TECHNICAL MEMORANDUM NO. 1

SUMMARY REPORT OF EXISTING INFORMATION GEOLOGY, SEISMICITY AND GEOTECHNICAL ISSUES (AS OF JANUARY 2008)

LAKE ELSINORE ADVANCED PUMPED STORAGE PROJECT (LEAPS)

FERC Project No. 11858
Riverside County, California

Prepared For:

The Nevada Hydro Company
2416 Cades Way
Vista, California 92083

Submitted To:

Devine, Tarbell & Associates, Inc.
2720 Gateway Oaks Dr., Suite 300
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Prepared By:

GENTERRA CONSULTANTS, INC.
Irvine, California

January 25, 2008

January 25, 2008 Project No. 320-DTA

Devine, Tarbell & Associates, Inc.
2720 Gateway Oaks Dr., Suite 300
Sacramento, CA 95833

Attention: Mr. Kelly Tilford, PG, CEG

Subject: RFS No. 1, Task 1 Deliverable
Technical Memorandum No. 1
Summary Report of Existing Information
Geology, Seismicity and Geotechnical Issues
Lake Elsinore Advanced Pumped Storage (LEAPS)
FERC Project No. 11858, Riverside County, California

Dear Mr. Tilford:

GENTERRA Consultants, Inc. (GENTERRA) is pleased to submit this revised report in fulfillment of the Request for Services (RFS) No. 1, Task 1 deliverable requirements. The report presents a summary of existing information available as of the end of January 2008 on geology, seismicity and geotechnical issues that will affect the design and construction of the proposed Lake Elsinore Advanced Pumped Storage (LEAPS) project in Riverside County, California. This report presents available information as of the end of January 2008 based on previous feasibility-level studies by GENTERRA and others, supplemented by information in readily-available published literature.

The initial draft of this report was dated January 25, 2008. The report has been revised based on DTA review comments received subsequent to submittal of the initial draft. Subsequent documents prepared by GENTERRA for this project include Technical Memorandum No. 2, presenting the results of geologic mapping performed after January 2008, and Technical Memorandum No. 3, presenting the results of the preliminary evaluation of faulting and seismicity, also performed after January 2008.

We appreciate the opportunity to conduct this study. Please do not hesitate to contact either of the undersigned at (949) 753-8766 should you have any questions or require additional information.

Sincerely,

GENTERRA CONSULTANTS, INC.

Joseph J. Kulikowski, PE, GE	Michael Wolff, PG, CEG
President/Principal Engineer	Principal Engineering Geologist
RCE 17478, GE 491	PG 3370, CEG 970

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RIVERSIDE COUNTY, CALIFORNIA

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LAKE ELSINORE ADVANCED PUMPED STORAGE PROJECT (LEAPS)

EXECUTIVE SUMMARY

This Technical Memorandum presents a summary of available geology, seismicity and geotechnical information, as of the end of January 2008, pertinent to the design and construction of the proposed Lake Elsinore Advanced Pumped Storage Project (LEAPS) in Riverside County, California. The report has been prepared by GENTERRA Consultants, Inc. (GENTERRA). GENTERRA has been involved in geologic and geotechnical studies for the project during the permitting stages since late 2000.

The initial draft of this report was dated January 25, 2008. The report has been revised based on DTA review comments received subsequent to submittal of the initial draft. Subsequent documents prepared by GENTERRA for this project include Technical Memorandum No. 2, presenting the results of geologic mapping performed after January 2008, and Technical Memorandum No. 3, presenting the results of the preliminary evaluation of faulting and seismicity, also performed after January 2008.

The proposed LEAPS project is an advanced pumped storage hydroelectric generating facility located on the west side of Lake Elsinore in Riverside County, California. When completed, the project will provide approximately 500 megawatts of renewable energy to the Southern California power grid during peak demand periods. The project components include: a dam and upper reservoir constructed near the crest of the Elsinore Mountains connected by a shaft and headrace tunnel to an underground powerhouse located at the base of the mountain on the west side of Lake Elsinore, and one or more tailrace tunnels connecting the underground powerhouse to an inlet/outlet structure within Lake Elsinore near its western shore.

At night, when electricity demand is low, water would be pumped from the lake up to the upper reservoir. During daytime peak electricity demand periods, water would flow back down from the upper reservoir, drive turbines in the powerhouse generating electricity, and discharge back into Lake Elsinore. This cycle would be repeated daily.

The planned facilities will require extensive geotechnical support for design and construction. The upper reservoir will require excavation and shaping of the natural drainage course in the headwaters of Decker Canyon, construction of a reservoir liner to prevent seepage, and construction of a major dam. The dam will likely be a zoned earth or concrete-faced rockfill dam that will exceed 200 feet in height. The shaft and headrace tunnel will be bored in hard rock and will descend more than 1,000 feet in elevation from the upper reservoir to the powerhouse. A separate utility tunnel may parallel the headrace tunnel. The underground powerhouse will be constructed within a mined cavern in rock at the base of the mountain front.

The tailrace tunnels will be bored in highly variable ground conditions that will start in rock at the powerhouse, but will then transition in a easterly direction into alluvial fan deposits and soft saturated lake bed deposits approaching the lake. The tailrace tunnels will cross the mapped trace of the Willard fault, and possibly also the Wildomar fault, which are branches of the major active Elsinore fault zone. Portions of the Elsinore fault zone are recognized as being capable of generating damaging earthquakes and surface fault displacement. Near the lake, the tailrace tunnels and inlet/outlet structure will be supported on potentially liquefiable saturated lake bed sediments that will likely need to be improved using ground improvement techniques to minimize static and dynamic settlement to acceptable limits. These lake sediments likely exceed several hundred to thousands of feet in thickness beneath the lake.

In general, foundation conditions within the upper reservoir area appear favorable for constructing a large dam. While some foundation and abutment stripping will be required to remove weathered and decomposed rock near the ground surface, the depths of stripping should not be excessive due to the presence of rock at or near ground surface along the dam axis and in the abutments. With the exception of organic debris, all of the excavated materials should be suitable for use in the dam construction. Fine-grained low permeability material for use in the core of a zoned earth or rockfill structure will not be available onsite and will need to be imported.

