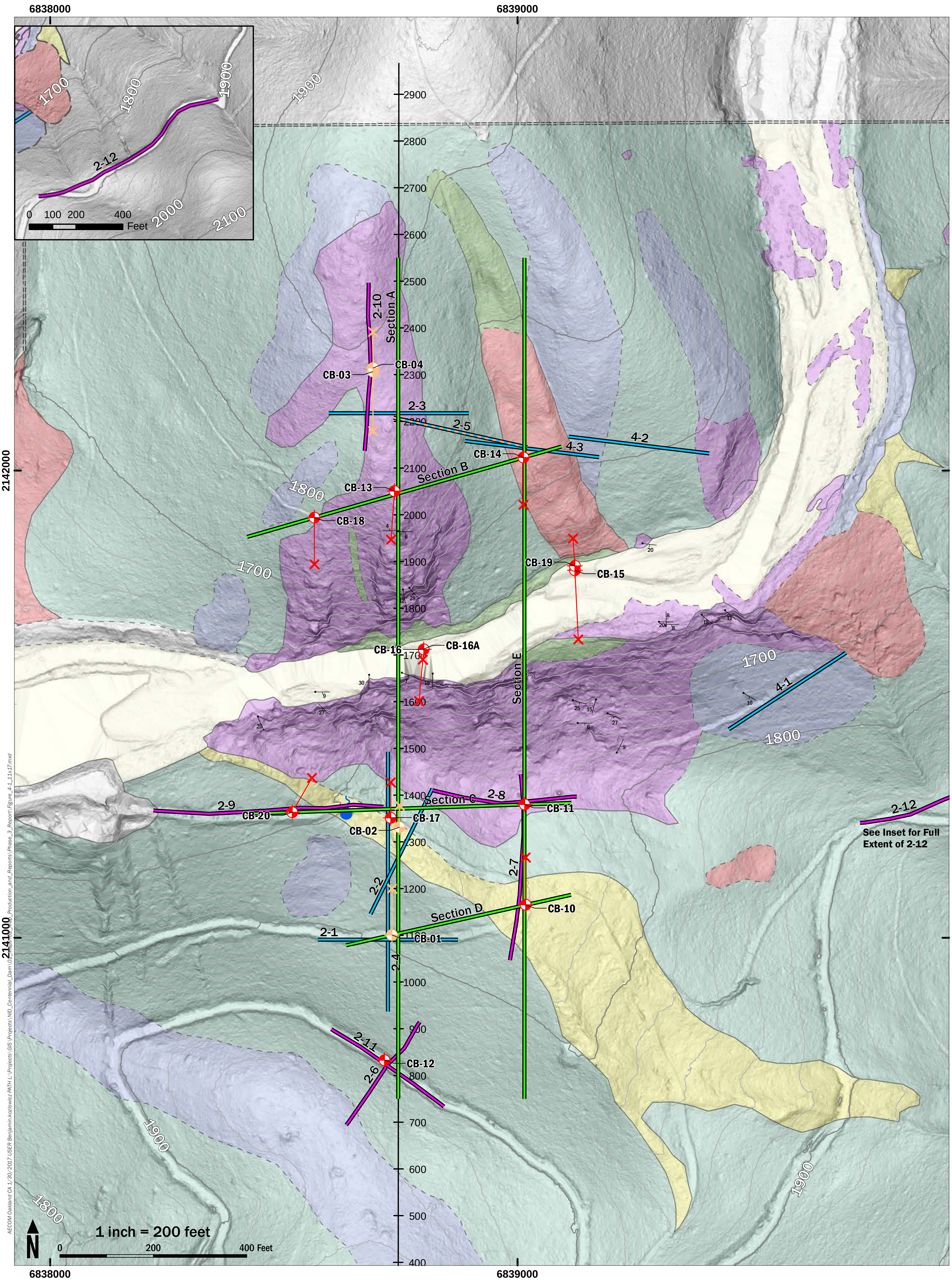
60503855

FIGURE 2-2

Centennial Reservoir Plan



AECOM	Project No. 60503855	HISTORICAL SEISMICITY (1855-2014)	Figure
	Nevada Irrigation District		3-1



Borings

- Borehole Top, Phase II
- Inclined Borehole Bottom, Phase II
- Borehole Top, Phase III
- Inclined Borehole Bottom, Phase III

- Proposed Dam Axis 2
- Geologic Cross Section Alignment
- Seismic Refraction Survey (Phase I)
- Seismic Refraction Survey (Phase II)
- Seismic Refraction Survey (Phase III)

- Index Contour (100ft)
- Contour (20ft)

- Bedding
- Spring

Surficial Geology
Contacts

- contact, approximate or gradational
- contact
- Limit of Mapping

Surficial Geology
Units

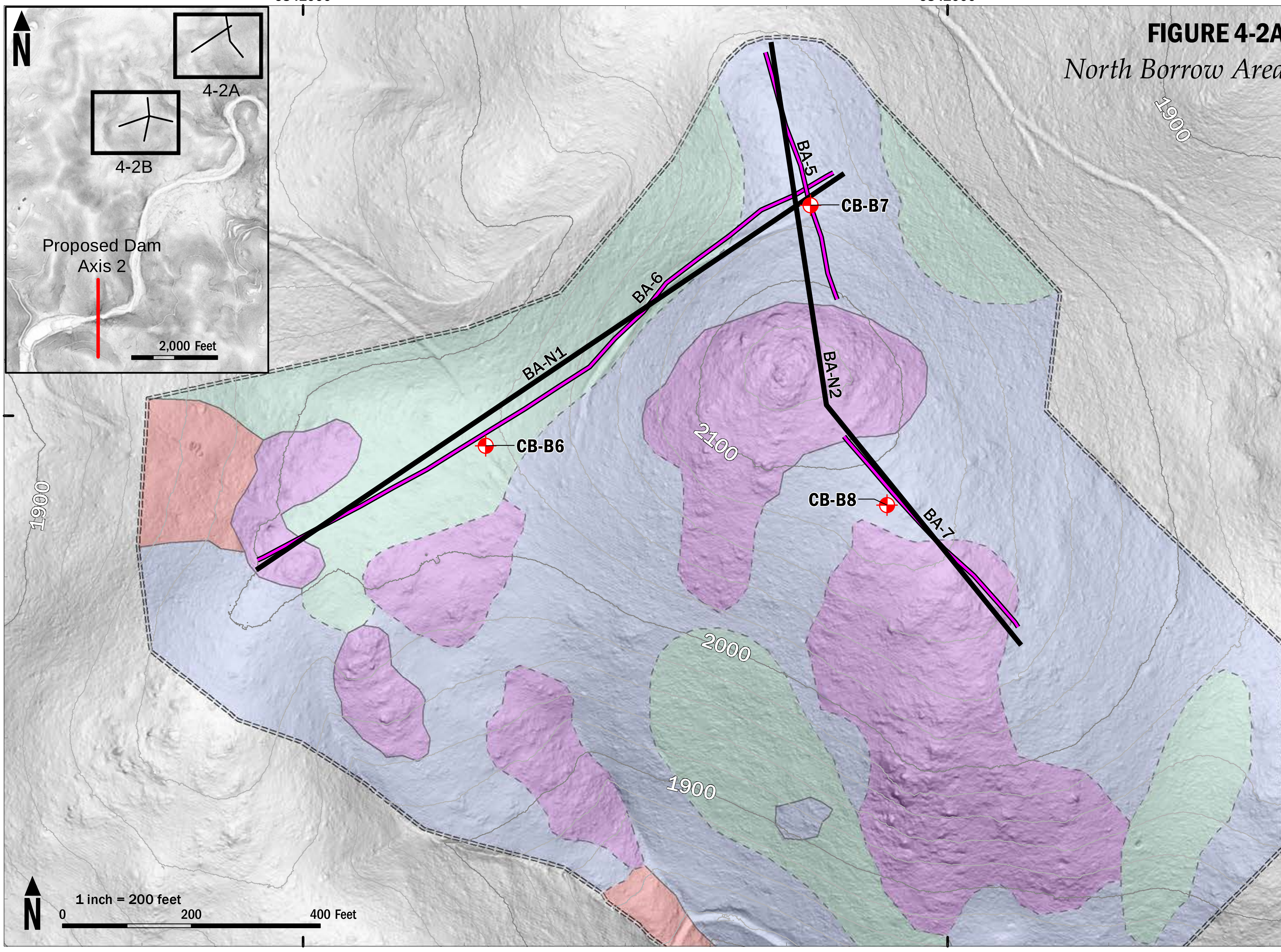
- Artificial Fill/Disturbed Ground
- Channel Alluvium
- Alluvial/Debris Fan Deposits
- Talus/Colluvial Deposits
- Landslide/Debris Flow Deposits
- Colluvial Slope
- Bedrock Outcrop-Class 1
- Bedrock Slope-Class 2

