

**Fountain Wind Project**  
**Shasta County, California**

***Desktop Study***

Prepared for



January 2017



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## 1.0 Executive Summary

The Fountain wind project is located in central Shasta County, about 10 miles west of the town of Burney (Figure 1). The project area is on the edge of the recent Cascade volcanics near where they transition to the Klamath Mountains to the west. The site is generally rolling hills on basaltic lava flows. Fountain is tentatively planned as a 200 MW project using 57 Gamesa G132 turbines.

### 1.1 Foundation Design

Based on the soil conditions expected at the site, a spread footing is an economical option. Rock anchors or sockets may also be feasible alternatives in isolated areas if site bedrock has adequate strength and joint characteristics. Surficial soils at the site generally pose a low to moderate risk for concrete and steel corrosion. Shallow groundwater may be perched on bedrock surfaces on ridgelines and may require localized drain systems. Ancillary structures in the valleys of the project area may be affected by shallow groundwater levels.

### 1.2 Civil Design

The climate has wet, cool winters and dry and hot summers. With the elevation of the proposed turbines flooding is not a concern. The project area drains to the Sacramento River.

Access to the site is limited. The project area has some steep slopes exceeding 25%. And there are topographical challenges to the site.

The availability of granular material for road construction is assumed to be good. Barr anticipates the method for constructing access roads in areas with exposed or shallow bedrock will be to build the roads with 6 to 8 inches of gravel or suitable road base material on a geotextile fabric. In areas with a significant thickness of soil, the method of road construction will be to strip off the upper layers of unsuitable soil, thoroughly compact the subgrade, and build the roads with 10 to 14 inches of gravel or suitable road base material on a geotextile fabric.

### 1.3 Electrical Design

The site soils tend to be thin and stony, with low clay content, and the climate is warm and dry. The electrical resistivity may be high and the shallow rock may complicate grounding.

The soil density suggests the soil thermal resistivity will be in the range of 200 to over 700 °C-cm/W. Excavation for the collection system will be difficult due to the shallow competent bedrock.

### 1.4 Geotechnical Investigation

Based on this desktop review and Barr's experience on wind power developments with similar geological terrains, a preliminary investigation may not be warranted given the expected site conditions. In their current state, proposed turbine locations are largely inaccessible to drill rigs or other heavy equipment

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due to the site's thick forest growth. Thick, compressible, or weak soil layers are not anticipated at the turbine sites, which reduces the need for a preliminary geotechnical drilling.

The review of geologic and geotechnical risks completed as part of the desktop study indicate that there are potential concerns related to depth of bedrock, corrosion potential for buried metal and concrete structures, and slope stability. There is the potential for areas of lower strength or high compressibility soils, though due to limited soil thickness, soil strength and compressibility considerations will not likely affect turbine foundation design. Consideration of rock anchors and socket foundations would require in-depth investigation of bedrock properties at proposed turbine locations. Based on Barr's experience with similar geology, rock anchor and socket foundations may not be economical due to the quality and variability of the volcanic and sedimentary bedrock, despite its shallowness.

Aspects of a preliminary geotechnical investigation could be performed during a site visit. Samples could be obtained with a backhoe to provide thermal resistivity, compaction, and corrosivity test results for time-sensitive aspects of the electrical collections system, roadway, and foundation design. Barr estimates that these aspects of a preliminary geotechnical investigation will cost about \$20,000, depending upon scope desired. The recommended scope would be to:

- Obtain soil and rock samples to identify soil engineering properties and soil reactivity
- Preliminarily characterize site bedrock for excavatability, and, to a lesser extent, the use of rock anchor or socket foundations
- Document the presence of shallow groundwater (if present) and shallow bedrock
- Perform preliminary site reconnaissance for field identification of geotechnical risks such as slope instability
- Collect bulk samples of soils to evaluate thermal resistivity and backfill density
- Preliminary geotechnical report summarizing investigation, site reconnaissance, and limited laboratory testing

**Table 1 Geological Hazard Summary**

Hazard	Likelihood	Potentially Fatal Flaw	Significance	Potential Mitigation Measures	Recommended Next Steps	Timing	Next Step Cost
Slope failure (Figure 3 and Figure 8)	High in places	No	Some locations may be at risk. Proposed turbine location IS is at the head of a slope failure that may be associated with development of a downslope road.	<ul style="list-style-type: none"> <li>Slope stability evaluation</li> </ul>	Site-by-site stability evaluations.	Preliminary or Design Phase	None. Will be assessed during normal investigation
Shallow bedrock (Figure 12)	High	No	Low cost of investigation and moderate cost of mitigation	<ul style="list-style-type: none"> <li>Raised foundation design</li> <li>Blasting for excavations</li> </ul>	Drilling and soil testing	Preliminary or Design Phase	None. Will be assessed during normal investigation

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## 2.0 Description of Project

The Fountain wind project is located in central Shasta County, about 10 miles west of the town of Burney (Figure 1). Figure 2 is a map of the project site, showing proposed turbine locations. Fountain is tentatively planned as a 200 MW project using 57 Gamesa G132 turbines.



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## 3.0 Purpose and Scope

The scope of the work is limited to review and assessment of readily available existing information. The goals of this report are to:

- Review readily available existing information, such as geologic maps and reports, geophysical reports, topographic maps, wetlands maps, FEMA flood maps, proposed development maps, and aerial photographs.
- Summarize geologic/geotechnical conditions.
- Identify and qualify geologic/geotechnical risks.
- Recommend a geotechnical investigation approach.
- Summarize soil conditions as it relates to electrical design parameters, thermal, and electrical conductivity.
- Recommend whether or not a preliminary field investigation is warranted and, if so, recommend a scope.
- Address feasible foundation options and issues.
- Identify potential roadway issues.
- Provide conceptual-design level cost estimates.

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## 4.0 Site Geology

The Fountain wind project is on the edge of the recent Cascade volcanics near where they abut the Klamath Mountains to the west. A short distance to the southwest is the northern end of the Great Valley, and the northern end of the Sierra Nevada Mountains is to the southeast. Directly east is the Modoc Plateau. Figure 3 is a topographic map of the project area.

From northern California up to the central coast of Canada, the Pacific plate is sliding under the North American plate, and one result is the vast number of volcanoes and volcanic deposits in this region. Mt Shasta and the other Cascade Mountains are the prominent volcanoes, but there are many smaller examples. The Modoc Plateau is a large lava plain, and is an extension of the Columbia River basalts of Oregon and Washington. These volcanic deposits are generally interspersed with accreted terrain like the Klamath Mountains. As the plates come together, small masses of land that were on the Pacific plate, and were lighter in mass than oceanic crust, smeared onto the North American plate rather than sliding under, sometimes with bits of oceanic crust and deeper earth materials. The Klamath Mountains are a large area of such land ([Sawyer, 2006](#)).

The site is between three volcanic centers that are considered to be active ([Shasta County, 2011](#)):

- Medicine Lake volcano has erupted at least seven times in the past 4,000 years, most recently about 950 years ago
- Mount Shasta erupted with pyroclastic flows in 1786, and has had relatively minor activity since
- Lassen Peak experienced a series of small explosions in 1914 that was followed by destructive lava flows in 1915

### 4.1 Bedrock Geology

Figure 4 shows the geology of the area; this map is based on data available from the web, consistent with the Bedrock Geologic Map of California: Westwood Sheet ([Lyndon et al, 1960](#)).

The site is primarily underlain by Tertiary andesite (an intermediate volcanic rock, between a rhyolite and a basalt), with basalt and pyroclastics, between 2 and 5 million years old. The extreme northern part of the site is underlain by a younger andesite. The extreme west-central part of the site is underlain by Eocene (56-33.9M years old) sandstone mapped as non-marine by Lyndon et al. (1960). It is likely the volcanics were deposited on an uneven surface of older deposits like the Eocene sandstone, and so the thickness of the volcanics may vary considerably and the top and bottom elevations vary.

The individual formations are not identified on the geologic map. According to Lydon and O'Brien (1964), the most widespread and continuous unit is the Tuscan Formation. The Tuscan contains over 300 cubic miles of volcanic debris, extending many miles to the south. In the area of the site, the Tuscan Formation is overlain by the later succession of Pliocene basalts and andesites, which are the uppermost bedrock under most of the site. These lava flows originated from eruptive centers in the higher elevations of the

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Cascade Range. These were later intruded by even younger Quaternary volcanics, such as Burney Mountain, Magee Peak, and Mounts Shasta and Lassen.

The site is bounded by fault lines on the east that have been active since Quaternary time: the Hatchet Mountain fault, active in the last 1.6M years, unnamed faults active in the last 600,000 to 1.2M years, and the Rocky Ledge fault which has been active in the last 15,000 years.

## 4.2 Soils

Figure 5 shows the soil map unit names, which are summarized by turbine locations below:

- CmD, CmE: Cohasset stony loam: 23 proposed turbine sites
- WeD, WfG: Windy and McCarthy stony sandy loams: 14 proposed turbine sites
- 173im, 174im Gaspar-Scarface complex: 8 proposed turbine sites
- CrD: Cohasset-McCarthy complex: 4 proposed turbine sites
- 179im: Goulder gravely sandy loam 3 proposed turbine sites
- 266im: Obie-Mounthat complex: 3 proposed turbine sites
- JdE: Josephine gravelly loam, moderately deep: 1 proposed turbine sites
- LhE: Lyonsville-Jiggs complex, deep: 1 proposed turbine sites
- TcE: Toomes very rocky loam: 1 proposed turbine sites

As with the other soils, the soil complexes are similarly gravely and stony loams. The parent materials are volcanic ash, lava flows, and volcanic rocks, consistent with the geologic mapping. The Gaspar-Scarface and Goulder soils tend to be the thickest (greater than 200 cm); the others are thin soils over a restrictive layer.

Figure 6 shows the USCS classifications of the surficial soils, which are dominated by silty sands and silty gravel. Most of the proposed turbine locations are underlain by silty gravel.

## 4.3 Groundwater

Groundwater occurrence is not well documented, and the State of California does not yet release well information on line. According to one report ([California Department of Water Resources, June 1984](#)) groundwater production from the volcanic deposits can vary. The volcanic sediments in the Tuscan Formation may yield good amounts of groundwater. The overlying lava flows may be fractured and brecciated and vesicular enough to produce good amounts of groundwater. However, the project area has significant relief and the proposed turbine locations are on high ground. While there is some potential for perched water to occur if an area is underlain by a more crystalline deposits, in most places the

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groundwater should be at sufficient depth that it is inconsequential to the project development. This is generally supported by the NRCS soil mapping of depth to water (Figure 7).

## 4.4 Economic Geology

While there are some oil and gas leases in the County, there is no evidence of exploration or development in the proposed project area.

The Klamath Mountains east of the site contain several mining districts with deposits of copper-zinc, gold, and silver, along with many other mineral commodities including metals, minerals (asbestos and talc), limestone, dimension and crushed stone, and sand and gravel. The volcanic and associated sediments in the Cascade Range, where the site is located, is a source of pumice, cinders, crushed and decorative stone, and sand and gravel (Lyndon and O'Brien, 1974).