Tunneling conditions from the upper reservoir to the powerhouse will involve hard granitic rock of variable quality depending upon the fracture and joint spacing and amount of shearing. It is anticipated that rock quality will increase with depth, but geotechnical investigations are pending to evaluate this assumption. The rock appears to be highly sheared near the base of the mountain. If sheared rock is encountered within the powerhouse cavern, the sheared rock will pose problems for roof support and may produce inconsistent foundation support conditions beneath critical equipment. Proper engineering design and construction methods will be needed to mitigate anticipated rock quality issues.

Groundwater inflows into the shaft, headrace and powerhouse excavations may be locally severe due to the high head created by the depth of the excavations. The vertical shaft will be more than 1,000 feet below ground surface at its base, and water under high pressure may be encountered in fracture zones within the rock. In addition, hydrostatic pressure on the tunnel lining will likely be high during construction and when the tunnels are dewatered. A concern for the tunnel lining will be the relationship between the water pressure in the pressure tunnels during operation (higher than hydrostatic) and the minimum horizontal stress in the rock mass. If the pressure in the tunnel is higher than the minimum horizontal stress, hydraulic jacking of the rock mass can occur and the linings would have to be steel-lined or designed for minimal cracking.

The project poses several major geological, seismic and geotechnical challenges. These include:

1. Peak horizontal ground accelerations from earthquakes on nearby active faults that could exceed 1g.
2. Up to several hundred feet of soft saturated liquefiable lake sediments underlie portions of the tailrace tunnels and inlet/outlet structure. Substantial ground improvement will likely be needed to mitigate static and dynamic settlement, including liquefaction of these lake sediments.
3. There is the presence of the potentially active Willard and Wildomar faults, one or both of which cross the tailrace tunnel alignment. Movement on these faults could result in offset of the project conveyance features. There may also be previously unidentified faults within the region which also require design mitigations.
4. There may be sheared rock in the area of the powerhouse cavern.
5. There would be potentially large groundwater inflows to underground excavations along much of the lower portion of the project alignment.
6. The excavation, dewatering and construction of the inlet/outlet structure, as well as connections to the tailrace tunnels, will be within Lake Elsinore. Water from construction will have to be treated and discharged in accordance with local and state regulations.

SECTION 1:
INTRODUCTION

1.1 GENERAL

This Technical Memorandum presents a summary of available geology, seismicity and geotechnical information, as of the end of January 2008, pertinent to the design and construction of the proposed Lake Elsinore Advanced Pumped Storage Project (LEAPS) in Riverside County, California. The report has been prepared by GENTERRA Consultants, Inc. (GENTERRA). GENTERRA has been involved in geologic and geotechnical studies for the project during the permitting stages since late 2000.

The initial draft of this report was dated January 25, 2008. The report has been revised based on DTA review comments received subsequent to submittal of the initial draft. Subsequent documents prepared by GENTERRA for this project include Technical Memorandum No. 2, presenting the results of geologic mapping performed after January 2008, and Technical Memorandum No. 3, presenting the results of the preliminary evaluation of faulting and seismicity, also performed after January 2008.

The primary purpose of this summary report is to bring together existing available geologic and geotechnical information from previous studies by GENTERRA and others, supplemented by available published and unpublished literature, to comprise a resource document useful to project stakeholders as the LEAPS project moves into the engineering, procurement and construction (EPC) phases. As such, this report contains conceptual-level interpretation of the existing information but is not intended to provide conclusions or design recommendations. Those will be developed based on further site-specific geologic and geotechnical investigations that are currently in the planning stage.

1.2 PROJECT DESCRIPTION

The proposed LEAPS project is an advanced pumped storage hydroelectric generating facility located on the west side of Lake Elsinore in Riverside County, California (Figure 1.1). When completed, the project will provide an additional approximately 500 megawatts of renewable energy during peak demand periods to the Southern California power grid. The project concept is as follows: water will be cycled between an upper reservoir and a lower reservoir. The existing Lake Elsinore will function as the lower reservoir, and a new upper reservoir will be constructed at a location approximately 1,540 feet higher in elevation (surface of lower reservoir to surface of upper reservoir) within the Elsinore Mountains of the Cleveland National Forest (CNF). The lake and the upper reservoir will be connected by one or more tunnels bored beneath the mountain front. During peak electricity demand periods, water will be released from the upper reservoir to flow down through a headrace tunnel to an underground powerhouse where the water pressure will drive turbines generating electricity. The water will discharge through one or more tailrace tunnels into Lake Elsinore. During off-peak electricity demand periods, the direction of water flow will be reversed. Water from the lower reservoir will be pumped back through the headrace tunnel to the upper reservoir for storage. The major project facilities are briefly described below, and are shown in Figure 1.2:

Upper Reservoir. The upper reservoir will be constructed in Decker Canyon just west of South Main Divide Road, and a short distance south of State Highway 74 (Ortega Highway), within the Cleveland National Forest. The upper reservoir will be designed to contain roughly 5,500 acre-feet of water and will comprise a dam approximately 200 feet in height, a spillway, possibly a fully-lined reservoir, and a low-level outlet works structure.

Headrace Tunnel. The conceptual design involves a large (up to approximately 30 feet) diameter shaft and tunnel system to connect the upper reservoir to the underground powerhouse. There will be two unlined and/or concrete- and steel-lined shafts and tunnels excavated through bedrock. A smaller utility tunnel may be constructed parallel to the tunnels. The number and sizes of the tunnels is still under consideration and subject to revision.

Powerhouse. The powerhouse will be located underground near the base of the mountain on the west side of Lake Elsinore near the upper end of Santa Rosa Avenue. The powerhouse will contain two reversible 250-megawatt turbines and ancillary equipment for pumping water up to the upper reservoir, and for generating electricity when the water flows back down and turns the turbines. The underground powerhouse will be constructed in a mined cavern with dimensions on the order of 80-feet wide, 450-feet-long, and 160-feet high. The base of the powerhouse cavern will be approximately 300 feet below ground surface.

Tailrace Tunnel. One or more tailrace tunnels will connect the underground powerhouse to an intake/outlet structure at Lake Elsinore (the lower reservoir). During pumping operations, the tailrace tunnels will serve as the inlet for water to flow to the powerhouse for pumping up the hill to the upper reservoir. During electricity generation, the tailrace tunnels will serve as the outlet to the lake for water flowing down through the powerhouse from the upper reservoir and turning the turbines. The tailrace tunnels will be concrete-lined.