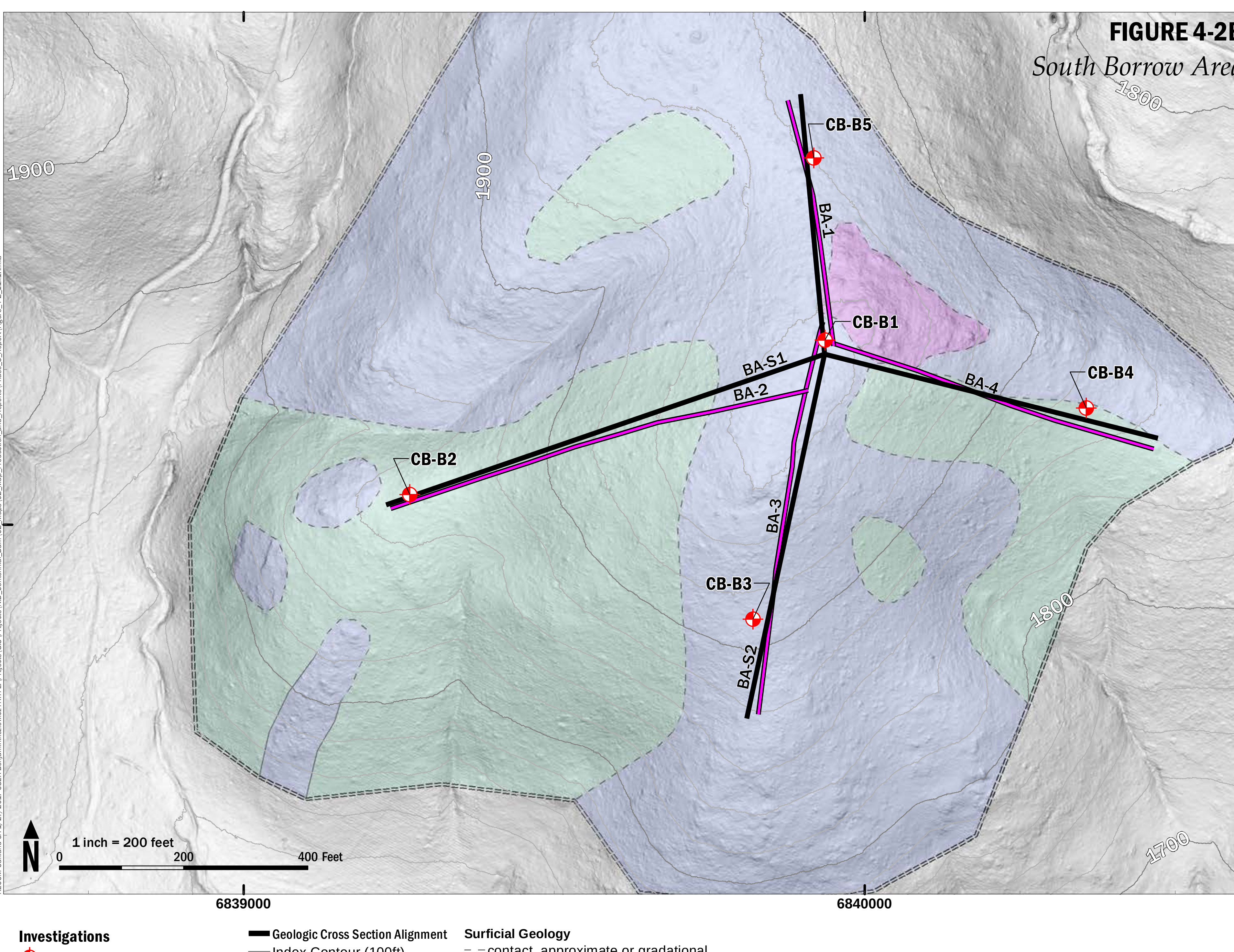
Reference:
NID Parker Dam Lidar, Nevada Irrigation District, November 2014.

AECOM
Nevada Irrigation District
Centennial Reservoir Project
60503855

FIGURE 4-1

Surficial Geology and Geotechnical Exploration Plan





Investigations
Borehole, Phase III
Seismic Refraction Survey (Phase III)

Geologic Cross Section Alignment
Index Contour (100ft)
Contour (20ft)

Surficial Geology
contact, approximate or gradational
contact
Limit of Mapping

Units
Residual Soil/Colluvium
Landslide/Debris Flow Deposits
Bedrock Outcrop-Class 1
Bedrock Slope-Class 2

Reference:
NID Parker Dam Lidar,
Nevada Irrigation District, November 2014.

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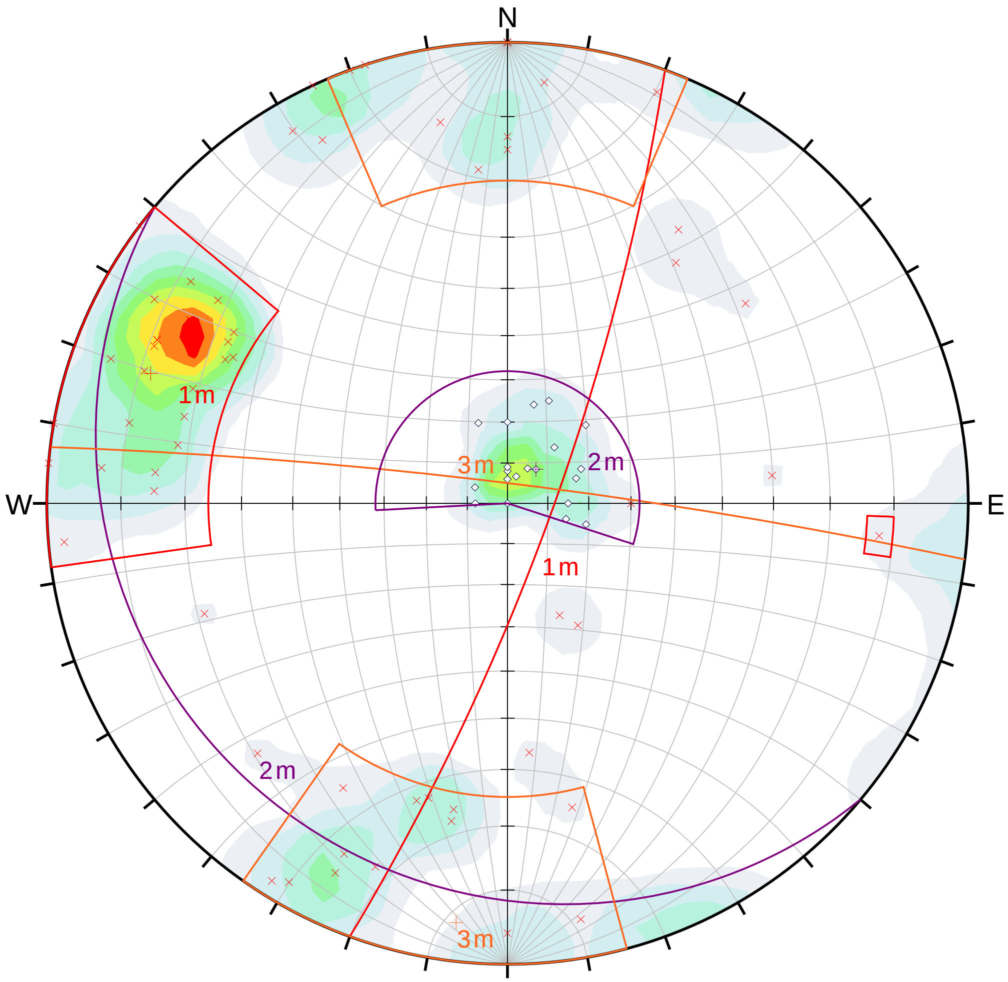
Nevada Irrigation District
Centennial Reservoir Project
60503855

FIGURE 4-2
Geotechnical Exploration Plan
Potential Rock Borrow Areas



Symbol	TYPE	Quantity
◇	bedding	20
×	joint	61

Color	Density Concentrations
	0.00 - 1 20
	1.20 - 2.40
	2.40 - 3 60
	3.60 - 4 80
	4.80 - 6 00
	6.00 - 7 20
	7.20 - 8.40
	8.40 - 9 60
	9.60 - 10 80
	10.80 - 12 00

Contour Data	Pole Vectors
Maximum Density	11.97%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	81 (81 Entries)
Hemisphere	Lower
Projection	Equal Angle

