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Soil Development Processes on the Western Slope of the Southern Sierra Nevada Mountains: A Geographic Study

Introduction

The Sierra Nevada Mountains are a spectacular range dominating eastern California. It stretches over 300 miles north to south and is up to 50 miles wide in places. Mountains contain a great diversity of environments that are expressed in their soils. The parent material, topography, microclimates, age, and biotic life forms of the Sierra Nevada mountains create some of the most diverse and unique environments in the western United States. This study examines the 5 soil forming factors at 5 sites in the Sierra Nevada mountains; the sites are located along an approximate east-west transect with elevation and plant communities differing in each one (see Appendix 1). The goal of this study is to determine which factors have the most influence on soil development including the effects of Native American and modern land management techniques. As California's population increases, more pressure will be put on these soils, soil forming processes, and associated environments. It is important to understand their nature in order to manage them in a sustainable fashion.

Highway 180

California Highway 180 connects western communities such as Fresno to the interior of Kings Canyon National Park, approximately 112.3 miles to the east. Also known as the Kings Canyon-Sequoia Freeway, the highway is a two lane road which receives moderate traffic as one of two access avenues to a wide variety of outdoor activities. The highway enters Kings Canyon Nation Park near Grant Grove briefly before entering the Sierra National Forest for about 30 miles; it then re-enters Kings Canyon National Park near Cedar Grove. Kings Canyon National Park and surrounding wilderness areas provide plenty of opportunities for hiking, camping, backpacking, fishing, and tourism. The road provides an excellent route for this study because it provides easy access to all of the sites and follows a general east-west path. In addition, the road increases in elevation passing through several different climatic/vegetation regimes. Travelling east from Fresno, highway 180 rolls through the lower and upper foothills before climbing to the lower montane forests. Once in the forest, highway 180 continues east into the Kings River canyon travelling through multiple forests which are dominated by different tree species due to microclimatic differences. Several side roads provide easy access to a large variety of meadows, groves, and forested areas. Highway 180 ends at the Road's End Trailhead which provides access to the rest of the park on foot.

Geology

The Sierra Nevada Mountains have a complex geologic history. California was formed beginning ~90 million years ago (mya) as the Farralon Plate subducted under the North American Plate. The subduction resulted in a volcanic arc where the current Sierra Nevada batholith is located. The subduction also formed an accretionary wedge which includes the Franciscan Mélange formation of the central coast, and the Central Valley forearc basin (Johnston, oral communication). As the volcanic arc weathered down and eroded; its sediment filled the Great Central Valley to form the great valley group. The great valley group has been subsequently buried beneath quaternary sediment from the Sierra Nevada Batholith on the eastern side of the Central Valley and coast range sediment on the western side. Outcrops of the great valley group can be observed on the western edge of the valley as recent tectonic activity has turned up the edges of this formation.

Granodiorite plutons subsequently intruded underneath the volcanic arc (Johnston, oral communication). Normal faulting along the eastern edge of the batholith uplifted the mountain range to its current height and tilted the batholith creating a gradual western slope and a steep drop on the eastern side (Peters, 2004). The volcanic remnants can only be found in relatively small areas at high elevations. The Sierra Nevada Batholith is composed of over 100 plutons that range in date from 80mya – 210mya (Peters, 2004). Most of the batholith is a granite, granodiorite, or tonalite. The batholith has been carved by several periods of glaciations creating some of the most scenic valleys in the world such as Yosemite and Kings Canyon. Several substantial rivers carve through the batholith and empty into the Central Valley. Most of these rivers drain into the Sacramento-San Joaquin delta. However, the runoff of the study area drains into the Tulare Basin, a region of internal drainage.

Climate

The Central Valley has a semiarid climate due to the rain shadow effect of the Coast Ranges. Fresno has hot, dry summers and mild, wet winters. The eastern side of the valley receives a few more in of rain than the west side, due to being farther from the rain shadow of the Coast Ranges. The climate of the Sierra Nevada Mountains is a Mediterranean climate characterized by warm, dry summers and wet, cool winters. In the Sierra Nevada Mountains, altitude generally affects climate; temperatures decrease as altitude increases. Higher elevations receive considerable snow during the winter with a peak zone between 5,000-6,500 ft that can receive up to 80 ft of snow in a single month (Peters, 2004). Available moisture content therefore increases with elevation to a certain point. Although most of the precipitation falls between November and April, the summer months experience isolated thunderstorms (Giger, 1983).