## 5.0 Geologic/Geotechnical Risks

**Table 2 Summary of Geologic Hazards**

Hazard	Present at Site?	Comment
Flooding/High groundwater	No	The proposed turbine locations are on high ground (Figure 3). FEMA does not project any flood zones in the project area.
Slope failure	Yes	Landslides are apparent on Google Earth™ imagery, notably not far from the proposed I5 turbine location (Figure 8).
Subsidence – Pumping	No	There is little to no irrigation or other high-demand pumping in the region.
Subsidence – Mining	No	Mining has not historically taken place in the project area, although there is mining in the region.
Subsidence – Caves/Karst	No	There are no carbonate or sulfate sedimentary rocks present in the project area (Figure 4).
Earthquake – Seismicity	No	This is a seismically active region, although the area of the site is relatively low hazard (Figure 9; <a href="#">Shasta County, 2011</a> ). <a href="http://earthquake.usgs.gov/hazards/products/conterminous/">http://earthquake.usgs.gov/hazards/products/conterminous/</a>
Earthquake – Ground rupture	No	There are no active faults mapped in the region. <a href="http://earthquake.usgs.gov/hazards/qfaults/map/">http://earthquake.usgs.gov/hazards/qfaults/map/</a>
Liquefaction	No	There is low seismicity in the region.
Swelling/ shrinking soil	No	NRCS indicates site soils have low plasticity indices.
Settlement	Unlikely	Some proposed turbine locations are underlain by clayey soil. However, most soils are relatively thin.
Corrosive soil (Steel)	Unlikely	The majority of the site is rated as moderately corrosive by NRCS (Figure 10).
Corrosive soil (Concrete)	Unlikely	The majority of the site is rated as moderately corrosive by NRCS (Figure 11).
Reactive aggregate (ASR)	Unlikely	There should be a variety of aggregate sources.
Made ground	Unlikely	The proposed site is undeveloped and heavily forested.
Collapsible soil	No	The geology and climatic conditions are not suitable for the formation of collapsible soils.
Volcanic activity	Yes	There is known volcanic activity in the region. Although most is hundreds to thousands of years old, Mt Shasta and Mt Lassen are still very much active volcanos and Medicine Lake volcano has been active as recently as about 100 years ago ( <a href="#">DeCourten, accessed 12/27/16</a> ).

The County hazard plan calls out only two geological hazards: seismic activity and volcanoes ([Shasta County, 2011](#)). As noted in Table 5-1, while seismically active, the seismicity generally is relatively low intensity and should not be a controlling factor for turbine foundation design.

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## 5.1 Volcanic Hazards

From the Shasta County Mitigation Plan:

“Volcanoes produce a wide variety of hazards that can kill people and destroy property. Large explosive eruptions can endanger people and property hundreds of miles away and even affect global climate. Some of the volcano hazards, such as landslides, can occur even when a volcano is not erupting.

Volcanic eruptions result in fires, toxic gas emissions, air pollution, extensive ash deposits, and could catalyze earthquakes, landslides, and floods. Ash deposits can create public health, telecommunications, and structure damage hazards.”

The site is about 40 miles from Mt Shasta, 25 miles from Mt Lassen, and 45 miles from Medicine Lake volcano. The most hazardous areas are those within the surrounding 10 mile radius and the downstream river valleys ([https://volcanoes.usgs.gov/volcanoes/mount\\_shasta/hazard\\_summary.html](https://volcanoes.usgs.gov/volcanoes/mount_shasta/hazard_summary.html) and [https://volcanoes.usgs.gov/volcanoes/lassen\\_volcanic\\_center/hazard\\_summary.html](https://volcanoes.usgs.gov/volcanoes/lassen_volcanic_center/hazard_summary.html)) may be subject to lava, landslides, and lahars. Ash fall, while generally not as hazardous, can cover a much larger area. It is subject to weather and the nature of the eruption, so it is difficult to predict. Major volcanic events are generally not sudden, but are preceded by a series of smaller events that act as warning. The USGS actively monitors such activity.

## 5.2 Shallow Bedrock

While depth to bedrock is generally not considered a hazard, shallow bedrock will complicate excavations for roads, turbines and the collection system. Shallow bedrock will also complicate installation of grounding systems. The depth to a restrictive layer (generally bedrock) is generally less than 7 feet, except in the northeast corner of the project site (Figure 12).

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## 6.0 Feasible Foundation Types

Feasible foundation types for the project are selected, in part, based upon a combination of critical geotechnical, climatological, and mechanical factors which drive the design selected.

1. **Geotechnical Factors.** The soils at the site are anticipated to consist of alluvium, colluvium, and residual soil. The ridgelines that host turbines onsite contain thin sandy and gravelly soils with silt. The site has low seismicity of a magnitude that would not supersede the design loads due to wind (IBC, 2009). Shallow groundwater may be present on ridgelines where it is perched on the bedrock surface. This condition may require consideration of localized drainage systems for the foundations. Corrosion of steel and concrete is low to moderate across most of the site.
2. **Climatological Factors.** Flooding is not a concern for turbine foundations. Shallow groundwater may be perched on bedrock surfaces along the ridgelines and within the valleys. Frost action is applicable for this site and so the effects of frost heave should be considered during design.
3. **Mechanical Factors.** The overturning moment for a typical Gamesa G132 wind turbine should be considered.

The following foundation types are feasible based on the combination of critical geotechnical and climatological factors identified:

1. **Spread Footing.** In areas with adequate depth of soil or shallow bedrock, the soil conditions will likely be suitable for support of a spread footing.
2. **Spread Footing on Engineered Fill.** It is anticipated that the majority of the site soils will provide sufficient bearing capacity. If low strength soil deposits are encountered at depths less than 15 feet below the surface, some soil correction (likely consisting of removal and replacement of soil with engineered fill or use of stone columns/Geopiers) may be necessary. If shallow groundwater is encountered, stone columns/Geopiers may be a more desirable soil remediation option.

The following foundation types may be feasible in isolated locations (if site bedrock has adequate strength characteristics) based on the combination of critical geotechnical, climatological, and mechanical factors identified:

1. **Rock Anchor Foundation.** This type of foundation is feasible in shallow (i.e., within 1 to 3 feet of the ground surface), strong, and massive bedrock. Shallow bedrock is present in portions of the site, specifically along the western extents of the project site. This type of foundation is constructed by blasting an excavation approximately 25-35 feet in diameter by 5-7 feet deep into the bedrock, drilling anchors to an approximate depth of 20-50 feet, placing an anchor bolt cage and reinforcing in the excavation, and pouring a concrete cap. This type of foundation is highly dependent on the rock strength, joint patterns, and condition. Because this type of foundation is

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highly dependent on the competency of the rock at each turbine location, there is more uncertainty associated with it than with a conventional spread footing.

2. **Rock Socket Foundation.** This type of foundation is only feasible in shallow (i.e., within 1 to 3 feet of the ground surface), strong, and massive bedrock. Shallow bedrock is present in portions of the site, specifically along the western extents of the project site. This type of foundation is constructed by blasting an excavation approximately 20 ft x 20 ft x 20 ft into the bedrock, placing an anchor bolt cage and reinforcing in the excavation, and filling the excavation with concrete. This type of foundation is highly dependent on the rock strength, joint patterns, and condition. Because this type of foundation is highly dependent on the competency of the rock at each turbine location, there is more uncertainty associated with it than with a conventional spread footing.

The following foundation types are not feasible based on the combination of critical geotechnical, climatological, and mechanical factors identified:

1. **Deep Foundations.** Due to the shallow depth of bedrock, deep foundations will likely not be required. Less expensive foundation options are suitable for the site.
2. **Dynamic Compaction of Soil Supporting Spread Footing.** The project site is underlain by competent rock; therefore, remediation of loose soils by dynamic compaction is unnecessary.

Based on the competency of the soil and bedrock expected to be encountered at the project location, it is expected that a conventional spread footing will be the most economical type of foundation. Some soil correction may be necessary in areas where soils exhibit lower strengths or higher compressibility, likely consisting of either (a) removal and replacement of soil with engineered fill, or (b) use of stone columns/Geopiers. Rock anchors or sockets may also be feasible alternatives in isolated areas if site bedrock has adequate strength and joint characteristics.

Most of the turbines are underlain by soil that is moderately corrosive to concrete and steel, as shown in Figure 7 and Figure 8. Corrosive soils may require special cement. At worst, sulfate resistant cement (S02) may be required and result in increased foundation costs on the order of 10-20%. Some corrosion-resistant cements are not readily available and can require several months of testing, so early determination is important.

If Avangrid wants to consider foundation options other than a spread footing, a preliminary phase geotechnical assessment is warranted. In addition, if Avangrid wants to consider foundation options other than a spread footing, then the contractor selection process sooner than normal.



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## 7.0 Electrical Design

As reported by the USDA NRCE, the site soils are primarily clayey and silty sands and gravels, typically very gravelly or stony and thin (less than 7 feet thick) over bedrock.

### 7.1 Soil Electrical Resistivity

The soil types of the site indicate generally low ground electrical resistivity across the project area due to generally clayey soils and deep bedrock.

For most engineering applications in soils, the motion of ions in the interstitial formation water is the dominant factor affecting the electrical resistivity. Ions in the formation water come from the dissociation of salts such as sodium chloride, magnesium chloride, etc. (Mooney, 1980). For water-bearing earth materials, the resistivity decreases with increasing:

1. Fractional volume of the material occupied by water
2. Salinity or free-ion content of the water
3. Interconnection of the pore spaces (permeability)
4. Temperature

The presence of clay minerals tends to decrease the resistivity because: (a) the clay minerals can combine with water; (b) the clay minerals can absorb cations in an exchangeable state on the surface; and (c) the clay minerals tend to ionize and contribute to the supply of free ions.

The general range of electrical resistivities for sandy clays is from 1,000 to 8,000 ohm-centimeters ( $\Omega\text{cm}$ ) or 10 to 800 ohm-meters ( $\Omega\text{m}$ ). Values can range from 100 to 60,000  $\Omega\text{cm}$  (1 to 6,000  $\Omega\text{m}$ ) for gravels (Telford, 1976).

Climatic variables, including fluctuating average low and high air temperatures of 15°F to 85°F, are important to note when comparing shallow soil electrical resistivity values to studies from other climates (IEEE, 1983). The electrical resistivity of surficial soils will decrease when the soils are warm, increase when cold, and will be notably higher when soils are frozen. However, the bulk resistivity of soils through the depth of construction is not likely to be impacted by air temperature fluctuations. High soil moisture will decrease resistivity.

Redding, California has a mediterranean climate with dry hot summers and mild winters (<https://weatherspark.com/averages/31447/Redding-California-United-States>).

The USDA NRCS-NCGC SSURGO database was queried for clay contents of soils across the entire site and for soil in the immediate area of the preliminary turbine locations. About 62 percent of the site in general has soils with low clay content and therefore likely high electrical resistivity. About 45 percent of the

proposed turbine locations have similar low clay/high resistivity soils. Soils across much of the site area is thin and stoney (Figure 5), so there may be some bedrock interference with grounding.