Transmission lines, switchyard, and substations in support of the power generation components of the project will be located in the vicinity of the upper reservoir.

1.3 SOURCES OF INFORMATION

Geologic, seismicity and geotechnical information pertinent to the design and construction of the project is available from many published and unpublished sources. GENTERRA has compiled a bibliography of references which is presented in Section 4 of this report. Not all of the listed references are cited in this report, but the complete bibliography is included to serve as a resource.

The references are from a wide variety of sources, including on-line maps and reports, published maps and reports by agencies such as the United States Geological Survey (USGS), the California Geological Survey (CGS) and its predecessor agencies such as the California Division of Mines and Geology (CDMG), other agencies such as the Elsinore Valley Municipal Water District (EVMWD), reports prepared specifically for the LEAPS project during earlier permitting stages, professional papers published in journals, unpublished dissertations, geotechnical reports prepared for other projects in the area, logs of water wells, etc.

GENTERRA has copies of many but not all of the references. Much of the early geologic mapping of the area is in agency reports that are out of print, but are available in libraries. This earlier geologic mapping is generally more detailed than later more readily-available maps that are essentially compilations of earlier work. In some cases, out of print references that GENTERRA used reside in private collections of individual geologists who are knowledgeable about the site area.

1.4 PRIOR STUDIES

In addition to the published literature, two previous geotechnical studies have been done for the LEAPS project. These include:

1. GENTERRA, 2003a. *Geotechnical Feasibility Report, Lake Elsinore Advanced Pumped Storage Project (LEAPS);* prepared by GENTERRA Consultants, Inc., Irvine, CA, August 28.

2. Berger, V.D. and Hart, M.W., 1997. *Second Stage Geotechnical Evaluation, A 300-MW Advanced Pumped Storage Project, Lake Elsinore, Riverside County, California*; as Exhibit E, Appendix E-11 in: Final Application for License of Major Unconstructed Project, Lake Elsinore Advanced Pumped Storage Project, by Elsinore Valley Municipal Water District and The Nevada Hydro Company, Inc. April 23.

The 1997 Berger report was prepared in support of a previous FERC license application package. This report reviewed published literature, included a site reconnaissance, and preliminary evaluation of geologic and seismic parameters affecting the project.

The 2003 GENTERRA feasibility study updated the results and conclusions of the earlier Berger report and included a site reconnaissance, limited geologic mapping, and limited seismic refraction surveys at candidate dam and powerhouse locations. The GENTERRA report also provided recommendations for geotechnical investigation to support preliminary design, conceptual alternative project designs and layouts, estimates of materials quantities, and feasibility level construction costs.

1.5 ORGANIZATION OF THIS REPORT

This report is divided into four sections. Section 1 provides introductory information. Section 2 provides an overview of the geology and seismicity of the project area. Section 3 presents summary information on the geologic, seismic and geotechnical factors that affect each of the major project components. Section 4 presents the bibliography of references.

The report text is supplemented with tables and figures that follow the text.

SECTION 2:
OVERVIEW OF THE GEOLOGY AND SEISMICITY OF THE PROJECT AREA

2.1 GEOLOGIC FRAMEWORK OF THE ELSINORE AREA

The LEAPS project is located in the Elsinore Mountains of the Santa Ana Mountain Range, a prominent northwest-trending range of the Peninsular Ranges Physiographic Province of southern California.

The Peninsular Ranges comprise an extensive region of linear northwest-trending mountain ranges separated by alluvial valleys and fault-bounded troughs. This region extends from the east-west trending Transverse Ranges on the north well down into Baja California south of the Mexican border on the south. The northern Peninsular Ranges span from the offshore continental borderland on the west to the Coachella Valley on the east, and include the Los Angeles basin. The southern Peninsular Ranges span from the offshore continental borderland on the west to the Imperial Valley on the east (Jahns, 1954).

The Peninsular ranges are characterized by a basement complex of igneous and metamorphic rocks that were intruded and locally altered by younger igneous rocks of the Southern California batholith [1] during Cretaceous time (approximately 65 to 145 million years before present). The pre-batholithic rocks vary in age from Middle Cretaceous to Paleozoic (approximately 100 to 600 million years ago).

The igneous rocks of the Southern California batholith stretch from the tip of Baja California to the northern edge of the Peninsular Ranges. They are unconformably overlain by a thick sequence of Upper Cretaceous and Tertiary (1.6 to 65 million years) sedimentary and volcanic rocks. Quaternary (11,000 to 1.6 million years) and Holocene (present to 11,000 years) sediments locally overlie the Tertiary rocks (Jahns, 1954).

In the LEAPS project area, the rocks are primarily comprised of crystalline Cretaceous-age intrusive igneous rocks that represent several distinct episodes of magmatic intrusion. These episodes are differentiated by their differing mineralogy, and the inclusion of xenoliths of older igneous rocks near the margins of younger intrusive bodies. In general, the older intrusions are more mafic, varying in composition from diorite to gabbro, while the younger intrusions are more felsic, ranging from granite to granodiorite and associated rocks. The older igneous rocks are generally recognized by their darker color, ranging from gray to locally black, reflecting the greater percentage of iron- and magnesium-rich minerals present in these rocks. The younger igneous rocks are recognizable by their light color, varying from light gray to tan to pink, reflecting the greater percentage of light-colored minerals such as quartz and plagioclase in these rocks.

All of the igneous rocks are deeply weathered at ground surface, but the weathering is highly uneven, with very hard “corestones” developing within a deeply weathered and decomposed matrix. These corestones remain at the ground surface as the weathered matrix erodes away giving the resulting

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[1] The term “batholith” refers to a very large regional mass of intruded igneous rock. A batholith may be comprised of smaller individual “plutons” that represent discrete episodes of magmatic intrusion.

landscape a characteristic “boulder-studded” appearance. This effect is most pronounced for the light-colored granodiorite in the upper reservoir area. This type of rock produces very well-rounded corestones that dot the landscape downstream from the dam axis in Decker Canyon. The darker mafic rocks produce fewer corestones, and these tend to be more angular in appearance. These rocks can be seen along the South Main Divide Road, and are present in the upper reservoir area as well as the mountain crest and the steep descending slope down to the powerhouse area west of Lake Elsinore.