AECOM

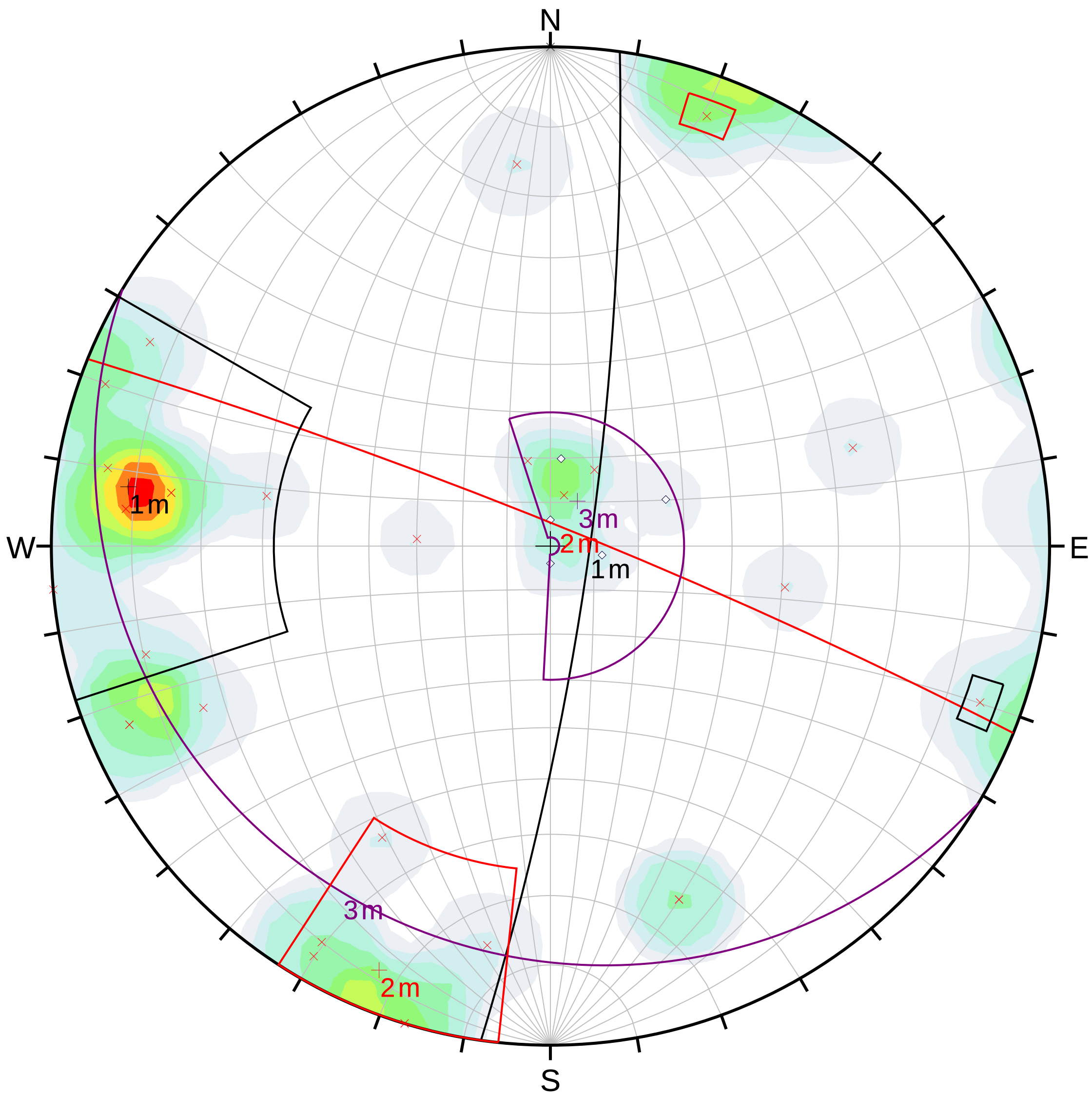
Nevada Irrigation District

Centennial Reservoir Project

60503855

Figure 4-3a

Stereonet Plots of Surface Discontinuities - Dam Site Left Abutment



Symbol	TYPE	Quantity
◇	bedding	5
×	joint	30

Color	Density Concentrations
	0.00 - 1.40
	1.40 - 2.80
	2.80 - 4.20
	4.20 - 5.60
	5.60 - 7.00
	7.00 - 8.40
	8.40 - 9.80
	9.80 - 11.20
	11.20 - 12.60
	12.60 - 14.00

Contour Data	Pole Vectors
Maximum Density	13.04%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	35 (35 Entries)
Hemisphere	Lower
Projection	Equal Angle

Figure 4-3b

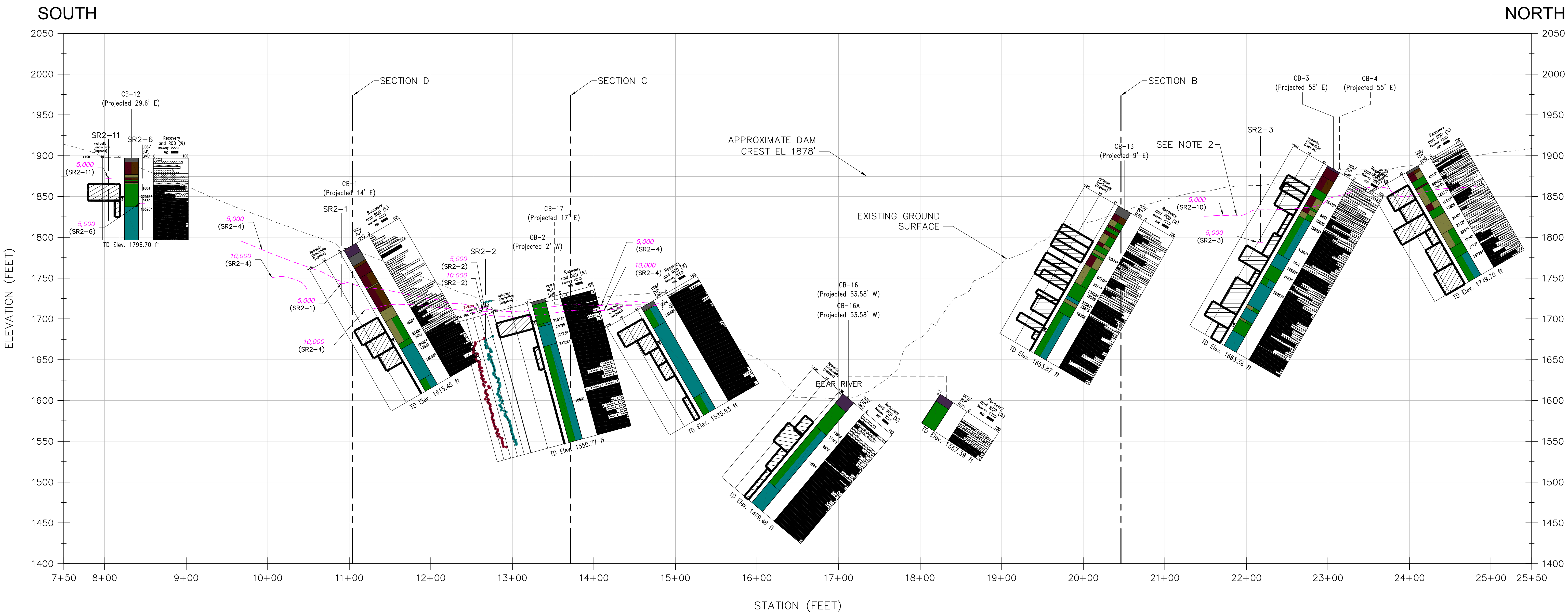
Stereonet Plots of Surface Discontinuities - Dam Site Right Abutment

AECOM

Nevada Irrigation District

Centennial Reservoir Project

60503855



SECTION A 4-1
SCALE: 1" = 60'

LEGEND:

WEATHERING PROFILE:

- COLLUVIUM
- RESIDUAL SOIL
- COMPLETELY WEATHERED
- HIGHLY WEATHERED
- MODERATELY WEATHERED
- SLIGHTLY WEATHERED
- FRESH

GROUNDWATER LEVEL DURING DRILLING (MAY NOT REFLECT NATURAL GROUNDWATER LEVEL)

TD — TOTAL DEPTH OF HOLE

UCS/PLI* — UNCONFINED COMPRESSIVE STRENGTH; * INDICATES RESULT FROM POINT LOAD TEST; SEE APPENDICES H AND I FOR DETAILS

5,000 — P-WAVE VELOCITY (ft./sec.) FROM SEISMIC REFRACTION SURVEY; SEE APPENDIX C FOR DETAILS

SR2-4 — SEISMIC REFRACTION LINE 2-4

LOCATION OF SR LINE, AT CROSSING OF PROFILE

NOTES:

1. ELEVATION DATUM IS NAVD (1988).
2. WHERE SEISMIC REFRACTION PROFILE DATA ARE PROJECTED ONTO THE SECTION FROM SURVEYS ACQUIRED AT DIFFERENT SURFACE ELEVATIONS, THE DEPTH TO THE PROFILE DATA IS MAINTAINED.