The American Petroleum Institute (API) provides guidance for the potential corrosivity of materials based upon resistivity measurements (API-651, [Cathodic Protection of Aboveground Petroleum Storage Tanks, 1997](#)). Following is the General Classification of Resistivity reference adapted from API 651, Chapter 5.3.1.2, Table 1.

**Table 3 Classifications of Resistivity**

Resistivity Range, $\Omega\text{cm}$	Resistivity Range, $\Omega\text{m}$	Resistivity Range, $\Omega$ feet	Potential Corrosion Activity
<500	<5	<16	Very Corrosive
500 – 1000	5 - 10	16 – 33	Corrosive
1000 – 2000	10 – 20	33 – 66	Moderately Corrosive
2000 – 10,000	20 – 100	66 – 330	Mildly Corrosive
> 10,000	> 100	> 330	Progressively Less Corrosive

The clay content suggests most site soils have low to moderate corrosivity to steel which is similar to the SSURGO data base rating (Figure 8).

Barr recommends an electrical resistivity survey be conducted in order to confirm grounding and cathodic protection design parameters. The work should be performed in accordance with ASTM method G57 “Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method” (equivalent to IEEE Std. 81). Testing should be conducted at each construction site or at a representative number of sites for each soil type and topographic setting.

## 7.2 Soil Thermal Resistivity

The best approach is to determine site-specific values during the geotechnical investigation phase. However, it is generally the case that the higher the moisture content, density, and quartz content in the soil, the better the thermal properties with respect to heat dissipation. At this site, the soil densities are very low and quartz contents are moderate, and the moisture content is expected to be low, indicating heat dissipation may be low to very low.

Based on data collected by Barr on several wind farms in the Upper Midwest, it was found there is a correlation between dry density and thermal resistivity. This lab data can be further compared with NRCS soil properties to estimate the relative range of thermal resistivity values. In these comparisons, only the dry density of a soil was used, since moisture content cannot be obtained from the NRCS.

Figure 13 shows a 90% confidence interval applied for the thermal resistivity correlation to dry density.

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## 8.0 Civil Design

Available resources including USGS topographic maps, aerial photography, surface soil properties, and regional flooding and rainfall information were reviewed to identify construction limitations that may be present at the project site, as well as potential issues for long-term operation and maintenance. The information collected and analyzed for the Civil Design review is described in this section.

The climate is characterized as a Mediterranean climate with wet, cool winters and warm, dry summers. The average annual precipitation in the region is 28 inches rain and 35 inches snow. Historical averages show that July through September are typically the dry months. Snowfall typically occurs between the months of November to April with December and January receiving the highest totals. The summers are typically warm and dry with no average monthly temperatures above 71.6°F.

The proposed turbine locations are on high ground so flooding is not a concern. FEMA does not project any flood zones in the project area.

The project area is located in the Lower Pit River watershed which drains to the Sacramento River.

Highway access to the site is limited to State Route 299, between I-5 and State Route 89. Access to interstate I-5 is in the city of Redding west of the project area. Most of the public roads in the region are paved and graveled roads, though some of the planned turbine sites are a significant distance from the nearest road.

A pair of parallel 230-kilovolt transmission lines owned by PG&E run east-west through the middle of the proposed turbine locations.

There are topographical challenges to the site. The project area has some steep slopes along the ridgelines of southern Cascade Mountains, sometimes exceeding 25%.

The availability of granular material for road construction is good. Several pits are identified from online searches in Shasta County near the project limits, which have been shown to be suitable for road construction aggregate. Road construction materials for the existing Hatchet Ridge Windfarm were provided from a pit just east of the project area near Burney, California.

Barr anticipates the method for constructing access roads in areas with exposed or shallow bedrock will be to build the roads with 6 to 8 inches of gravel or suitable road base material on a geotextile fabric. In areas with a significant thickness of soil, the method of road construction will be to strip off the upper layers of unsuitable soil, thoroughly compact the subgrade, and build the roads with 10 to 14 inches of gravel or suitable road base material on a geotextile fabric. The gravel thickness and geotextile specification section will be determined after a geotechnical investigation is performed to determine the CBR values for final design. Existing drainage patterns will be maintained by the use of culverts or other drainage features.

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For grading activities that exceed 250 cubic yards movement of earth materials or that disturb 10,000 square feet or more Shasta County requires a grading permit. In addition, for earthmoving activities taking place between October 15 and May 1 a wet weather plan must be prepared by an erosion control specialist.

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## 9.0 Geotechnical Investigation

Some of the geologic and geotechnical hazards outlined in [Section 5](#) have the potential to affect project construction procedures and costs. Many of these hazards can be identified in a site visit and evaluated by obtaining bulk samples of the soil and rock. A full drilling program at the preliminary stage of the project could present significant costs, logistical difficulties, and is likely not required if spread footing foundations are planned for the project site, then a full drilling program is likely not required. However, if alternative foundation types are being considered, then the strength, joint patterns, and condition of the near surface bedrock should be assessed during a preliminary investigation.

### 9.1 Summary of Known Conditions

Based on the information available, the key issues at the project site include: corrosivity to concrete, corrosivity to steel, slope stability, and shallow bedrock. Of these issues, the possible presence of shallow bedrock will have the biggest impact on project risk and cost, from a geotechnical and geological standpoint.

### 9.2 Recommended Preliminary Investigation

The investigation methods required to address these issues are preliminary and low-cost, such that they may be incorporated into a site visit. For this reason, Barr recommends a preliminary investigation to further evaluate these key geologic and geotechnical issues. The proposed preliminary investigation is summarized below:

1. Complete limited geotechnical investigation of site characteristics:
  - a. Collect soil and rock samples with a backhoe to identify soil engineering properties and soil reactivity
  - b. Preliminarily characterize site bedrock for excavatability, and, to a lesser extent, the use of rock anchor or socket foundations
  - c. Perform preliminary site reconnaissance for field identification of geotechnical risks such as slope instability
  - d. Further document the presence of shallow groundwater and shallow bedrock
  - e. Collect bulk samples of soils to evaluate thermal resistivity and backfill density

Approximately two or three days will be required to complete the recommended scope for the purposes of the preliminary investigation. It is assumed that the boring locations can be accessed by foot from the established network of gravel roads within/surrounding the site.

1. Complete preliminary geotechnical report summarizing site reconnaissance and limited laboratory testing. Though this would be a preliminary investigation, it will need to be a detailed evaluation

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of the key issues noted previously, including soil corrosivity/reactivity, shallow groundwater and, to a lesser extent, soil strength/compressibility.

2. Barr estimates that a preliminary geotechnical investigation will cost approximately \$20,000, but will vary depending on specific scope details.

### **9.3 Design Geotechnical Investigation**

The final design geotechnical investigation should confirm the depth to bedrock and the stability of slopes adjacent to the final turbine locations, in addition to the typical design program. If a rock socket or rock anchor foundation is considered for the project, the geotechnical investigation would need to be adjusted to collect the appropriate design data.

Assuming a spread footing foundation, the following sections describe the recommended scope for the final investigation.

#### **9.3.1 Site Reconnaissance**

A site reconnaissance should be performed to identify any geologic hazards, such as slope failures, perched ground water, or undocumented fill that may be present onsite. In addition, the survey should consist of measurement and locating slope instability or failure planes within rock outcrops for use in analyzing possible block failure. The field survey should be performed by personnel with a background in engineering geology and wind power development.

#### **9.3.2 Drilling Investigation**

Borings provide for the ability to sample soil and rock for visual classification and laboratory testing. The resulting data is used to infer such material properties as friction angle, undrained shear strength, unit weight, soil and rock type classification, and groundwater level.

#### **9.3.3 Seismic Refraction Testing**

A field seismic refraction study should be performed to allow for the determination of soil and rock shear modulus for use in stiffness calculations during foundation design. The recommended method is by Multi-channel Analysis of Surface Waves (MASW). Measurements should be taken at approximately ten percent of the proposed turbine locations.

#### **9.3.4 Laboratory Testing and Other Work**

Testing that should be performed on split spoon, Shelby tube, and bulk soil samples, as well as rock cores, gathered during drilling and should include (but may not be limited to):

- Grain size, Atterberg limits, moisture content, and Proctor density testing for primary soil classification.
- Unconfined compressive strength (with strain measurement) and/or direct shear testing for determination of soil/rock shear strength, elastic moduli, and bearing capacities.

- 
- Chemical testing, including pH, soluble sulfates, and chloride ions, to identify corrosive soils for use in foundation concrete design.

In addition to the geotechnical investigation recommended above, Barr recommends performing field and laboratory testing for use in design of the electrical infrastructure (by others) and roadway design concurrently. This testing should include field electrical resistivity and laboratory thermal resistivity testing as described in [Section 7](#), as well as soil sampling and laboratory testing and data analysis for roadway design as described in [Section 8](#).

### **9.3.5 Estimated Costs**

Based upon experience with similar projects, assuming exploration is limited to that described above (not including testing for electrical design, civil design, or design of other structures), that site access is such that a water truck may reach the turbine locations, and that no additional clearing is required, the cost of implementing this next phase of work is estimated to be on the order of \$150,000 to \$200,000.

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## 10.0 Limitations

The opinions and probable costs provided in this report are made on the basis of Barr's experience and qualifications and represent our best judgment as experienced and qualified professionals familiar with the project. The cost opinion is based on project-related information available to Barr at this time and includes a conceptual-level design of the project. The opinion of cost may change as more information becomes available. In addition, since we have no control over the cost of labor, materials, equipment, or services furnished by others, or over the contractor's methods of determining prices, or over competitive bidding or market conditions, Barr cannot and does not guarantee that proposals, bids, or actual costs will not vary from the opinion of probable cost prepared by Barr. If Avangrid wishes greater assurance as to probable cost, additional information will need to be collected.