The igneous rocks were intruded into older metamorphic rocks that are thought to be Jurassic in age (145 to 200 million years old). Remnants of these older metamorphic rocks are present in the LEAPS area as roof pendants and rafted inclusions near the margins of individual plutons. These rocks are comprised of metasediments such as slates and argillites, and are readily recognized by their characteristic variegated reddish to black color, intense fracturing and shearing, and sharply angular morphology in outcrops. Intrusive dikes and prominent quartz veins from the younger intrusive events cut through these older rocks. The rocks were named the “Santa Ana” formation by early geologists (Engel, 1959) mapping in the project area, but have also been assigned to the “Bedford Canyon” formation by other geologists (Gray, 1954). Later workers mapped these rocks as “hybrid” rocks (Weber, 1977), or as “heterogeneous” granitic rocks (including metamorphic rocks) (Morton 1999, Morton and Weber, 2003). Within the project alignment, metamorphic rocks are present at ground surface only in the vicinity of the powerhouse location, but can also be observed in road cuts along South Main Divide Road south of the project alignment, and in outcrops in the steep east-facing slopes south of the headrace and powerhouse areas.

Alluvial deposits are present in some of the lower gradient areas of canyon streambeds. A thin mantle of alluvium exists in the drainage of Decker Canyon in the upper reservoir area. Thick accumulations of colluvium and alluvial fan deposits occur on the lower flanks of the steep east-facing mountain slopes. Holocene lake deposits are present at the surface along the shoreline of Lake Elsinore. These lake deposits reflect a history of higher stands of the lake surface.

Figures 2.1, 2.2 and 2.3 present varying interpretations of site area geology through time. Figure 2.1 reproduces a portion of Engel’s geologic mapping in 1947, subsequently published by the California Division of Mines as Engel, 1959. Figure 2.1 shows an area mapped by Engel as Triassic-age “Santa Ana Formation” metamorphic rocks extending into the powerhouse area. Figure 2.2 reproduces a portion of Weber’s geologic mapping of 1977. This map shows mixed granitic and “hybrid” metamorphic rocks close to the powerhouse area. Figure 2.3 reproduces a portion of Morton’s mapping of 1999 that is available for digital download (Morton, 1999). Morton’s map shows “heterogeneous” granitic rocks (including metamorphic rocks) generally in the project area. These maps are generally consistent with each other but reflect tendencies of some previous workers to lump units together while others split them out. Site-specific geologic mapping currently in progress will reconcile any areas of disagreement among these previous maps as they affect conditions along the project alignment.

2.2 SEISMOTECTONIC FRAMEWORK

2.2.1 Faulting

Figure 2.4 is a reproduction of a portion of the Fault Activity Map of California (Jennings, 1994). This figure shows the locations of faults, including active faults with displacement during historical and Holocene (<11,000 years) time, that are relevant to the following discussion.

The Peninsular Ranges are characterized by large northwest-trending fault zones that display large right-lateral displacements. Chief among these in an east to west progression are the San Andreas, the San Jacinto, the Whittier-Elsinore and the Newport-Inglewood fault zones. The right lateral sense of relative displacement is the result of the Pacific tectonic plate moving northwest against the North American plate. The plate boundary in Southern California is generally defined as the San Andreas fault zone; thus, the Peninsular Ranges are a part of the Pacific plate and are moving steadily northwest relative to the region east of the San Andreas fault which is part of the North American plate.

At their northern extremity, the northwest-moving Peninsular Ranges impinge on the east-west Transverse Ranges, creating a steadily-increasing north-south compressional tectonic stress regime throughout the region. This constantly-increasing stress is periodically relieved by rupture along the faults of the area, resulting in earthquakes. Much of the regional stress is relieved by horizontal displacement on the major strike slip faults, but a significant amount of stress is also relieved by rupture along low angle thrust faults whose rupture surfaces trend at various oblique angles to the north-south direction of principal tectonic stress. Many of these low angle thrust faults do not extend to the ground surface and are referred to as “blind” thrusts. No blind thrusts have been identified in the LEAPS project area, but blind thrusts have been identified to the northwest and west that have the potential for significant earthquakes.

The Elsinore fault zone is the closest active fault to the LEAPS site. This fault zone is over 200 kilometers long and extends from the southern Imperial Valley northwards to the city of Chino where the fault splits into the Whittier and Chino Faults. Portions of the Elsinore fault zone have been designated as “active” (ground rupture during Holocene time, “about the last 11,000 years”) by the State of California (Hart and Bryant, 1999). The “active” designation requires additional fault investigation studies to be performed so that structures are not placed on active fault traces.

Branches of the Elsinore fault zone are the closest known faults to the site. These include the Willard and Wildomar Faults, located on the west side of Lake Elsinore, and the Glen Ivy Fault, located northeast of Lake Elsinore. The Willard and Wildomar Faults are identified in Figures 2.1 through 2.4. At the northeast margin of Lake Elsinore, the stresses along the Willard and Wildomar branches “step over” to the Glen Ivy strand of the Elsinore fault zone. This right step (looking north) has created a localized extensional stress regime that has resulted in the down-dropping of the block of crust underlying Lake Elsinore. This subsiding block has created a structural trough that is a sink for area drainage resulting in formation of a natural lake. The Willard and Wildomar faults form the west boundary of the Elsinore trough, while the Glen Ivy fault forms the east boundary. The Willard and Wildomar faults on the west side of the lake therefore have large vertical components of displacement (east side down) in addition to right lateral displacement.

The depression formed by the down-dropping of the Elsinore trough has caused a steadily increasing thickness of lake bed sediments to accumulate as the trough subsided. Information from water well records indicates that a substantial thickness of sediments above basement rock exists beneath the lake. Figure 2.5 shows a geologic section prepared by Montgomery Watson Harza (MWH) for the Elsinore Valley Municipal Water District. This geologic section lies at the north end of Lake Elsinore and is therefore north of the project alignment; nevertheless, it reveals that a great thickness of sediments likely exists on the east side of the Willard and Wildomar faults at the project alignment. The lake deposits are saturated and likely poorly-consolidated in their upper portions. They are likely subject to liquefaction in the event of strong shaking during earthquakes.