The lower foothills receive about 14-20 in of precipitation annually, and the average temperature is 62°-58° F (Huntington, 1971). The upper foothills receive considerably more precipitation, 20-35 in. Again, temperature drops with altitude ranging from 59°-53° F (Huntington, 1971).

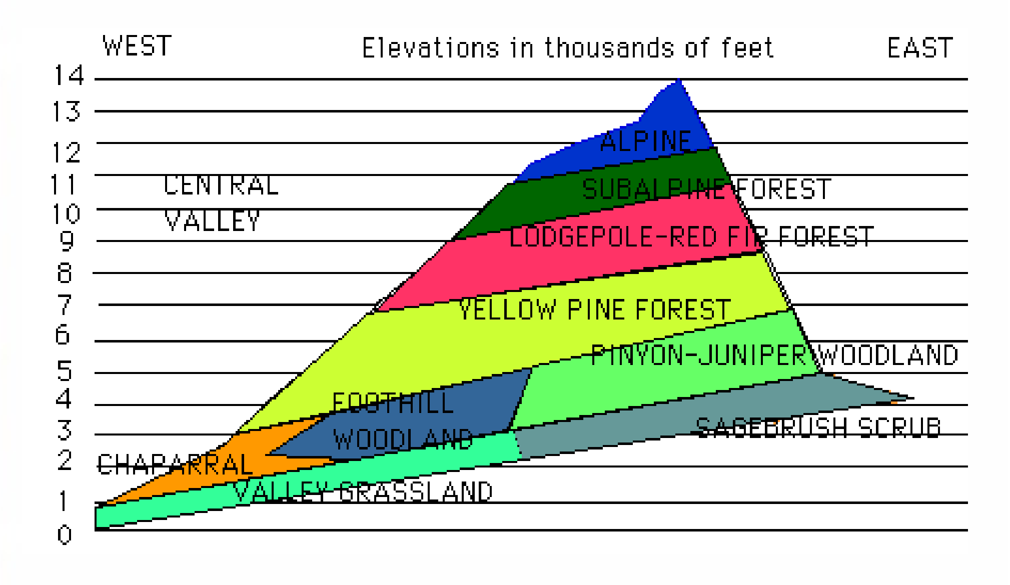

Figure 1- Cross Section of Vegetative Communities in the Southern Sierra Nevada Mountains as Elevation Changes (CampInternet.com)

Vegetation

Plant communities in the southern Sierra Nevada Mountains are determined predominantly by altitude. The first community is the foothill woodland which dominates from the Central Valley floor up to 3500 ft (Anderson, 2005). The dominant species is blue oak (*Quercus douglasii*) (Anderson, 2005). This community exhibits considerable diversity owing to topographical, geological, aspect, and climatic differences. This environment can be similar to an open savanna or dense woodland. Chaparral thrives in the dry, rocky areas. Higher elevations and areas with more moisture contain higher portions of oak, buckeye, and laurel (White, 2009).

Lower montane forest becomes the dominant community between 3,200-6,900 ft (Anderson, 2005). Here ponderosa pine and Jeffrey pine dominate xeric sites and white fir is more common on mesic sites. Jeffery pine replaces ponderosa at higher elevations. The Lodgepole-Red Fir forest is encountered between 7,000-9,000 ft (White, 2009). Above 9,500 ft, conditions become too harsh for many species; this area is known as the subalpine zone and extends to 12,000 ft (White, 2009). Here lodgepole and foxtail pines are two of the only trees that grow. Lodgepole pine thrives in the highest elevations from 8,000 – 11,000 ft where other trees cannot survive the harsh conditions (White, 2009). Subalpine meadows contain a huge selection of wildflowers, grasses and sedges that flourish during summer. Above 12,000 ft. conditions are so harsh only the hardiest plants survive (White, 2009).

The Sierra Nevada mixed coniferous forests are also home to the giant sequoia, the world's largest tree by volume. These incredible trees only grow in 75 groves on the western side of the Sierra Nevada Mountains, almost all of which are located in or around the Kings/Sequoia Canyon region (White, 2009).