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United States Geological Survey (USGS) Website, Accessed February 2016. US Seismic Design Maps Tool. <http://earthquake.usgs.gov/designmaps/us/application.php>

## Reference Checklist

Record Type	Record Location	Reference Outcome*
Water Well Records (local-electronic)	California has yet to release these <a href="http://www.water.ca.gov/groundwater/wells/well_completion_reports.cfm">http://www.water.ca.gov/groundwater/wells/well_completion_reports.cfm</a>	D
Water Well Records (state-electronic)	California has yet to release these	D
State DOT boring records	<a href="http://www.dot.ca.us">www.dot.ca.us</a>	D
USGS Maps (electronic)	<a href="http://ngmdb.usgs.gov/">http://ngmdb.usgs.gov/</a>	A
USGS Maps (hard copy)	<a href="http://pubs.er.usgs.gov/">http://pubs.er.usgs.gov/</a>	A
USGS Mining/Mineral maps (electronic)	<a href="http://mrdata.usgs.gov/">http://mrdata.usgs.gov/</a>	A
USGS Studies/Reports (electronic)	<a href="http://pubs.er.usgs.gov/">http://pubs.er.usgs.gov/</a>	A
USGS Studies/Reports (hard copy)	Barr Internal Library, <a href="http://pubs.er.usgs.gov/">http://pubs.er.usgs.gov/</a>	A
State GS maps (electronic)	<a href="http://www.conservation.ca.gov/cgs/publications/Pages/index.aspx">http://www.conservation.ca.gov/cgs/publications/Pages/index.aspx</a>	A
State GS maps (hard copy)	<a href="http://www.conservation.ca.gov/cgs/publications/Pages/index.aspx">http://www.conservation.ca.gov/cgs/publications/Pages/index.aspx</a>	A
State GS local/regional studies (electronic copy)	<a href="http://www.conservation.ca.gov/cgs/publications/Pages/index.aspx">http://www.conservation.ca.gov/cgs/publications/Pages/index.aspx</a>	A
State GS local/regional studies (hard copy)	<a href="http://www.conservation.ca.gov/cgs/publications/Pages/index.aspx">http://www.conservation.ca.gov/cgs/publications/Pages/index.aspx</a>	A
State GIS boring records (electronic)		D
Soil Survey Maps (electronic)	<a href="http://websoilsurvey.nrcs.usda.gov">http://websoilsurvey.nrcs.usda.gov</a>	A
FEMA Maps (electronic)	FEMA Map Service Center	A
Oil/Gas Exploration Boring Logs	<a href="ftp://ftp.consrv.ca.gov/pub/oil/maps/Map_S-1.pdf">ftp://ftp.consrv.ca.gov/pub/oil/maps/Map_S-1.pdf</a>	A
Earthquake Seismic Hazards (USGS)	<a href="http://earthquake.usgs.gov/earthquakes/eqarchives//">http://earthquake.usgs.gov/earthquakes/eqarchives//</a>	A
First Hand Karst/Cave Knowledge	<a href="http://www.nssio.org">http://www.nssio.org</a>	E
Climate Data (electronic)	<a href="http://www.noaa.gov">http://www.noaa.gov</a>	A

\*A = reference was reviewed or ordered from agency

B = reference is available, but only locally and at additional cost

C = reference is potentially available upon special request and at additional cost

D = reference was not found or does not exist

E = reference not applicable to this site

## Figures

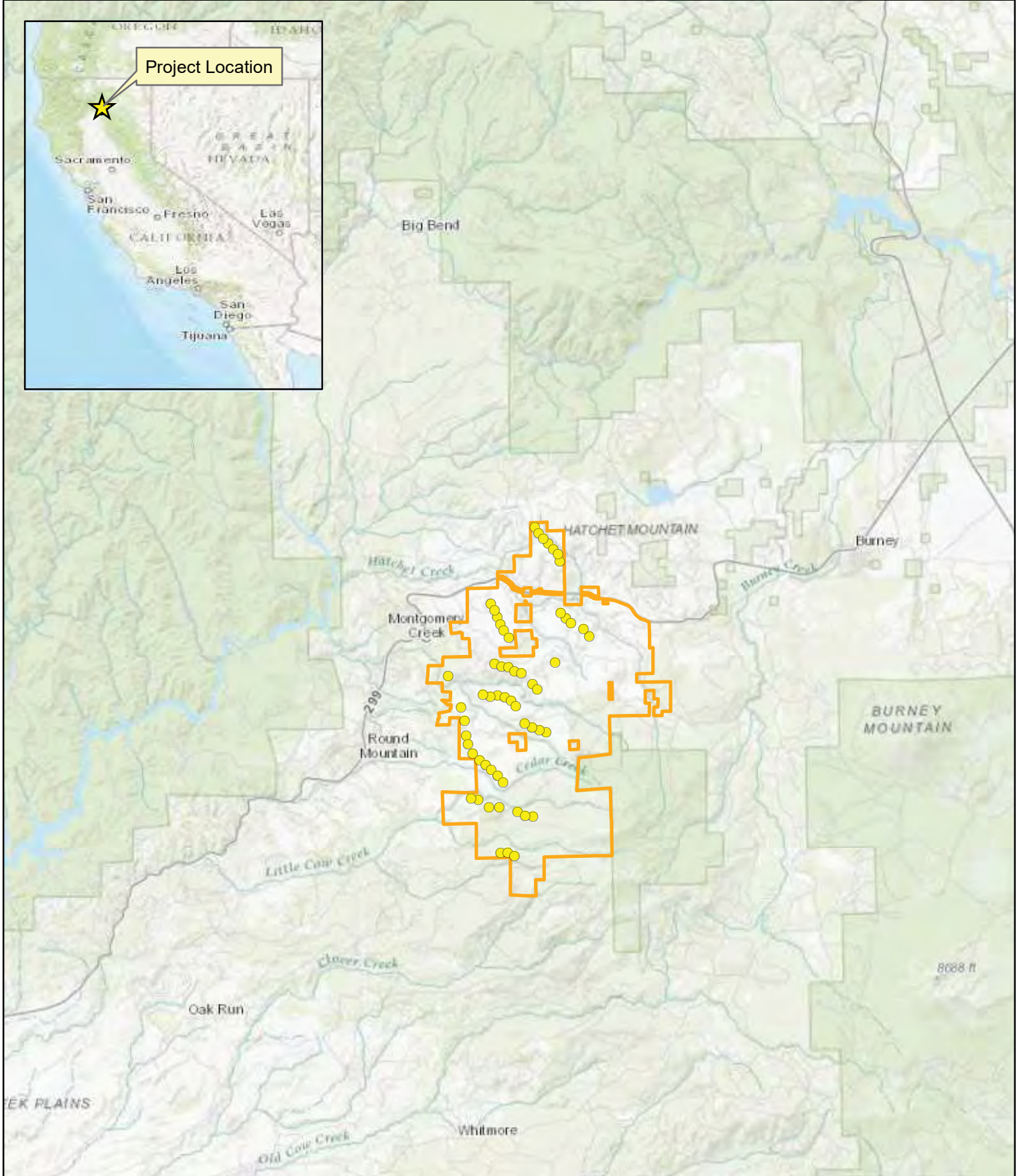
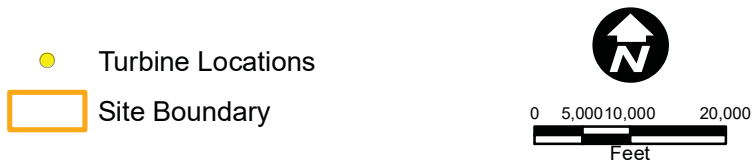
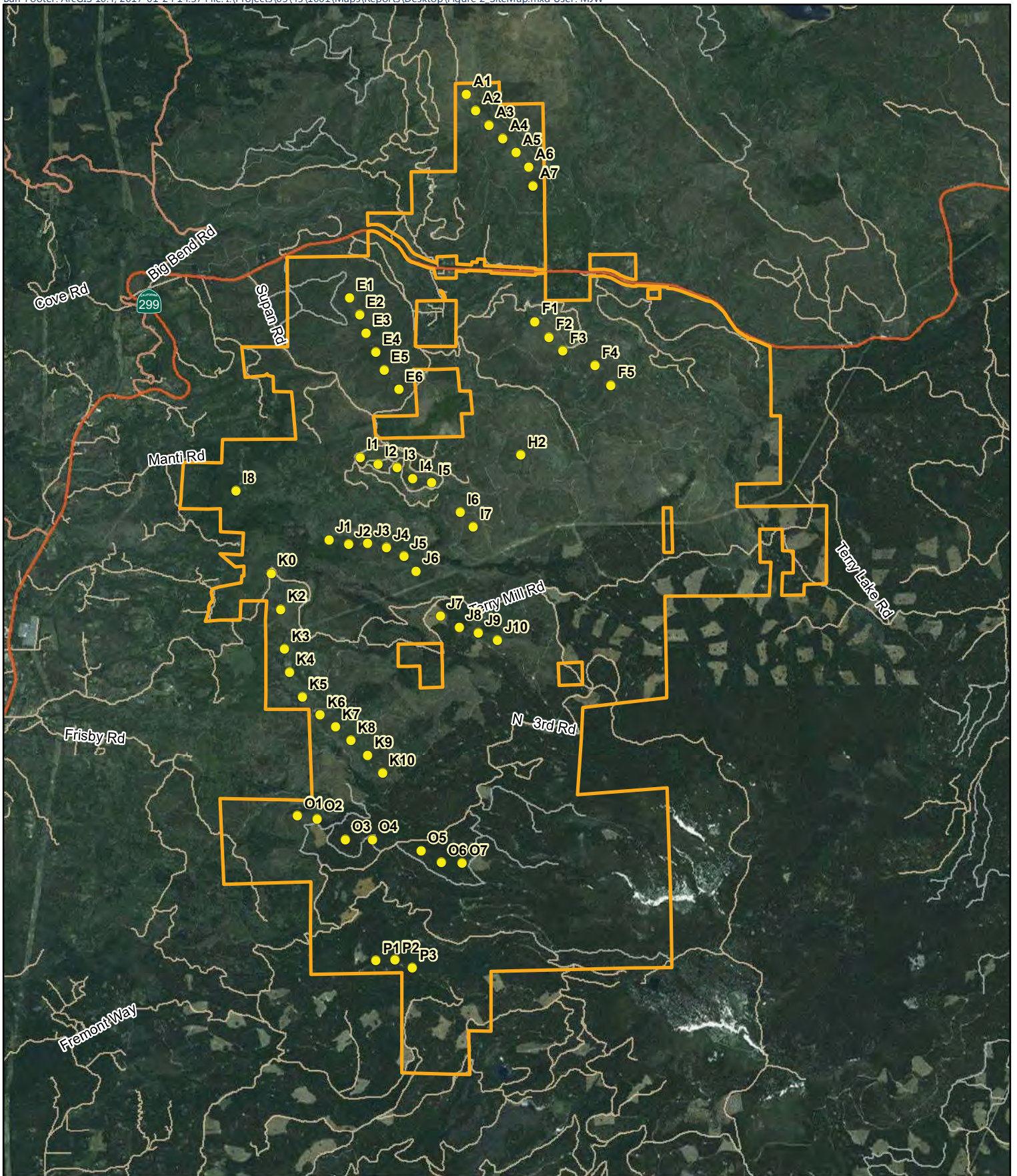








Figure 1



Site Location  
McCloud Project  
Avangrid Renewables  
Shasta County, California



-  Turbine Locations
-  Site Boundary
-  Primary US and State Highways
-  Secondary State and County Highways
-  Local, neighborhood, rural or City Street
-  4WD