The Willard and Wildomar faults are not individually identified as “active” by the State of California, but since they are branches of the Elsinore fault zone which is defined as active, they too should be considered as active faults.

2.2.2 Seismicity

The LEAPS project site is located in seismically active southern California and may be subjected to strong ground motions from earthquakes during the life of the project. For this summary report, GENTERRA accessed the historical record of earthquakes in the site vicinity using the National Earthquake Information Center (NEIC, 2007) internet search capability. The program effectively performs searches of historical earthquake catalogs. Our search was conducted to find earthquakes greater than Magnitude 6.0 within a 100-mile radius from the site, for the period from 1735 to the present.

The search indicated that 28 earthquakes of Magnitude 6.0 and above have occurred within a 100-mile radius of the site between 1735 and 2008. The maximum magnitude encountered in the search was the 1992 Magnitude 7.6 Landers Earthquake located about 66 miles from the site[2]. The closest earthquake with Magnitude 6.0 and above was the 1910 Magnitude 6.0 Elsinore Earthquake located about 4 miles from the site. The exact epicenter location for this event relative to the site is not known since there was no instrumentation in 1910 and the epicenter location was estimated from anecdotal reports of damage within a sparsely-populated area. It is likely that the 1910 earthquake occurred on a nearby branch of the Elsinore fault zone.

In addition to the historical earthquake record search on the website of NEIC, we used the computer program EQSEARCH (Blake, 1989-2000) for Windows Version 3.00b. This program effectively performs searches of historical earthquake catalogs. The search for this study was conducted to find significant earthquakes from 1800 to 2008 with magnitudes ranging from 4 to 9 within a 100-mile radius from the site.

The EQSEARCH results indicated that 1261 earthquakes of magnitudes between 4 and 8 had occurred within a 100-mile radius of the site between 1800 and 2008. This search produced identical results to the NEIC search; i.e. the maximum magnitude encountered in the search was the Magnitude 7.6 Landers Earthquake located about 66 miles from the site in 1992, and the closest

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[2] For this report, distances are assumed from the powerhouse location. Distances would be slightly different for the dam site.

earthquake greater than Magnitude 4.0 was the 1910 Magnitude 6.0 event located about 4 miles from the site.

For this summary, GENTERRA also used the computer program EQFAULT for Windows, Version 3.00b (Blake, 1989-2000) which uses digitized information on California faults compiled by the California Geological Survey (CGS 2002). Table 2.1 lists active faults within approximately 30 miles from the site. These faults are shown in Figure 2.4. For each fault, the CGS-determined maximum credible earthquake (MCE) is given. EQFAULT also generates peak ground accelerations (PGA) at the site from the MCEs for each fault using three commonly-accepted attenuation relations. These attenuation relationships are:

1. Abrahamson & Silva (1997)
2. Boore et al. (1997)
3. Sadigh et al. (1997)

The California Department of Water Resources, Division of Safety of Dams (DSOD) requires that the maximum credible earthquake (MCE) on fault zones be considered when developing a design earthquake for high hazard dams. The MCE is the largest, conceivable earthquake that appears possible along either a recognized fault zone or within a geographically-defined tectonic province, under the presently known or presumed tectonic framework. The MCE is conservatively assumed centered at the closest distance between the dam and related seismogenic source.

Because most of the faults that might potentially affect the LEAPS project have high rates of slip, deterministic ground motion estimates require the use of 84th percentile level criteria to define the ground motion that would be generated at the site in case of a tectonic rupture along these faults. This approach is based on the Consequence Hazard Matrix of the DSOD which describes appropriate hazard levels for deterministic development of seismic criteria.

For this initial summary, GENTERRA assumed the site location to be the powerhouse location, and assumed the foundation material conditions to be hard rock. PGAs for the dam location would be expected to be slightly lower than those in Table 2.1 due to its slightly greater distance from the Elsinore fault zone. PGAs for portions of the project with soft soil foundation conditions, such as the tailrace tunnels and inlet/outlet structure at Lake Elsinore would likely be greater than those shown owing to the amplification effect of the soft soil foundation.

GENTERRA emphasizes that the information on PGAs presented in this Technical Memorandum is highly preliminary and is presented for planning level purposes only. Actual design PGAs should only be determined following detailed site-specific seismic hazard analyses for individual project components. These detailed analyses should consider specific foundation material conditions at each project component of interest, directivity effects based on fault geometry (if any), the relative appropriateness of specific attenuation relationships to be used, and other relevant information.

2.3 GEOLOGIC HAZARDS

Geologic hazards normally considered for a project such as LEAPS include the following:

- Faulting and seismicity
- Landslides
- Rock slides and debris flows
- Liquefaction and seismic-induced settlement
- Tsunamis, seiches and flood inundation
- Subsidence

Faulting and seismicity pose major design challenges for various project components. These issues have been addressed in Sections 2.2.1 and 2.2.2 above, and are discussed for each project component in the sections that follow. Landslides, rock slides and debris flows may also affect certain project components. These are discussed in following sections. Liquefaction and seismic-induced settlement must be addressed for portions of the tailrace tunnels and inlet/outlet structure, as discussed in Section 2.2.2 and below.

Tsunamis (seismically-generated sea waves) will not affect the LEAPS project since it is not in a coastal location. Seiches (seismically-generated water waves within a closed water body such as a lake) may potentially be generated in Lake Elsinore by a significant earthquake on the Elsinore fault zone. The potential for a seiche should be evaluated and addressed in the design of the inlet/outlet structure. Flood inundation should also be evaluated and addressed for the inlet/outlet structure, since Lake Elsinore is a low point within a large watershed and has limited storage capacity.

SECTION 3: GEOLOGIC AND GEOTECHNICAL CONSIDERATIONS FOR PROJECT COMPONENTS

3.1 UPPER RESERVOIR

3.1.1 Excavation and Grading

The upper reservoir site is located in the upper reaches of Decker Canyon immediately west of South Main Divide Road. The geology of the site is characterized by granitic bedrock exposed throughout the canyon, with a thin mantle of soil principally derived from in-situ weathering. The bedrock is mapped as granodiorite, quartz diorite, and tonalite (Morton 1999, Greenwood 1992, and Engle 1959). These rocks are typically light gray medium to coarse grained, and moderately fractured.