0 60 120 Feet

AECOM

60503855

NEVADA IRRIGATION DISTRICT
CENTENNIAL RESERVOIR PROJECT

Geotechnical Profile
Axis 2

FIGURE 6-1

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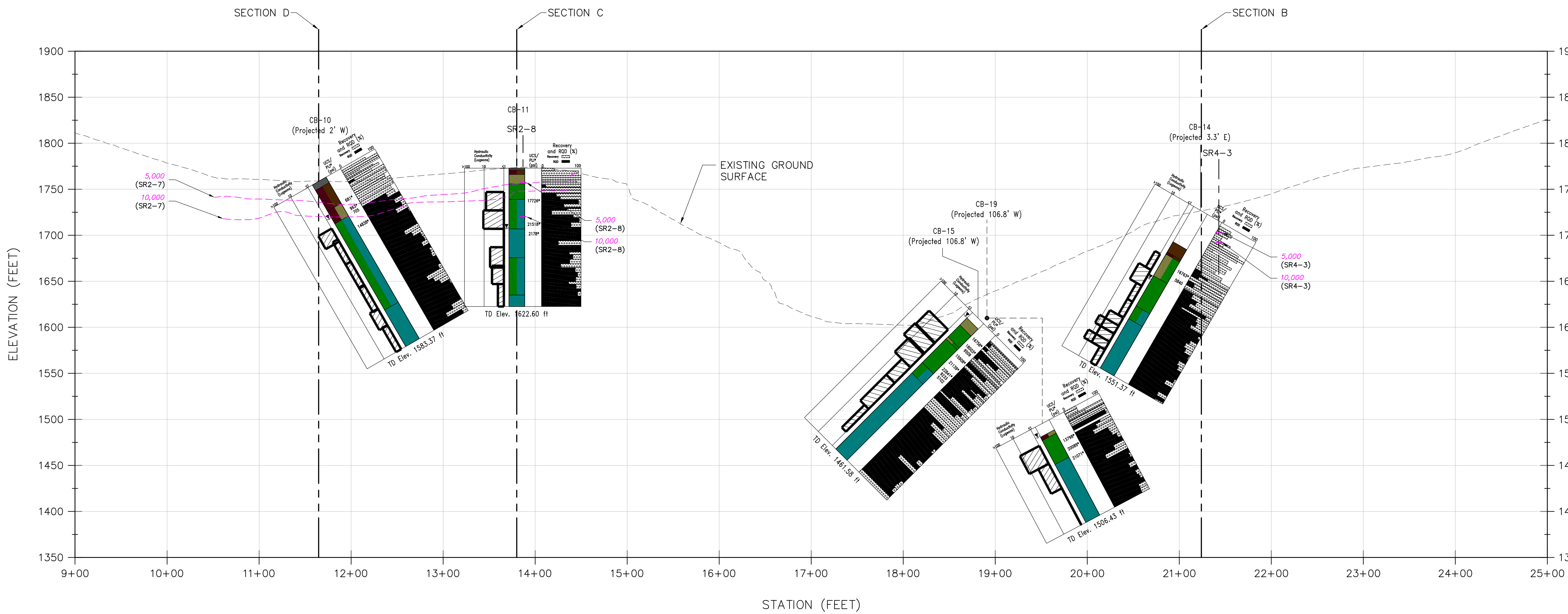

SECTION E
4-1
SCALE: 1" = 60'

LEGEND:

WEATHERING PROFILE:

- COLLUVIUM
- RESIDUAL SOIL
- COMPLETELY WEATHERED
- HIGHLY WEATHERED
- MODERATELY WEATHERED
- SLIGHTLY WEATHERED
- FRESH

GROUNDWATER LEVEL DURING DRILLING (MAY NOT REFLECT NATURAL GROUNDWATER LEVEL)

TD — TOTAL DEPTH OF HOLE

UCS/PLI* — UNCONFINED COMPRESSIVE STRENGTH; * INDICATES RESULT FROM POINT LOAD TEST; SEE APPENDICES H AND I FOR DETAILS

5,000 — P-WAVE VELOCITY (ft./sec.) FROM SEISMIC REFRACTION SURVEY; SEE APPENDIX C FOR DETAILS

SR2-4 — SEISMIC REFRACTION LINE 2-4

LOCATION OF SR LINE, AT CROSSING OF PROFILE

0 60 120 Feet

NOTES:

1. ELEVATION DATUM IS NAVD (1988).
2. WHERE SEISMIC REFRACTION PROFILE DATA ARE PROJECTED ONTO THE SECTION FROM SURVEYS ACQUIRED AT DIFFERENT SURFACE ELEVATIONS, THE DEPTH TO THE PROFILE DATA IS MAINTAINED.
3. SECTION E IS 270 FT. UPSTREAM OF SECTION A.