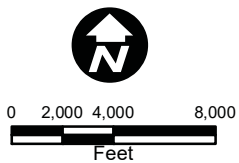
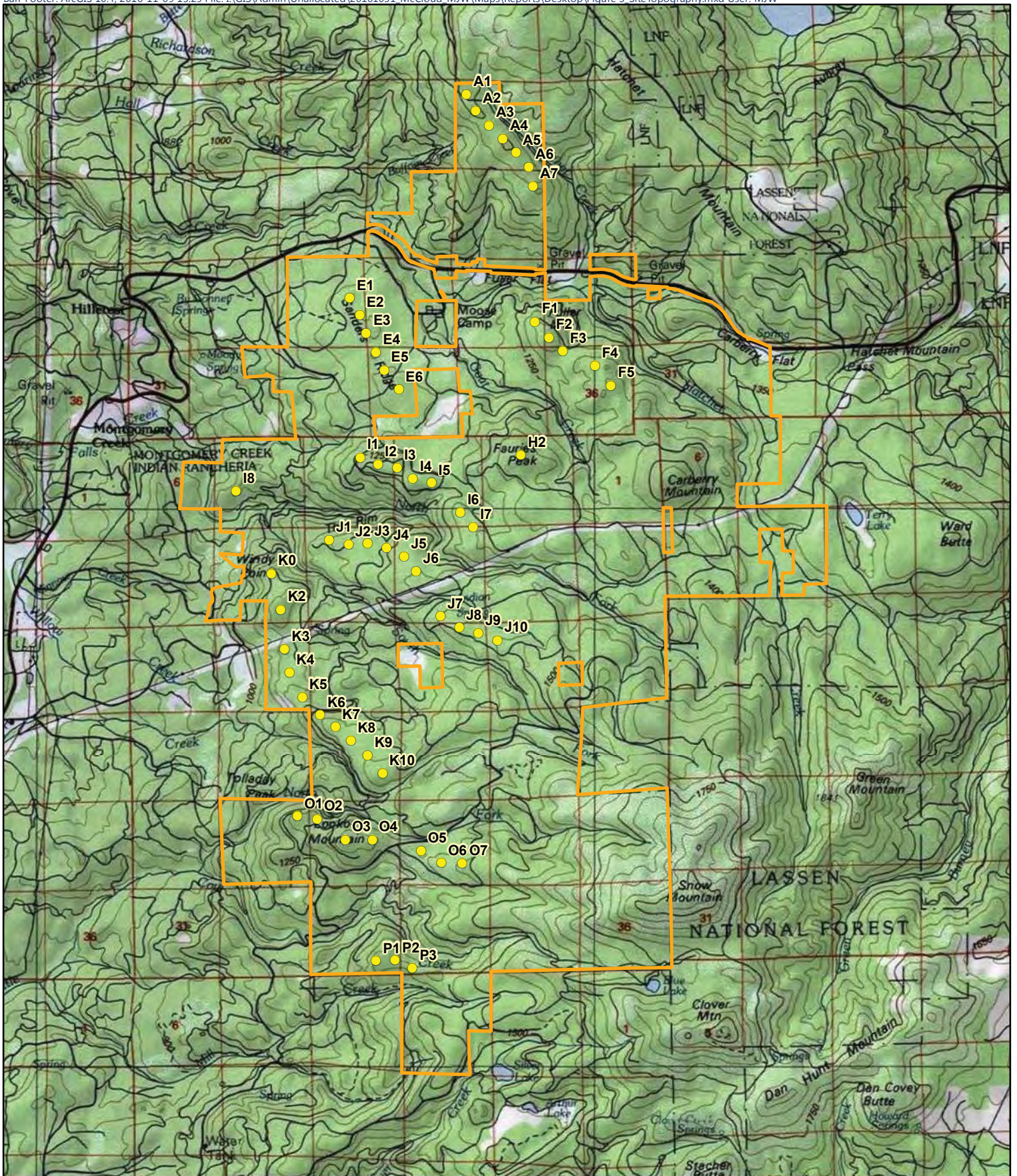


Figure 2  
Site Map  
McCloud Project  
Avangrid Renewables  
Shasta County, California



- Turbine Locations
- ▭ Site Boundary

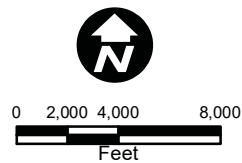
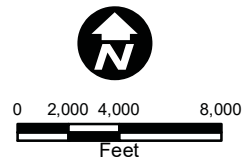


Figure 3  
Site Topography  
McCloud Project  
Avangrid Renewables  
Shasta County, California



- Turbine Locations
- Faults
- ▭ Site Boundary
- Site Geology
- Ec--Eocene--sandstone
- Mzv--Late Permian to Jurassic--intermediate volcanic rock

- Q--Pliocene to Holocene--alluvium
- Qrv--Holocene--andesite
- Qv--Quaternary--andesite
- Tv--Tertiary (2-24 Ma)--andesite
- Water



Source: U.S. Geological Survey, California Geological Survey

Figure 4  
 Site Geology  
 McCloud Project  
 Avangrid Renewables  
 Shasta County, California



- Turbine Locations
- Site Boundary
- Soil Map Unit Name
- 139, 139im, 140, 140im, 141, 141im -- Danhunt gravelly sandy loam
- 145, 146 --Depner gravelly sandy loam
- 169, 169im --Gardens-Jacksback complex
- 172, 172im, 173, 173im, 174, 174im-- Gasper-Scarface complex, mois
- 178, 178im, 179, 179im, 180 -- Goulder gravelly sandy loam
- 190, 190im --Jacksback loam
- 191, 192 --Jadpor gravelly sandy loam
- 266, 266im, 267, 267im, 268, 268im-- Obie-Mounthat complex
- 300--Riverwash
- 312, 312im, 313, 313im, 314, 314im-- Stacher gravelly coarse sandy loam
- 316, 316im--Stukel complex
- 330, 331--Winnibulli loam
- 335, 336--Wyntoon sandy loam
- 397, W--Water
- AaB, AaC, AaD--Aiken
- AbB, AbC, AbD, AcE--Aiken stony loam
- CID--Cohasset loam
- CmD, CmE, CnF, CoE --Cohasset stony loam
- CrD, CrE, CrG--Cohasset-McCarthy complex
- CsF--Colluvial land
- CuD--Cone stony loam
- CvE, CwF--Cone very stony loam
- JbD, JbE, JbF, JdD, JdE--Josephine gravelly loam
- KhC, KhD, KhE--Kilarc sandy clay loam
- KID, KIE--Kilarc very stony sandy clay loam
- KsD--Kilarc-Sites complex
- LgE, LhE, LkF--Lyonsville-Jiggs complex
- MbG2--Maymen very stony loam
- NaB--Nanny gravelly sandy loam
- NbB--Nanny stony sandy loam
- RxF--Rockland
- RyF--Rubbleland
- ShB--Shingletown clay loam
- SnC, SnD, SnE--Sites loam
- SoD, SpE--Sites stony loam
- TcE, TeD--Toomes very rocky loam
- WeD--Windy and McCarthy stony sandy loam
- WfE, WfG, WgE--Windy and McCarthy very stony sandy loams
- County Boundary

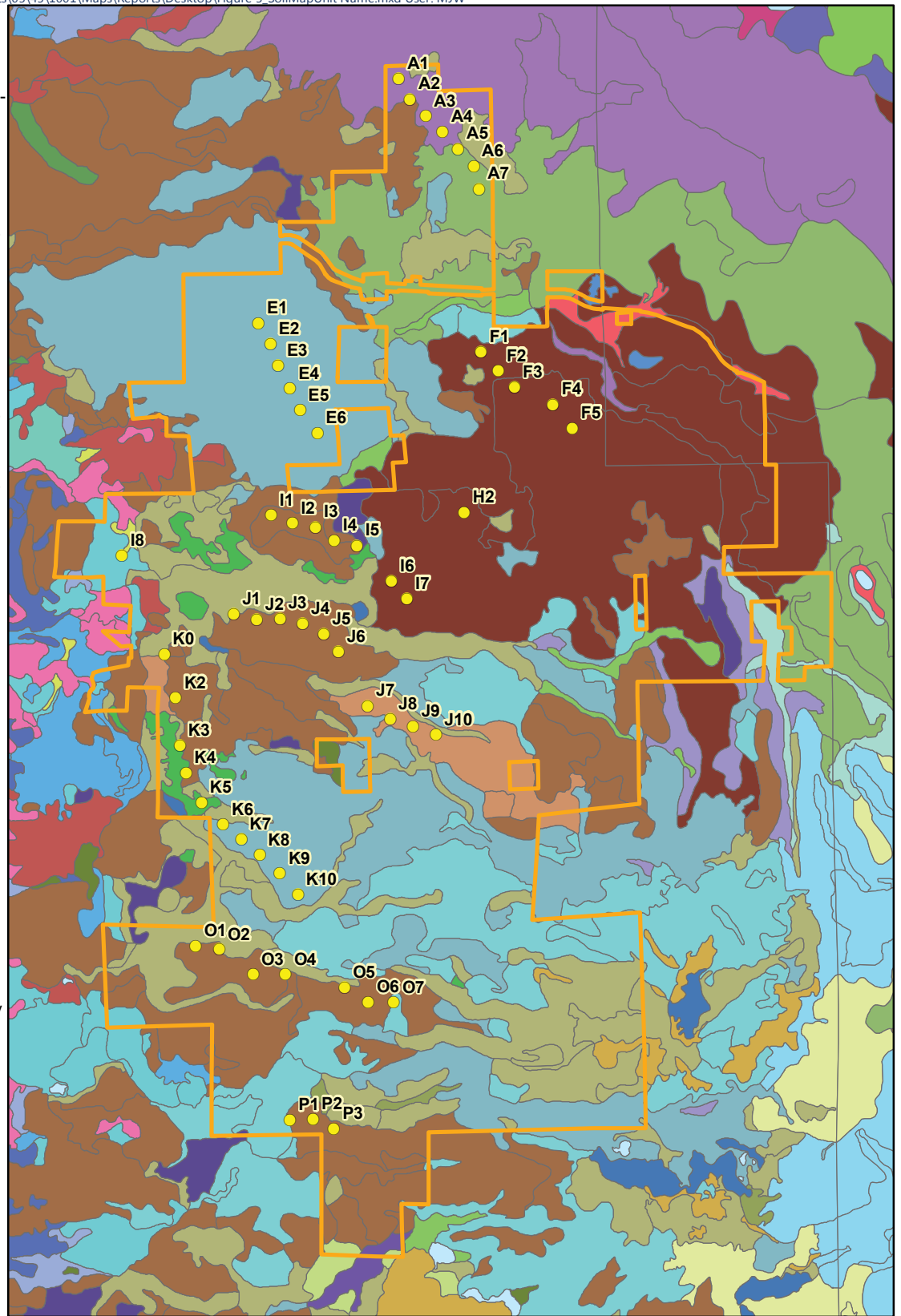
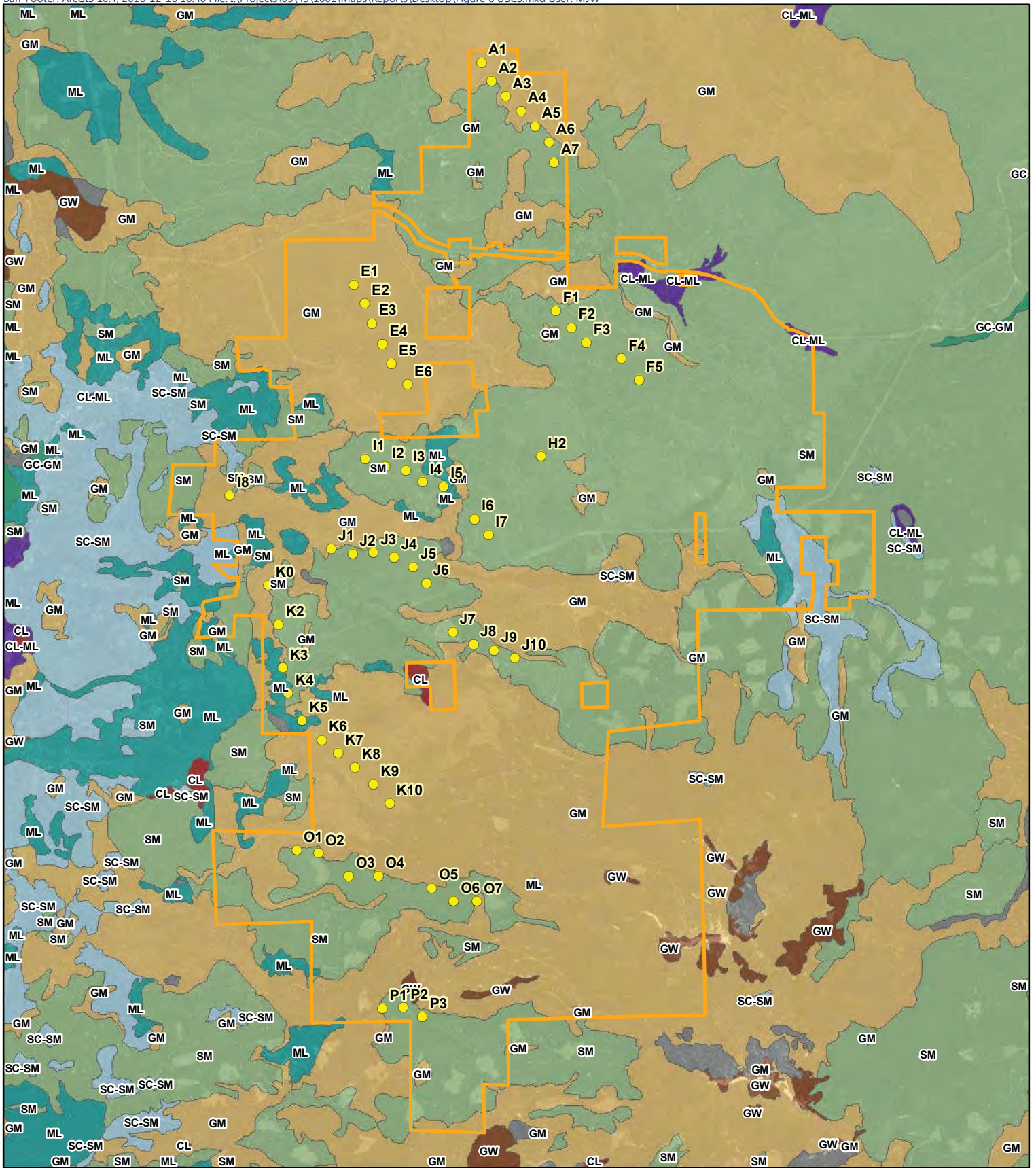