Weathering of the granitic rock is highly variable in the near-surface, as observed in outcrops, road cuts and aerial photographs. This variability in weathering produces hard, relatively unweathered granitic "corestones" surrounded by highly weathered and decomposed intact bedrock. This condition can be observed in the road cuts along South Main Divide Road, and as resistant "boulders" mantling the topography to the west. The granitic rocks are cut by occasional darker and finer-grained intrusive dikes. The intrusive dikes are typically more resistant to weathering.

Thin, patchy alluvium occupies portions of the valley floor of Decker Canyon. The alluvium is brownish medium- to coarse-grained sand derived from the nearby granitic rock. These materials are loose and generally unsaturated. The thickness of alluvium varies from zero to several feet. The alluvium is underlain by crystalline bedrock. Where small intermittent springs exist, a dense stand of mature trees has developed just upstream of the dam axis.

Excavation of near surface decomposed granitic bedrock can be accomplished with conventional excavation equipment, but local blasting of the hard corestones will likely be necessary. Material generated from excavation will be generally suitable for embankment fill after screening out oversize rock fragments. Larger hard rock fragments could be used in rockfill portions of the dam, and smaller sizes, if free of alkali-silica reactivity, could be used for concrete aggregate. The excavated rock will stand in steep temporary slopes with minor raveling, as evidenced by roadcuts along South Main Divide Road in the area.

3.1.2 Foundation and Abutment Conditions

Both weathered and fresh granitic bedrock should provide adequate foundation for the dam and abutments. The rock is moderately fractured and jointed; therefore, a core trench and grout curtain may be needed beneath the dam to reduce seepage through joints in the bedrock. Grouting of joints in the foundation and abutment rock may also be needed to minimize seepage and prevent internal erosion. The grouting would also supplement the reservoir liner in reducing the amount of potential seepage into the groundwater system.

3.1.3 Dam Foundation and Abutment Preparation

Foundation stripping requirements should be limited to localized areas where decomposition of the granitic bedrock is severe. Stripping depths will be variable and will be difficult to estimate with confidence until subsurface geotechnical exploration is done. The bedrock exposed in roadcuts is extensively weathered and locally decomposed except for hard corestones, as discussed above. GENTERRA anticipates that moderately weathered bedrock will be suitable for dam foundation, but decomposed bedrock and any alluvial materials will need to be removed within the dam footprint and influence zone of the dam.

3.1.4 Suitability of Excavated Materials for Fill

All excavated materials free of organic debris should be suitable for use on the project as select fill or for general fill purposes. A large variety of particle sizes will be generated, the vast majority of which will be sand size or larger. Low permeability materials for use in the core zone of the dam will likely not be encountered in sufficient quantity within the project limits. These materials will likely need to be imported from offsite sources.

3.1.5 Potential Borrow Areas

Borrow areas for the dam will include reservoir excavation and tunnel spoil. Offsite borrow areas may also be considered in later project studies. As stated above, these materials are expected to provide sand size and larger materials. Low permeability fine-grained material will need to be imported from offsite sources.

3.1.6 Groundwater and Seepage

The depth to groundwater in the upper reservoir area is unknown. Small springs have facilitated the growth of a dense stand of mature trees in the drainage course of the upper reservoir. Localized springs may be encountered during foundation stripping. These springs are not anticipated to produce any significant flows and should be addressed through normal construction methods.

3.1.7 Reservoir Liner Considerations

Excavation of rock in the reservoir area will create a rough surface due to irregularities in the degree of weathering of the rock and the need for local blasting of “corestones,” etc. The reservoir area excavations will be designed to create a relatively even surface for liner subgrade. Excavated sand size material (decomposed granite) can be used to create a sand bedding layer over rough surfaces. A geosynthetic liner will likely be needed to satisfy regulatory requirements for groundwater seepage control.

3.1.8 Geologic Hazards

3.1.8.1 Faulting

No active or inactive faults have been identified within the vicinity of the dam axis, abutments, or upper reservoir area in general. It is likely that excavation of the upper reservoir area will expose old, inactive bedrock faults associated with the original intrusion of the pluton. Such older faults, if present, may require local foundation treatment such as overexcavation and grouting.

3.1.8.2 Seismicity

The dam and upper reservoir will likely be subjected to strong ground shaking during the design life of the project. Site-specific seismic hazard analyses should be performed to support design. Refer to the general discussion of faulting and seismicity in Sections 2.2.1 and 2.2.2.

3.1.8.3 Landslides

No landslides have been identified in the upper reservoir area. Landsliding should not be an issue owing to the presence of competent granitic bedrock at or near ground surface and the relatively gentle topography throughout the upper reservoir area. Localized slope stability issues may arise as a result of unfavorably oriented joints or fractures in the bedrock, primarily within the primary channel within the canyon. These issues can be mitigated with local remedial measures as required.

3.1.8.4 Rock Slides, Debris Flows

Rock slides and debris flows should not affect the upper reservoir due to the gentle nature of the natural slopes surrounding this area.

3.1.8.5 Liquefaction and Seismic-Induced Settlement

Liquefaction and seismic-induced settlement is not an issue in the upper reservoir area owing to the presence of competent granitic bedrock at or near ground surface.

3.2 SHAFT AND HEADRACE TUNNEL

3.2.1 Excavation and Tunneling

Most of the length of the shaft and headrace tunnel(s) will encounter hard granitic rock between the upper reservoir and powerhouse. The hardness and degree of weathering will vary considerably near the ground surface where the rock is weathered, but should become more uniform with increasing depth. The type of granitic rock encountered will also vary from light colored granite and granodiorite, to dark colored mafic diorite and gabbro, with the former more prevalent near the upper reservoir and the latter more prevalent in the shaft and lower headrace tunnel near the powerhouse. The darker diorite and gabbro may be relatively harder than the granite and granodiorite where they are unweathered.