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NEVADA IRRIGATION DISTRICT
CENTENNIAL RESERVOIR PROJECT

Geotechnical Profile
Upstream of Axis 2

FIGURE
6-2

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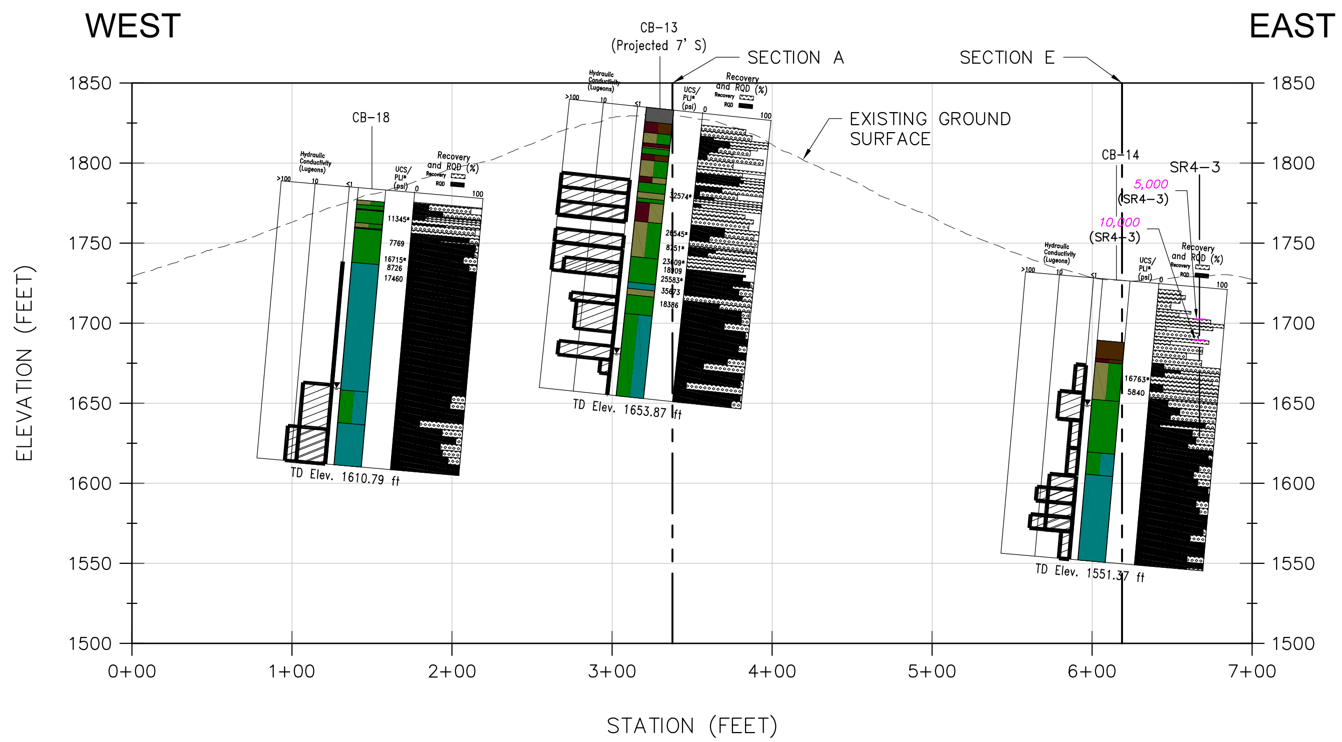
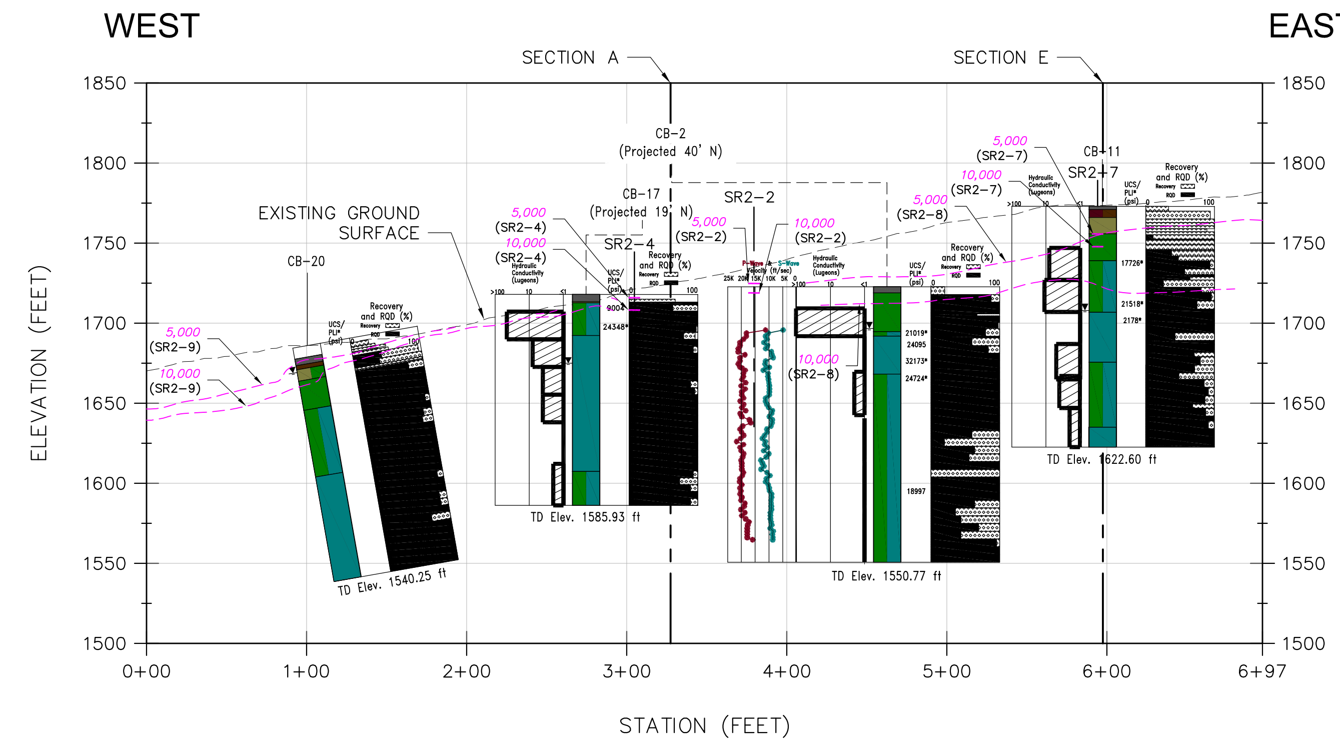
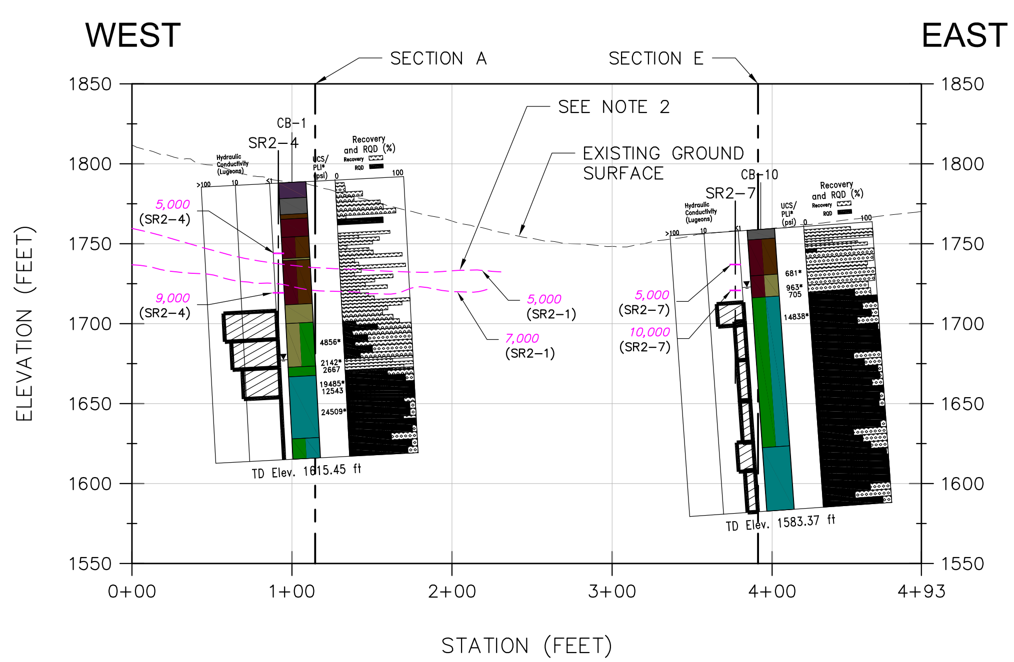


SECTION B
SCALE: 1" = 60'
B 4-1



SECTION C
SCALE: 1" = 60'
C 4-1



SECTION D
SCALE: 1" = 60'
D 4-1

LEGEND:

WEATHERING PROFILE:
- COLLUVIUM
- RESIDUAL SOIL
- COMPLETELY WEATHERED
- HIGHLY WEATHERED
- MODERATELY WEATHERED
- SLIGHTLY WEATHERED
- FRESH

▼	GROUNDWATER LEVEL DURING DRILLING (MAY NOT REFLECT NATURAL GROUNDWATER LEVEL)
TD	TOTAL DEPTH OF HOLE
UCS/PLI*	UNCONFINED COMPRESSIVE STRENGTH; * INDICATES RESULT FROM POINT LOAD TEST; SEE APPENDICES H AND I FOR DETAILS
5,000	P-WAVE VELOCITY (ft./sec.) FROM SEISMIC REFRACTION SURVEY; SEE APPENDIX C FOR DETAILS
SR2-4	SEISMIC REFRACTION LINE 2-4
	LOCATION OF SR LINE, AT CROSSING OF PROFILE

0 60 120 Feet

NOTES:

1. ELEVATION DATUM IS NAVD (1988).
2. WHERE SEISMIC REFRACTION PROFILE DATA ARE PROJECTED ONTO THE SECTION FROM SURVEYS ACQUIRED AT DIFFERENT SURFACE ELEVATIONS, THE DEPTH TO THE PROFILE DATA IS MAINTAINED.