Figure 5  
 Soil Map Unit Name  
 McCloud Project  
 Avangrid Renewables  
 Shasta County, California



- Turbine Locations
- ▭ Site Boundary
- Unified Soil Classification System
- No Data
- CL: Clay of low plasticity
- CL-ML: Clay/silt of low plasticity
- GC: Clayey gravel
- GC-GM: Clayey/silty gravel
- GM: Silty gravel
- GW: Well-graded gravel, fine to coarse gravel
- ML: Silt
- SC-SM: Silty/clayey sand
- SM: Silty sand

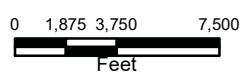
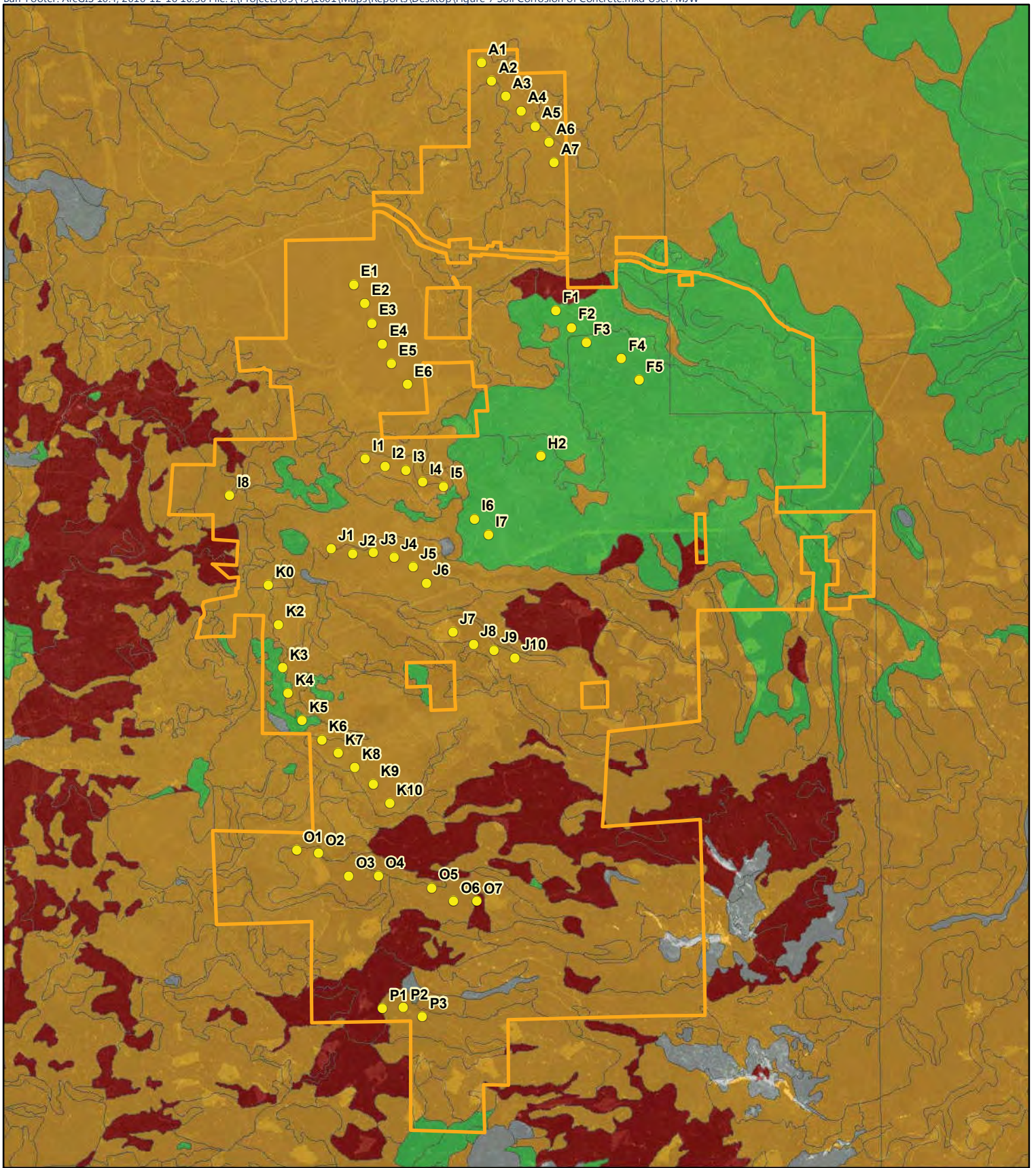


Figure 6  
 Unified Soil Classification System  
 McCloud Project  
 Avangrid Renewables  
 Shasta County, California

Source: NRCS SSURGO Soils



- Turbine Locations
- ▭ Site Boundary
- Corrosion of Concrete
- No Data
- High
- Moderate
- Low

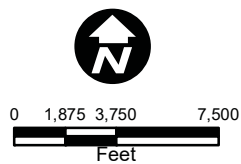
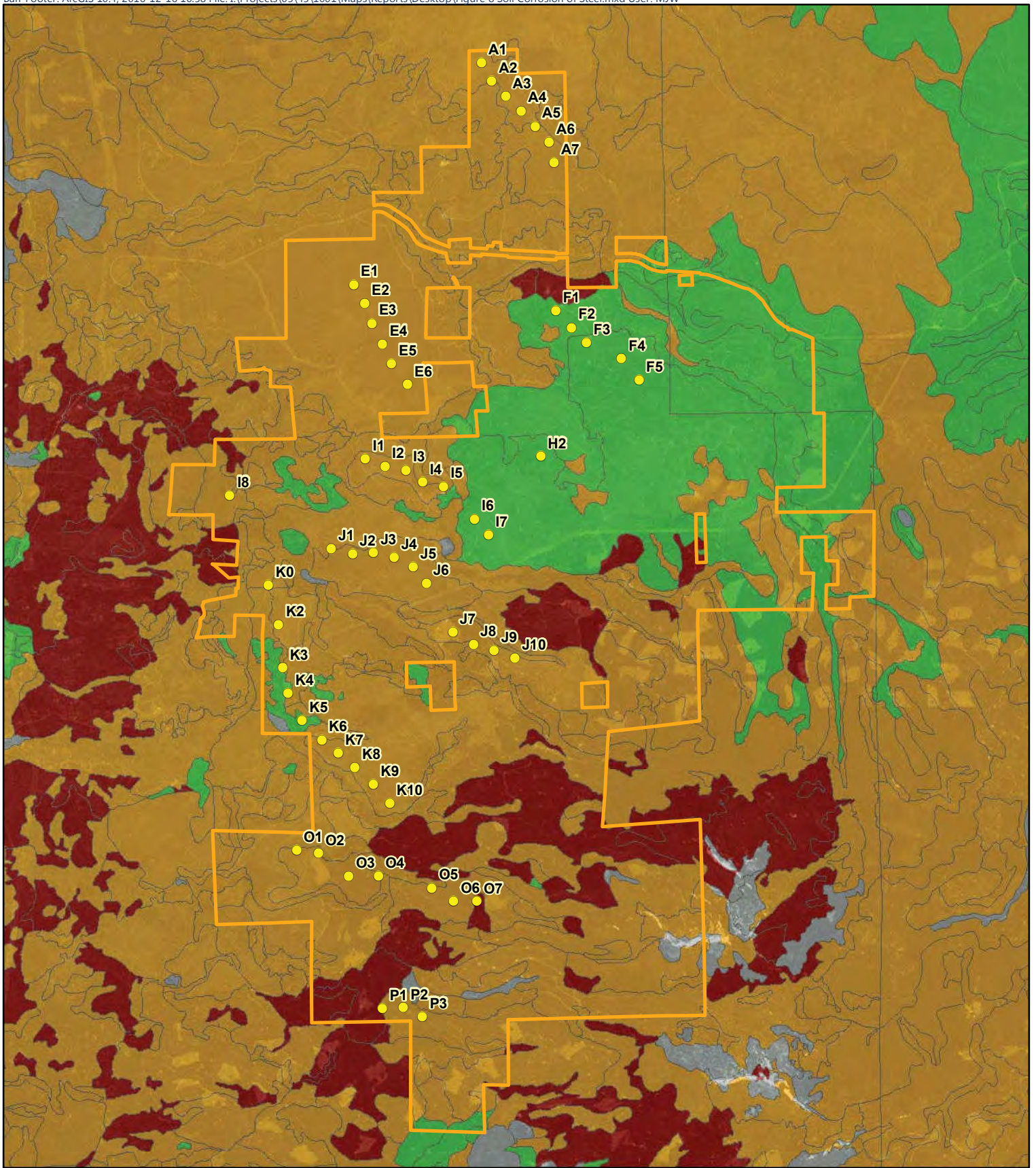