The degree of fracturing and shearing of the rock may also vary considerably. Available information suggests that inactive bedrock faults associated with the original intrusion of the pluton may be present in the subsurface, and such faults may have sheared the rock increasing the requirements for tunnel support locally. Extremely sheared metamorphic rocks have been mapped in the vicinity of the powerhouse location, and these rocks can be observed alternating with the granitic rocks in roadcuts along the lower portion of Ortega Highway. These rocks are extensively faulted and sheared where exposed at ground surface, and will likely create tunnel support issues where they are encountered in the subsurface.

3.2.2 Foundation Conditions

As described above, most of the length of the shaft and headrace tunnel(s) will encounter hard granitic rock between the upper reservoir and powerhouse. These rocks will likely have a high Young's modulus, and very high bearing capacity.

3.2.3 Suitability of Excavated Materials for Fill

Most of the excavated tunnel spoil is expected to be suitable for use as rock fill in dam construction. A relatively small fraction of the generated material will likely consist of smaller sand-size particles owing to the local presence of weathered material and shear zones. This smaller material can be used for engineered fill.

3.2.4 Groundwater and Seepage

Groundwater seepage will likely be encountered locally within joints and fractures in the rock. Hydrostatic heads may be very high in local fracture zones due to the planned depths of the shaft and lower headrace tunnel.

3.2.5 Tunnel Lining Considerations

As stated above, the hard granitic rock should have a high Young's modulus where fracture spacings are relatively wide. The degree of fracturing of the rock at depth is unknown and will need to be established by subsurface geotechnical exploration. Hydrostatic pressures against the outside of the tunnel liner may be locally high due to the planned depths of the shaft and lower headrace tunnel, as discussed above. Hydrostatic pressure on the tunnel lining will likely be high during construction and when the tunnels are dewatered. A concern for the tunnel lining will be the relationship between the water pressure in the pressure tunnels during operation (higher than hydrostatic) and the minimum horizontal stress in the rock mass. If the pressure in the tunnel is higher than the minimum horizontal stress, hydraulic jacking of the rock mass can occur and the linings would have to be steel-lined or designed for minimal cracking.

If highly sheared metamorphic rocks are encountered in the lower headrace tunnel in the vicinity of the powerhouse, these materials may pose challenges for tunnel lining, as they will be less competent and have a much lower Young's modulus than the hard, unsheared rock.

3.2.6 Geologic Hazards

3.2.6.1 Faulting

No active or inactive faults have been identified within the vicinity of the shaft and headrace area. It is likely that excavation of the shaft and headrace will expose old, inactive bedrock faults associated with the original intrusion of the pluton. Such older faults, if present, may require local tunnel support measures such as rock bolting, steel ribs and concrete lining, or grouting if groundwater seepage is encountered.

3.2.6.2 Seismicity

As with other project components, the shaft and headrace tunnel will likely be subjected to strong ground shaking during the design life of the project. Site-specific seismic hazard analyses should be performed to support design. Refer to the general discussion of faulting and seismicity in Sections 2.2.1 and 2.2.2.

3.2.6.3 Landslides

The shaft and headrace components of the project are underground and will not be directly affected by landsliding. The ground surface above the lower headrace tunnel is locally very steep and may be subject to landslide hazards during the life of the project. This surface hazard might affect any planned ventilation shafts or other surface features within the headrace alignment. Tunnel portals for powerhouse access may also require significant structural support or design to mitigate potential localized landslide features.

3.2.6.4 Rock Slides, Debris Flows

As with landslides, rock slides or debris flows would only affect any surface facilities along the headrace alignment. The likelihood of seismically-induced rock slides in the very steep escarpment above the headrace and tailrace tunnels is high in the event of strong ground shaking from an earthquake.

3.2.6.5 Liquefaction and Seismic-Induced Settlement

Liquefaction and seismic-induced settlement are not concerns for the shaft and headrace tunnel owing to the presence of competent bedrock at planned shaft and tunnel elevations.

3.3 POWERHOUSE

3.3.1 Excavation and Tunneling

Geophysical survey data collected for the siting study (GENTERRA, 2003) at the Santa Rosa powerhouse site indicated the presence of 10 to 30 feet of loose alluvial soils underlain by 60 to 125 feet of dense, unsaturated alluvial soils and/or weathered bedrock. The top of bedrock was interpreted at depths ranging from 70 to 145 feet below the ground surface in the area of the seismic line. The present tentative powerhouse location is generally north of the seismic line in an area where bedrock is exposed at ground surface.

Roadcuts on Ortega Highway near and immediately upslope of the present powerhouse location reveal alternating granitic and metamorphic rocks that are faulted and highly sheared. These conditions may extend to depth and may be encountered in the powerhouse shaft and cavern excavations in this area. The presence of highly sheared rock in the powerhouse cavern would pose significant problems for roof support.

Available geologic mapping and exposures in roadcuts further up Ortega Highway to the west suggest that the rock quality improves upslope from the present powerhouse location. If the apparently better rock quality in the upslope area extends to the powerhouse depth, then it would be advantageous to relocate the powerhouse further west and into the hill.

Previous published geologic mapping suggests that the rock quality may not improve substantially if the powerhouse location was shifted south into the area of the previous seismic work since mixed granitic and metamorphic rocks are thought to underlie that area as well (Gray 1954, Engel 1959, Weber 1977).

3.3.2 Foundation Conditions

In addition to problems with roof support, the highly sheared granitic and metamorphic rocks that may exist at the present powerhouse location may also cause uneven foundation support conditions within the powerhouse chamber that could cause differential settlement of critical structures such as turbine pedestals, etc. This condition may be mitigated with an appropriately-designed structure foundation.

3.3.3 Suitability of Excavated Materials for Fill

Most of the excavated spoil from the powerhouse shaft and cavern is expected to be suitable for use as rock fill in dam construction. A relatively small fraction of the generated material will likely consist of smaller sand-size particles due to the presence of intensely fractured rock and shear zones. This smaller size material can be still likely be used for engineered fill.

3.3.4 Groundwater and Seepage

Depth to groundwater in the powerhouse area is presently unknown, but since the powerhouse elevation will be below the water surface in Lake Elsinore, it is likely that the groundwater elevation will be above the roof of the powerhouse. Seepage may be substantial but should be localized within joints and fractures in the rock. Perimeter grouting will likely be required to mitigate groundwater inflows into underground excavations, and appropriate drainage systems behind walls and above the roof may be needed to prevent hydrostatic pressure buildup.