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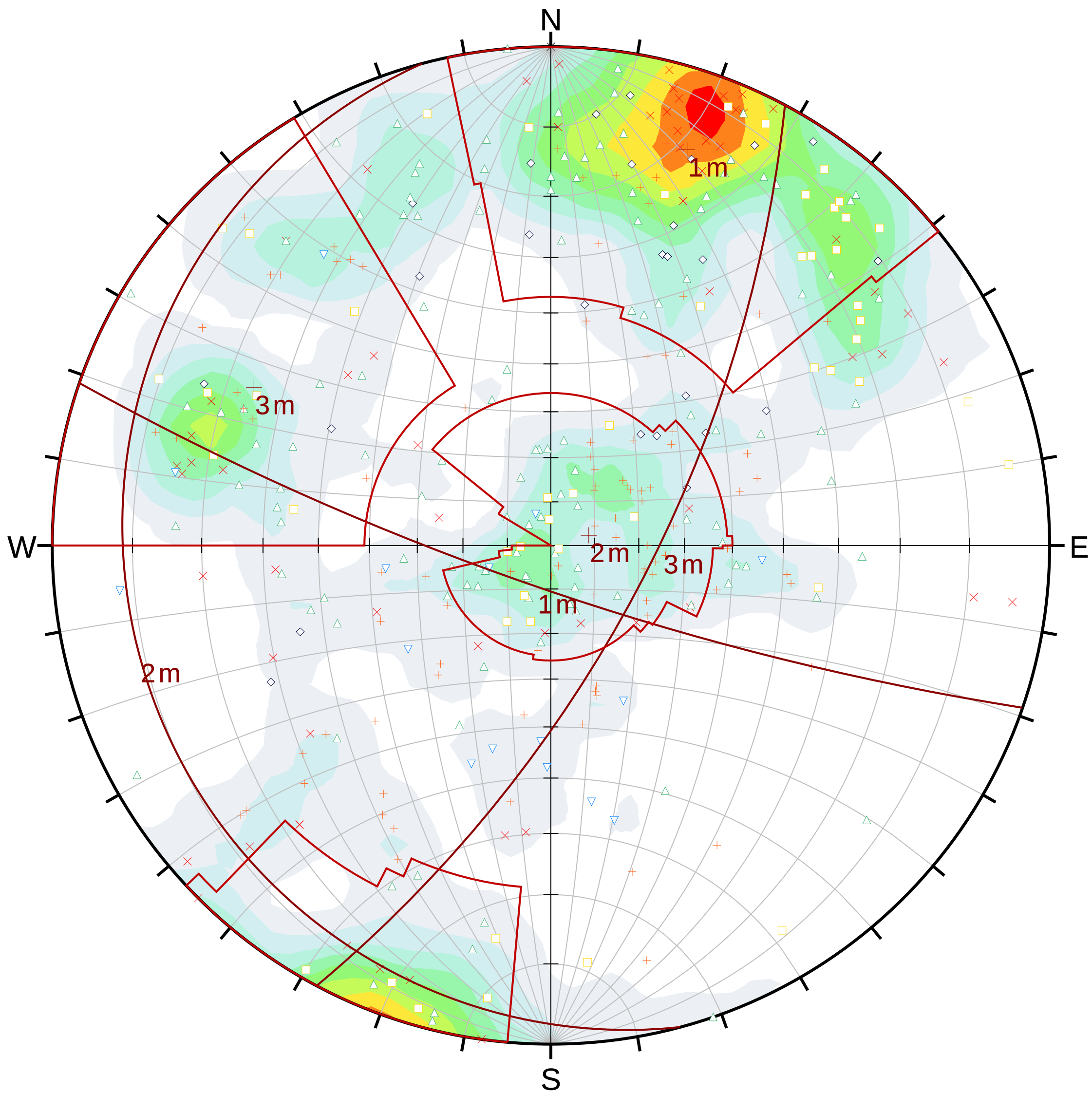
NEVADA IRRIGATION DISTRICT
CENTENNIAL RESERVOIR PROJECT

Geotechnical Transverse Sections
Axis 2

FIGURE
6-3



Symbol	BOREHOLE	Quantity
◇	CB-01	27
×	CB-02	62
△	CB-10	124
+	CB-11	93
▽	CB-12	15
□	CB-17	51

Color	Density Concentrations
	0.00 - 0.60
	0.60 - 1.20
	1.20 - 1.80
	1.80 - 2.40
	2.40 - 3.00
	3.00 - 3.60
	3.60 - 4.20
	4.20 - 4.80
	4.80 - 5.40
	5.40 - 6.00

Contour Data	Pole Vectors
Maximum Density	5.83%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	372 (372 Entries)
Hemisphere	Lower
Projection	Equal Angle

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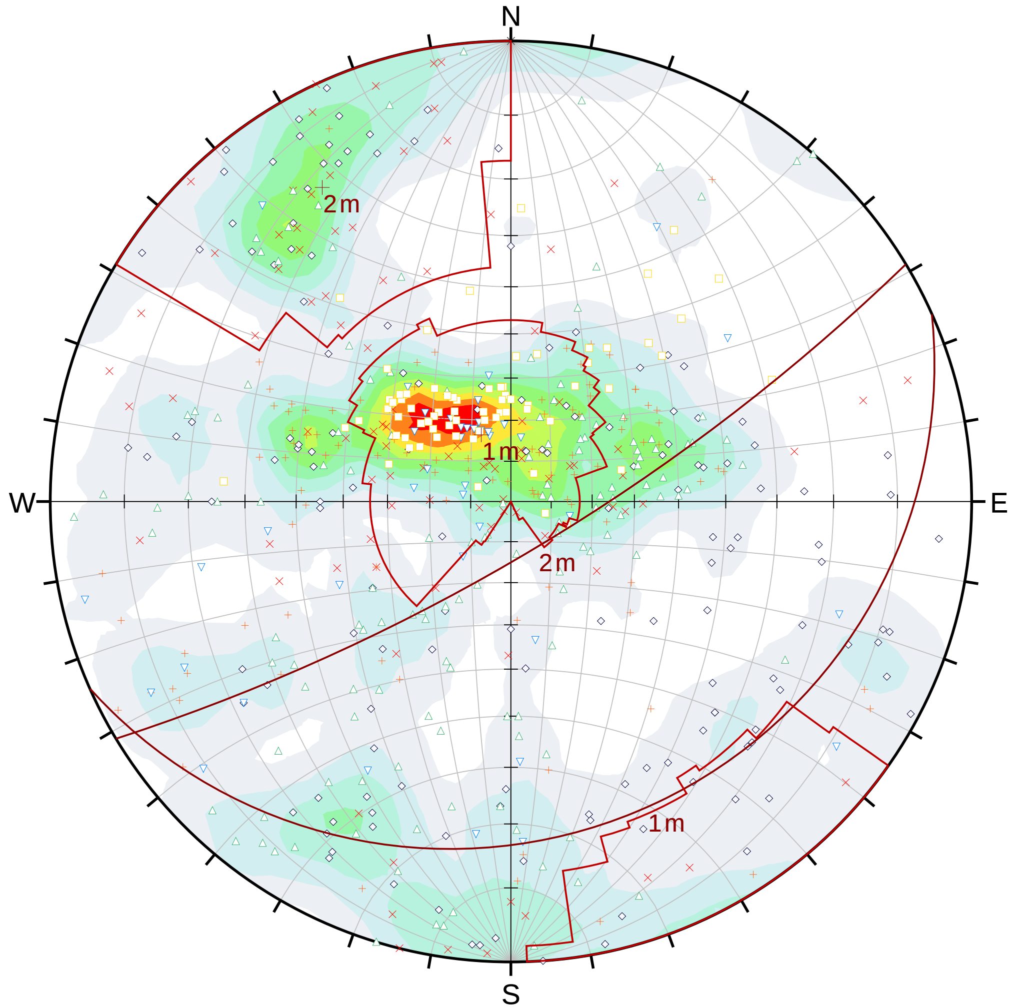
Nevada Irrigation District

Centennial Reservoir Project

60503855

FIGURE 6-4a

Stereonet Plots of Borehole Discontinuities - Left Abutment Axis 2



Symbol	BOREHOLE	Quantity
◇	CB-03	150
×	CB-04	95
△	CB-13	138
+	CB-14	100
▽	CB-18	43
□	CB-19	71

Color	Density Concentrations
	0.00 - 0.50
	0.50 - 1.00
	1.00 - 1.50
	1.50 - 2.00
	2.00 - 2.50
	2.50 - 3.00
	3.00 - 3.50
	3.50 - 4.00
	4.00 - 4.50
	4.50 - 5.00
Contour Data	Pole Vectors
Maximum Density	4.91%
Contour Distribution	Fisher
Counting Circle Size	1.0%

Plot Mode	Pole Vectors
Vector Count	597 (597 Entries)
Hemisphere	Lower
Projection	Equal Angle