Figure 7  
Soil Corrosion of Concrete  
McCloud Project  
Avangrid Renewables  
Shasta County, California

Source: NRCS SSURGO Soils



- Turbine Locations
- ▭ Site Boundary
- Corrosion of Concrete
- No Data
- High
- Moderate
- Low

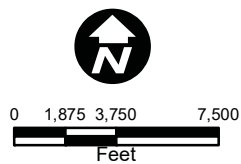
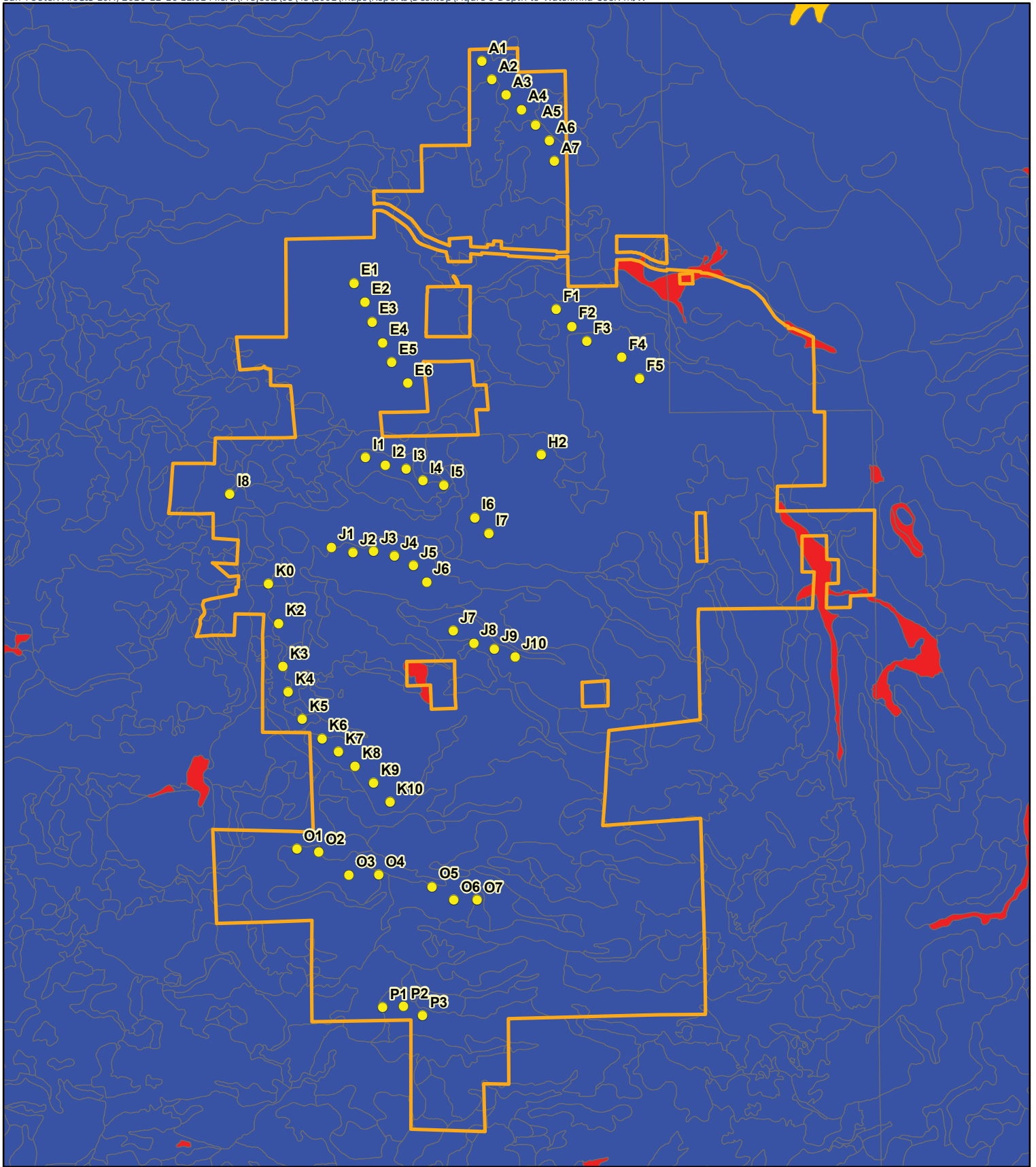


Figure 8  
Soil Corrosion of Steel  
McCloud Project  
Avangrid Renewables  
Shasta County, California

Source: NRCS SSURGO Soils



- Turbine Locations
  - 50 - 100 cm
  - 100 - 150 cm
  - 150 - 200 cm
  - 200+ cm
  - Site Boundary
- Depth to Water**
- 0 - 50 cm

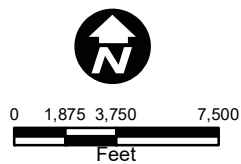
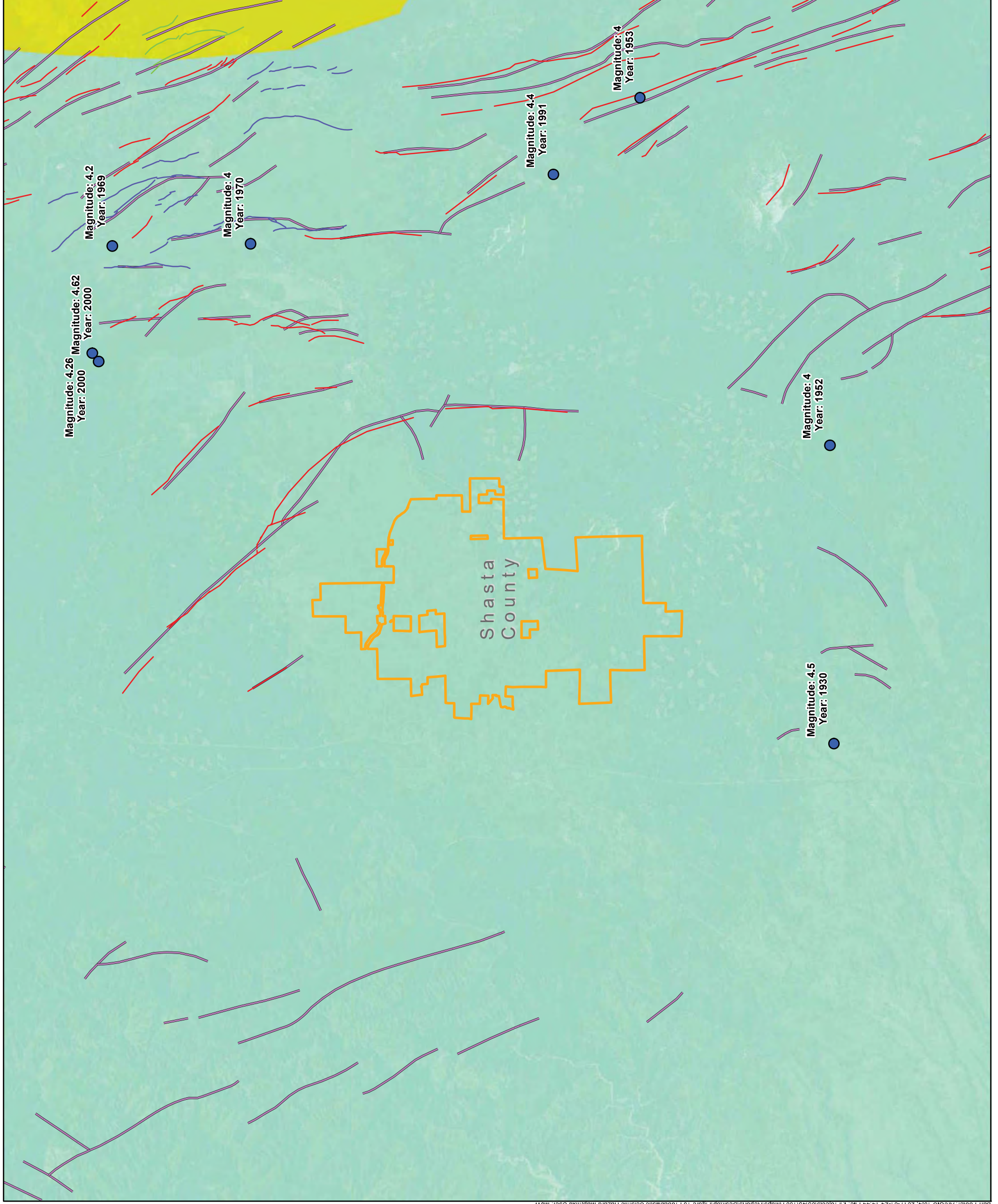


Figure 9  
Depth to Water  
McCloud Project  
Avangrid Renewables  
Shasta County, California



The unit "g" is acceleration of gravity.

Seismic Shaking Hazard Data Source: Based on the USGS/CGS Probabilistic Seismic Hazards Assessment (PSHA) Model, 2002 (revised April 2003).