3.3.5 Geologic Hazards

3.3.5.1 Faulting

The powerhouse will be very near mapped traces of the Willard fault, a branch of the active Elsinore fault zone. Though the Willard fault has not been identified as an active fault in the CGS model (CGS 2002), it is a part of the Elsinore fault zone and as such should be considered potentially active.

It is also likely that excavation of the powerhouse access shaft and cavern will expose old, inactive bedrock faults associated with the original intrusion of the pluton. Such older faults, if present, may require local tunnel support measures such as rock bolting, steel ribs and concrete lining, or grouting if groundwater seepage is encountered, as discussed above. It will also be important to conduct fault studies to determine whether any bedrock faults encountered in powerhouse excavations are tectonically associated with the Willard fault and therefore might be subject to displacement during an earthquake.

3.3.5.2 Seismicity

As with other project components, the underground powerhouse will likely be subjected to strong ground shaking during the design life of the project. Site-specific seismic hazard analyses should be performed to support design. Refer to the general discussion of faulting and seismicity in Sections 2.2.1 and 2.2.2.

3.3.5.3 Landslides

The powerhouse will be located underground and will therefore not be directly affected by landslides if they occur. The access tunnel(s) and ancillary surface components of the powerhouse complex would be subject to landslide impacts depending upon the final location of these features. The ground surface above the present powerhouse location is locally very steep and may be subject to landslide hazards during the life of the project.

3.3.5.4 Rock Slides, Debris Flows

As with landslides, rock slides or debris flows would only affect surface components of the powerhouse complex. The likelihood of seismically-induced rock slides in the very steep escarpment above the lower headrace tunnel and powerhouse is high in the event of strong ground shaking from an earthquake.

3.3.5.5 Liquefaction and Seismic-Induced Settlement

Liquefaction and seismic-induced settlement are not concerns since the powerhouse will be founded on competent rock.

3.4 TAILRACE TUNNELS AND INLET/OUTLET STRUCTURE

3.4.1 Excavation and Tunneling

For the purposes of this report, the tailrace feature is designated as a “tunnel”, but may include a combination of tunnel and “cut-and-cover” construction. Design and construction of the tailrace tunnels and inlet/outlet structure pose major challenges given the heterogeneous foundation conditions along the tunnel alignment. Anticipated geotechnical conditions include potentially liquefiable lake bed sediments, the requirement of crossing one or perhaps two potentially active faults, and peak horizontal ground accelerations from nearby earthquakes that might exceed 1g. The inlet/outlet structure will be founded on potentially liquefiable lake bed deposits that likely have a thickness of several hundred feet or more.

The tailrace tunnels will start at the powerhouse cavern in potentially competent rock, then transition in a easterly direction into highly sheared and faulted rock, then weathered, sheared and decomposed rock, then saturated granular alluvial deposits, and finally soft saturated fine-grained lake bed deposits. The tailrace will likely be below the groundwater table at all points. The tunnels will cross mapped traces of the Willard and Wildomar faults, branches of the active Elsinore fault system. The tunnels will likely need to be designed to accommodate displacement of these faults should they experience an earthquake during the design life.

The tunnels will connect either with an inlet/outlet structure constructed within Lake Elsinore, or with an excavated channel conveying water from the lake. This structure will have to be constructed within a temporary cofferdam constructed in the lake. Excavation will likely involve barge-mounted dredging equipment. Shoring and dewatering will be major challenges.

3.4.2 Foundation Conditions

As discussed above, foundation conditions along the tailrace tunnel alignment will vary from competent rock in the vicinity of the underground powerhouse, to less competent rock, to saturated alluvial deposits, to soft saturated fine-grained lake bed deposits near the edge of, and progressing beneath and into, Lake Elsinore. Substantial ground improvement will likely be needed to mitigate static and dynamic settlement, including liquefaction, where saturated and loose foundation materials are present.

3.4.3 Suitability of Excavated Materials for Fill

Tunnel spoil should be usable as engineered fill. If the excavated lake bed deposits are sufficiently fine-grained, they may be suitable for low permeability core material in a zoned earth or rockfill dam at the upper reservoir. Processing to reduce the moisture content of saturated materials to near optimum moisture content would likely be required.

3.4.4 Groundwater and Seepage

As discussed above, the tailrace tunnels will likely be below the groundwater table at all points. Groundwater inflow to the tunnels will likely be severe where the rock is sheared and faulted, and where the tunnels traverse permeable saturated sediments.

3.4.5 Geologic Hazards

3.4.5.1 Faulting

As mentioned above, the tailrace tunnels will cross mapped traces of the potentially active Willard and Wildomar faults. The tunnel will need to be designed to accommodate both lateral and vertical movement potentially generated by rupture along these faults.

3.4.5.2 Seismicity

As with other project components, the tailrace tunnels and inlet/outlet structure will likely be subjected to strong ground shaking during the design life of the project. Due to the proximity of the Elsinore fault zone, and soft foundation conditions, peak horizontal ground accelerations could exceed 1g. Site-specific seismic hazard analyses should be performed to support design. Refer to the general discussion of faulting and seismicity in Sections 2.2.1 and 2.2.2.

3.4.5.3 Liquefaction and Seismic-Induced Settlement

A substantial portion of the tailrace tunnel alignment, and the inlet/outlet structure, will be founded on soft potentially liquefiable sediments that will likely need to be improved using ground improvement techniques. The depth and thickness of liquefiable materials beneath various portions of the tailrace alignment has not been determined, but extrapolation of information from nearby water wells outside the alignment, it is reasonable to assume that these materials could be several hundred feet thick or more. Drilling, testing and seismic surveys would be needed to better define the depth and thickness of liquefiable deposits beneath the structures.

3.4.5.4 Seiches and Flood Inundation

Seiches (seismically-generated water waves within a closed water body such as a lake) may potentially be generated in Lake Elsinore by a significant earthquake on the Elsinore fault zone. The potential for a seiche should be evaluated and addressed in the design of the inlet/outlet structure. Flood inundation should also be evaluated and addressed for the inlet/outlet structure, since Lake Elsinore is a low point within a large watershed and has limited storage capacity.

SECTION 4:
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TABLE

FIGURES