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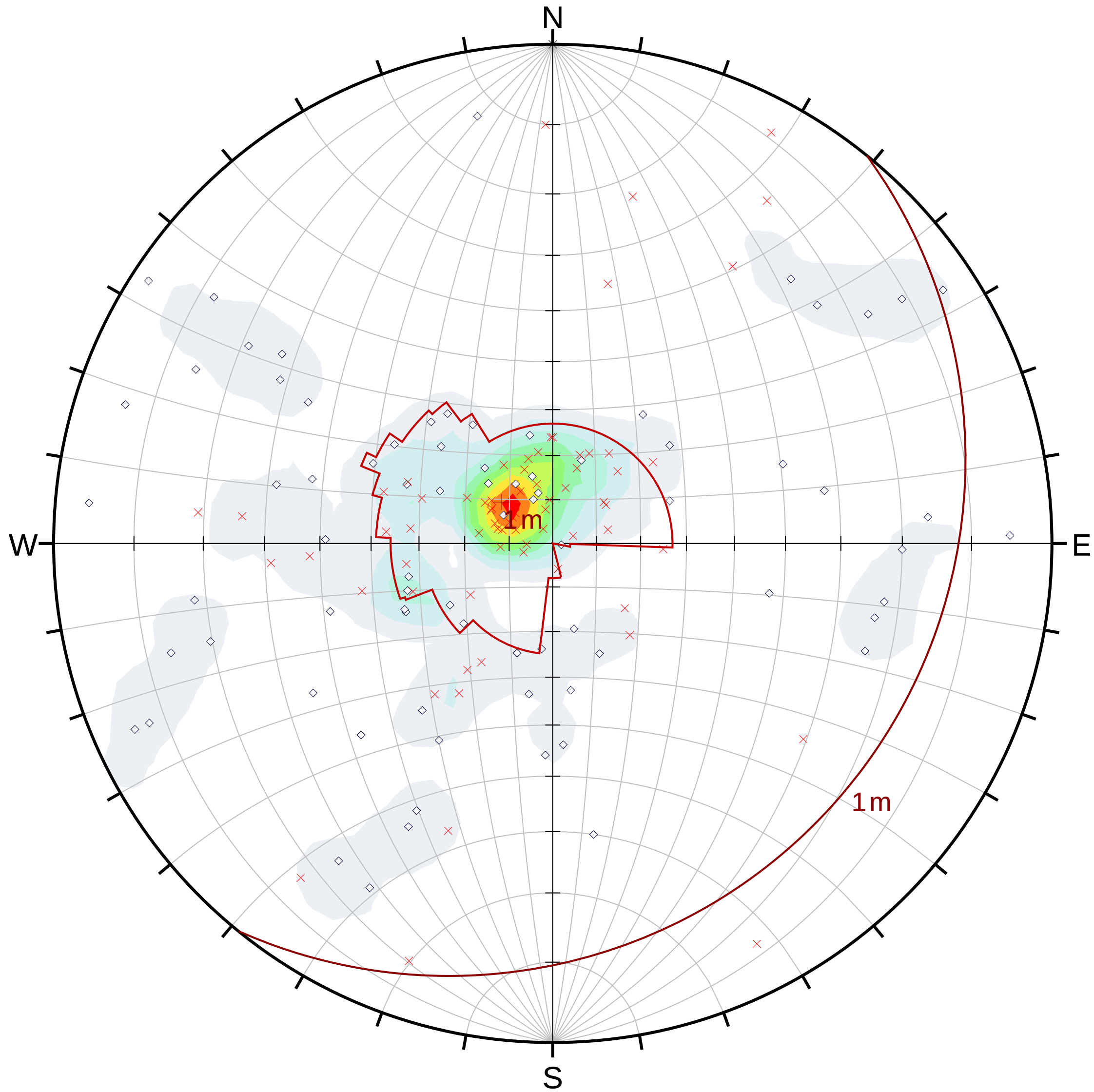
Nevada Irrigation District

Centennial Reservoir Project

60503855

FIGURE 6-4b

Stereonet Plots of Borehole Discontinuities - Right Abutment Axis 2



Symbol	BOREHOLE	Quantity
◇	CB-15	77
×	CB-16	70

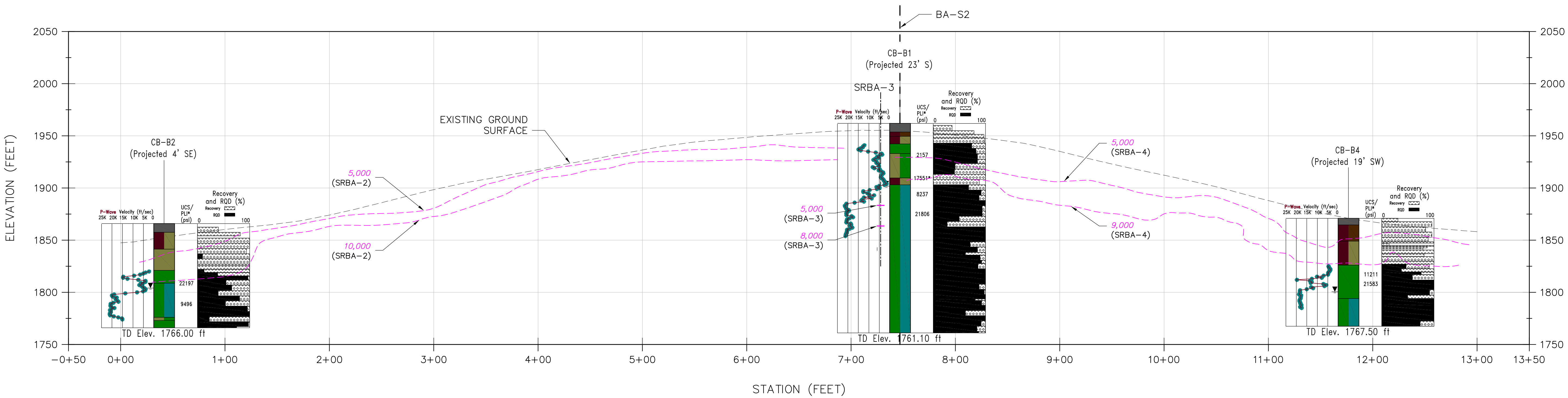
Color	Density Concentrations
	0.00 - 1.30
	1.30 - 2.60
	2.60 - 3.90
	3.90 - 5.20
	5.20 - 6.50
	6.50 - 7.80
	7.80 - 9.10
	9.10 - 10.40
	10.40 - 11.70
	11.70 - 13.00

Contour Data	Pole Vectors
Maximum Density	12.69%
Contour Distribution	Fisher
Counting Circle Size	1.0%

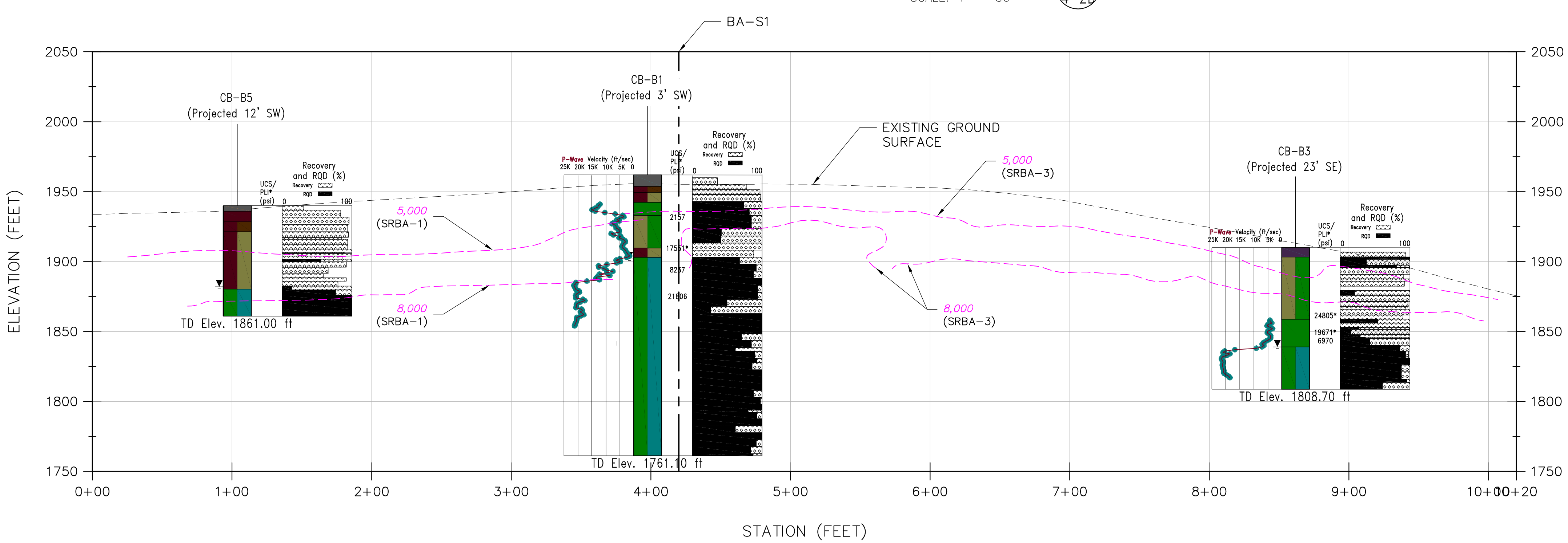
Plot Mode	Pole Vectors
Vector Count	147 (147 Entries)
Hemisphere	Lower
Projection	Equal Angle

Nevada Irrigation District
Centennial Reservoir Project
60503855

FIGURE 6-4c
Stereonet Plots of Borehole Discontinuities - Channel Axis 2



SECTION BA-S1
SCALE: 1" = 50' 4-2B



SECTION BA-S2
SCALE: 1" = 50' 4-2B

LEGEND:

WEATHERING PROFILE:

- COLLUVIUM
- RESIDUAL SOIL
- COMPLETELY WEATHERED
- HIGHLY WEATHERED
- MODERATELY WEATHERED
- SLIGHTLY WEATHERED
- FRESH

▼ GROUNDWATER LEVEL DURING DRILLING (MAY NOT REFLECT NATURAL GROUNDWATER LEVEL)

TD TOTAL DEPTH OF HOLE

UCS/PLI* UNCONFINED COMPRESSIVE STRENGTH; * INDICATES RESULT FROM POINT LOAD TEST; SEE APPENDICES H AND I FOR DETAILS

5,000 P-WAVE VELOCITY (ft./sec.) FROM SEISMIC REFRACTION SURVEY; SEE APPENDIX C FOR DETAILS

SRBA-1 SEISMIC REFRACTION LINE BA-1

LOCATION OF SR LINE, AT CROSSING OF PROFILE

0 50 100 Feet

NOTES:

1. ELEVATION DATUM IS NAVD (1988).
2. WHERE SEISMIC REFRACTION PROFILE DATA ARE PROJECTED ONTO THE SECTION FROM SURVEYS ACQUIRED AT DIFFERENT SURFACE ELEVATIONS, THE DEPTH TO THE PROFILE DATA IS MAINTAINED.