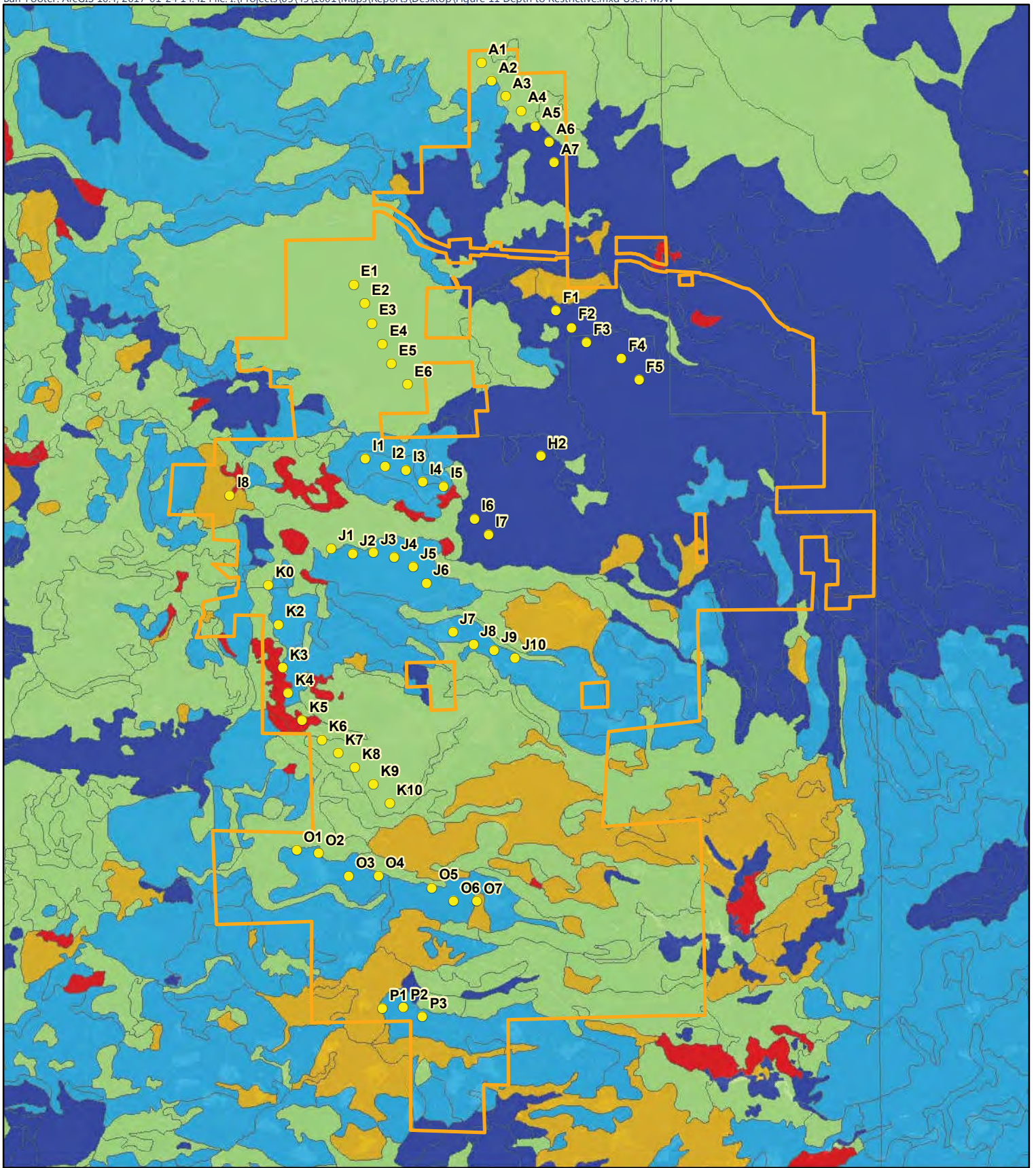
(<http://www.consrv.ca.gov/cgs/rghm/psaha/Pages/index.aspx>)

\*U.S. Geological Survey, California Geological Survey

\*\*U.S. Geological Survey 2006, Quaternary fault and fold database for the United States

Figure 10

**PROBABILISTIC SEISMIC HAZARD MAP**  
 McCloud Project  
 Avangrid Renewables  
 Shasta County, California



- Turbine Locations
- Site Boundary
- Depth to Restrictive Layer
- 0-50
- 50-100
- 100-150
- 150-200
- >200

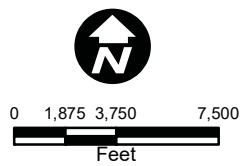
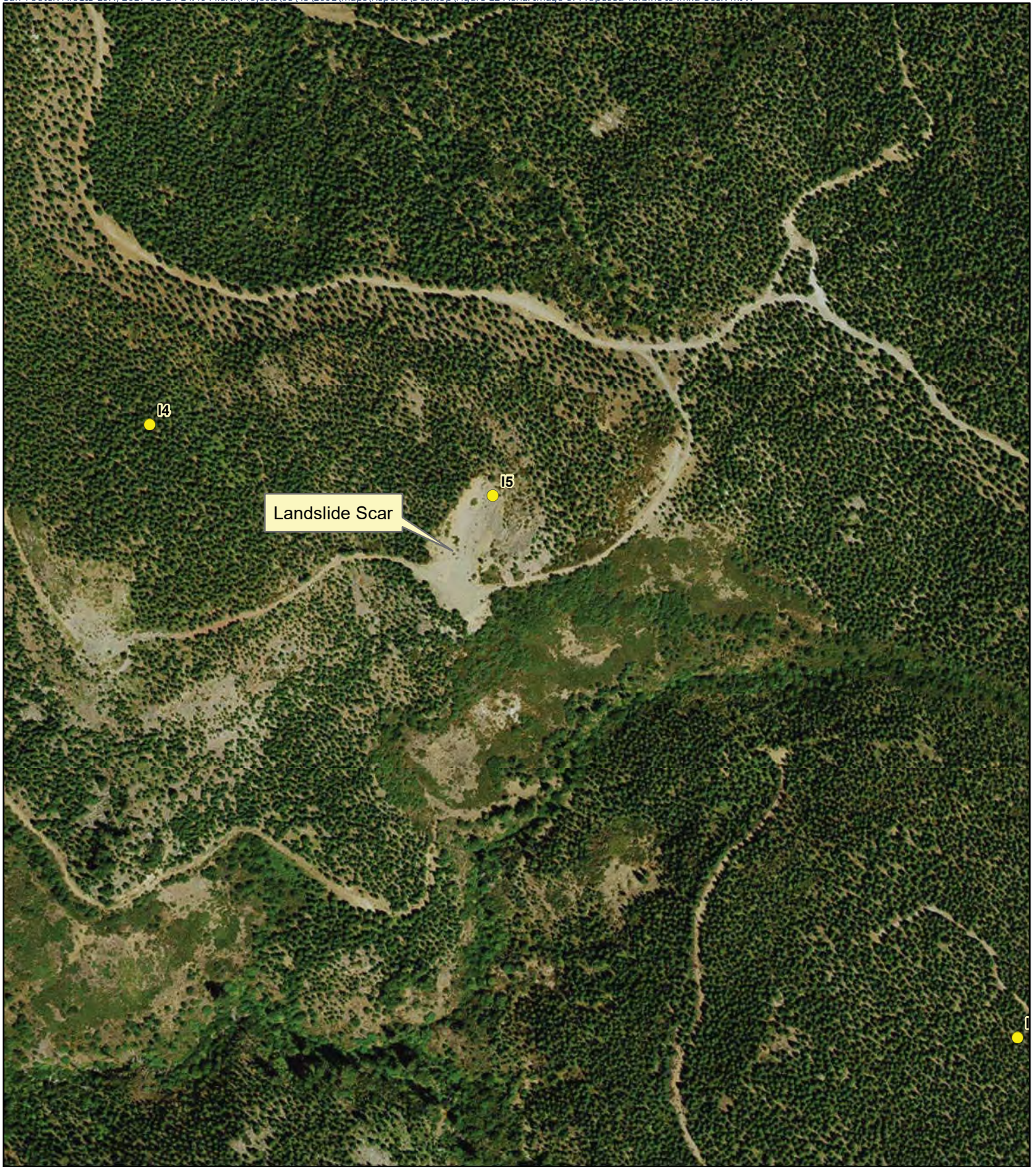


Figure 11  
Depth to Restrictive Layer  
McCloud Project  
Avangrid Renewables  
Shasta County, California



- Turbine Locations
- Site Boundary

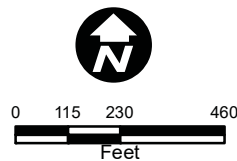
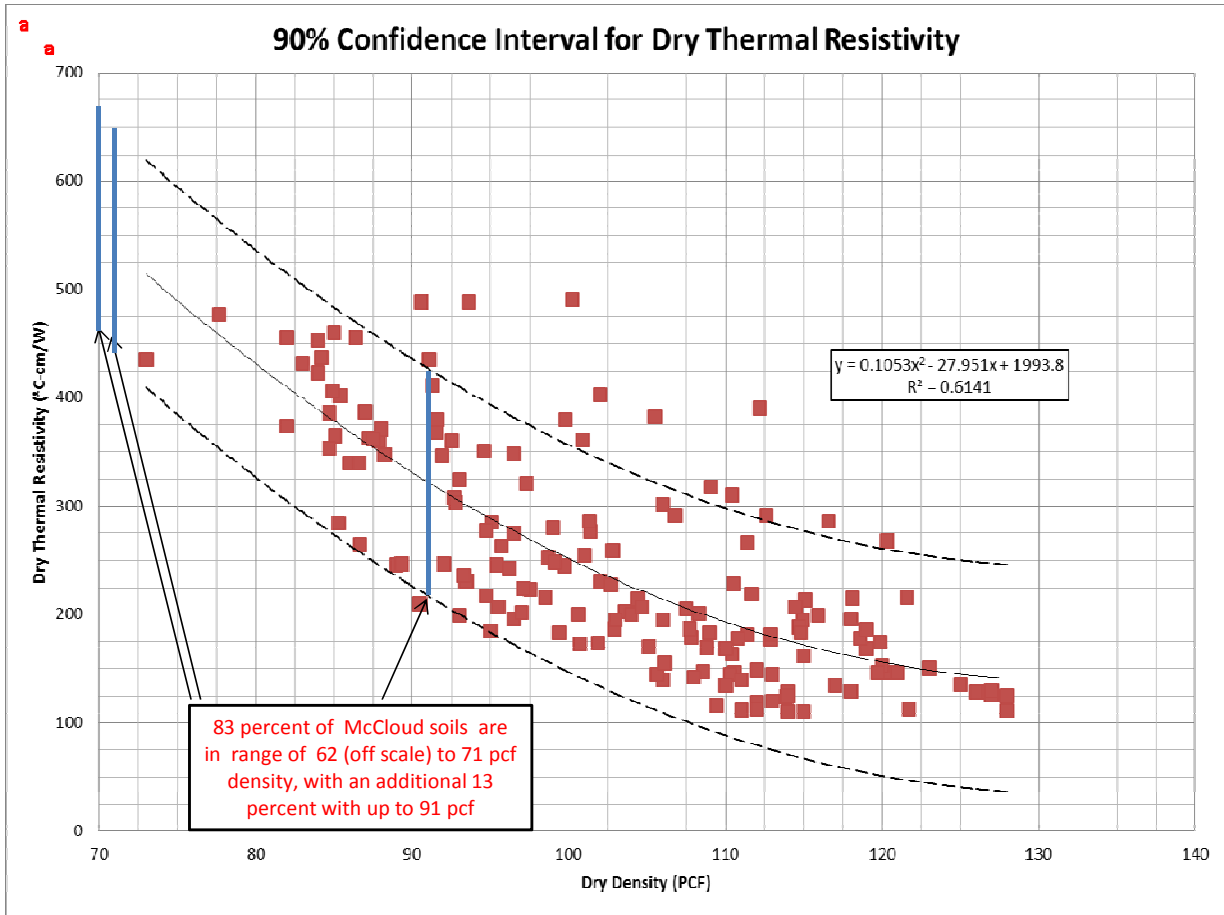


Figure 12  
Aerial Image of Proposed  
Turbine I5  
McCloud Project  
Avangrid Renewables  
Shasta County, California





**Figure 13**  
 90% Confidence Interval for Dry Thermal Resistivity