AECOM	60503855 NEVADA IRRIGATION DISTRICT CENTENNIAL RESERVOIR PROJECT	Geotechnical Sections South Borrow Area	FIGURE 7-1

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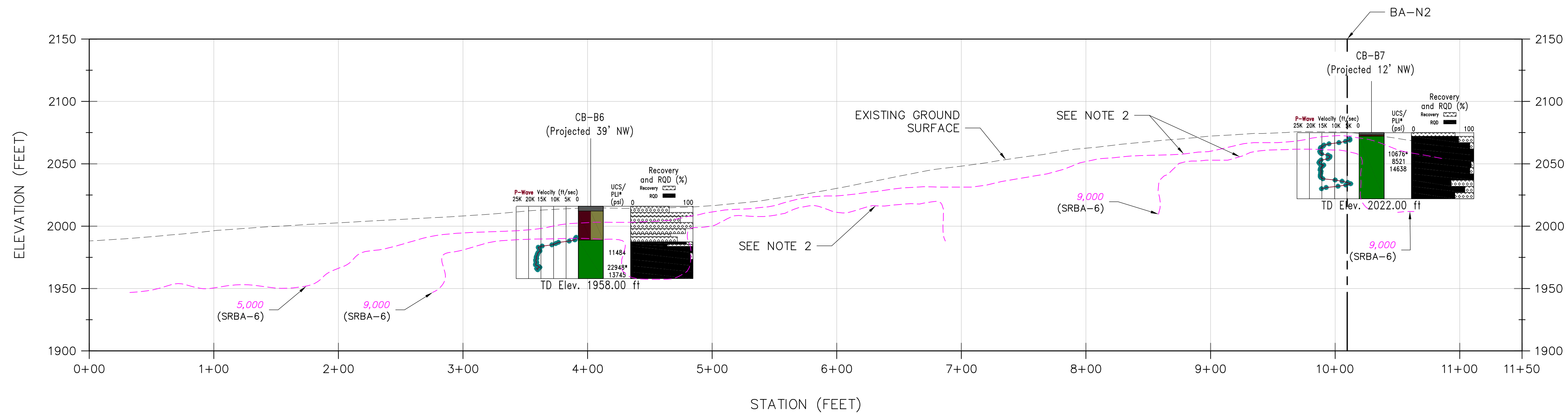
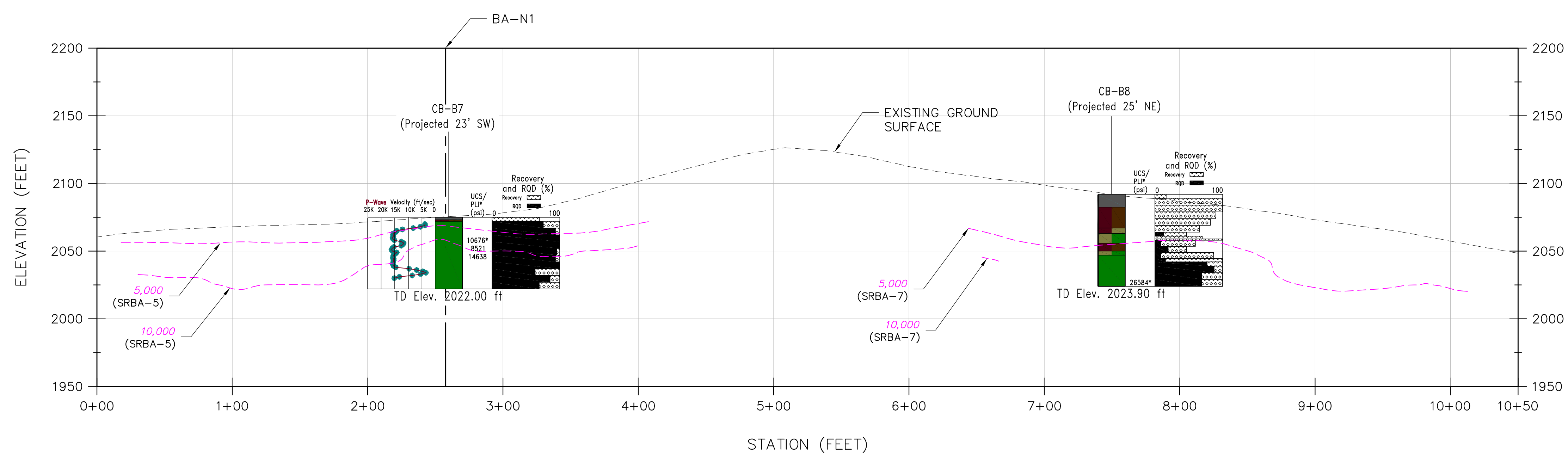


SECTION BA-N1 4-2A
SCALE: 1" = 50'



SECTION BA-N2 4-2A
SCALE: 1" = 50'

LEGEND:

WEATHERING PROFILE:

- COLLUVIUM
- RESIDUAL SOIL
- COMPLETELY WEATHERED
- HIGHLY WEATHERED
- MODERATELY WEATHERED
- SLIGHTLY WEATHERED
- FRESH

▼	GROUNDWATER LEVEL DURING DRILLING (MAY NOT REFLECT NATURAL GROUNDWATER LEVEL)
TD	TOTAL DEPTH OF HOLE
UCS/PLI*	UNCONFINED COMPRESSIVE STRENGTH; * INDICATES RESULT FROM POINT LOAD TEST; SEE APPENDICES H AND I FOR DETAILS
5,000	P-WAVE VELOCITY (ft./sec.) FROM SEISMIC REFRACTION SURVEY; SEE APPENDIX C FOR DETAILS
SRBA-4	SEISMIC REFRACTION LINE SR BA-4
¦	LOCATION OF SR LINE, AT CROSSING OF PROFILE

0 50 100 Feet

NOTES:

1. ELEVATION DATUM IS NAVD (1988).
2. WHERE SEISMIC REFRACTION PROFILE DATA ARE PROJECTED ONTO THE SECTION FROM SURVEYS ACQUIRED AT DIFFERENT SURFACE ELEVATIONS, THE DEPTH TO THE PROFILE DATA IS MAINTAINED.

AECOM

60503855

NEVADA IRRIGATION DISTRICT
CENTENNIAL RESERVOIR PROJECT

Geotechnical Sections
North Borrow Area

FIGURE
7-2

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Photographs

Photograph 1. Typical section of residual soil observed within a road cut southwest of the CRP site

Photograph 2. Northwest facing view of the Bear River from the southeast end of the site
[Illustrates distribution of alluvial deposits within the active channel (Left: point bar; Right: mid-channel bar)].

Photograph 3. West facing view of outcropping bedrock and mid-channel bar deposits within the Bear River upstream of Axis 2

Photograph 4. West facing view of bedding in outcropping bedrock (massive basalt) at the toe of slope along north bank of Bear River upstream of Axis 2
[Well rounded cobble and gravel sized point bar deposits are also visible (Left).]

Photograph 5. East facing view of typical discontinuities in outcropping bedrock (massive basalt) at the toe of slope along the south bank of Bear River

Photograph 6. North facing view of the Bear River channel

Photograph 7. North facing view of the right abutment at Axis 2
[Illustrates steep (up to sub-vertical) slopes of outcropping bedrock (massive basalt).]

Photograph 8. North facing view of quarry shear zone in Bear River Quarry
[Orientation between N10ºE and N12ºW (arrow points to shear zone).]

Photograph 9. North facing close-up of quarry shear zone

Photograph 10. Drilling Boring CB-3 (Axis 2, right abutment)

Photograph 11. Drill rig with televiewer logging at Boring CB-15

Photograph 12. Helicopter mobilization of equipment to CB-15 drill site

Photograph 13. CB-16 drill site

Photograph 14. Bear River at Axis 2
[CB-16 in background.]

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