Soils

Soils near the study area exhibit a great deal of variety. Soils in the Central Valley can be quite deep and consist of fine textured flood plain deposits (Huntington, 1971). The basin rim soils can range from poorly drained to somewhat excessively drained and are typically fine sandy loams (Huntington, 1971). The residual material in the valley is sedimentary rocks from the great valley group. The great valley group is buried by sediment transported by the San Joaquin and Kings rivers (Huntington, 1971). The sediment is dominantly from granitic material. Soils of the lower foothills are all well drained to excessively drained and formed from granitic, metamorphic and serpentine rocks (Huntington, 1971). Although there are no metamorphic rocks in the immediate vicinity of the sample site, there are several outcrops of metamorphic rocks within the Kings Canyon river drainage. Most soils are formed over residuum, but some localized areas are formed from colluvium or local alluvium. Soils developed over granitic material have a smooth, gentile slope while soils forming from other materials have steeper, rough slopes (Huntington, 1971). Upper foothill soils are formed in similar material to that of the lower foothills, with the exception of serpentinite (Huntington, 1971). Due to the cooler, more moist climate of the upper foothills, these soils are more leeched, usually deeper, have accumulated more surface organic matter, and have a granular structure instead of massive (Huntington, 1971). Soils in the upper montane forests receive the heaviest snow pack during winter and contain the most soil moisture. Cold climate and short growing conditions limit the accumulation of organic matter at high elevations. As a result, many higher elevations have less developed soils. An exception to this generalization is montane meadows, which are often formed in catchment basins by the infill of lakes. These sites can form much deeper, clay rich alluvial soils.

Cultural Occupation

It is often asserted that Native Californians were hunter-gatherers, who gathered only wild growing plants and hunted animals. These ideologies about Native Californians have led to the assumption that they had no influence over their environment and the first Europeans to make contact “discovered” a pristine California. We now know that these assumptions were false, and that native land management systems have been in place for at least 12,000 years (Anderson, 2005). Thousands of years of selective harvesting, tilling, pruning, sowing, weeding, transplanting, and burning created a “carefully tended garden” (Anderson, 2005). This garden supported an estimated population of 310,000 Native Californians, the most culturally diverse native population in the U.S. exhibiting some of the highest population densities north of the Valley of Mexico (Blackburn, 1993).

The land management systems used by Native Californians influenced the size, extent, pattern, structure, and composition of several of the vegetation types throughout the state

(Anderson, 2005). They perpetuated beneficial or useful plants using reciprocal interactions which assisted the regeneration cycle rather than destroying it (Anderson, 2005). Simple tools and methods, such as a digging stick or seed beating, helped to rejuvenate the soil by aerating it and spreading ripe seeds. Human intervention and disturbance created many features of plant communities like valley oak savannas and montane meadows which essentially became dependent on human activities through promotion of favored species (Anderson, 2005). One of the most important and powerful tools used by Native Californians was fire.

Fire is a natural disturbance in all vegetation types of the Sierra Nevada Mountains. Native Californians set fires regularly for several reasons. According to Katherine Anderson, there are five ecological reasons for Native Californians to use fire as a management tool: decreasing detritus and recycling nutrients, controlling insects and pathogens, managing wildlife, modifying the structure of forests and woodland vegetation, and maintaining habitat for shade-intolerant plant species (Anderson, 2005). Fires cleared brush to make travel easy, destroyed hiding spots for potential ambushers, aided in hunting, and promoted the sprouting of new plant growth. Prior to European contact, ~1.8-4.6 million hectares burned annually, that is around ~4.5-12.0% of California burned annually (Stephens, 2007).

The use of fire and other tools by Native Californians significantly affected soil development in the Sierra Nevada Mountains. Digging sticks, collecting root tubers, and harvesting tree roots aerates and disturbs the surface horizon. Soil derived from granitic parent material, which covers much of the Sierra Nevada Mountains, has coarse texture and relatively low nutrient levels. Fire helps to release these nutrients back into the soil, allowing for increased plant growth and development. It has been shown that grassland ecosystems which are deprived of fire become choked by detritus and show a drastic fall in productivity and reproduction owing to old material not being recycled (Stewart, 2002). Although this is not true globally for grasslands, Californian grassland ecosystems have become fire dependent due to Native Californian influence.

Methodology

Sites were chosen to be the most representative of the elevation determined categories of plant communities and landforms. Each site was located in close proximity to large specimens of the most dominant plant species, as well as on a slope that was as representative of the average steepness of the surrounding area. When picking sites, care was taken to avoid locations that had been recently disturbed, either naturally or anthropogenically. Sites were either uphill or at least 30 ft. from the road to avoid soil that was compacted, upturned, or buried during road construction.

Soil samples were taken using an open bucket auger and placed into one of two Ziploc bags. The first sample collected was a topsoil sample of the first six in of the soil profile. The second sample was subsoil, which was a blend of the soil collected below 6 in down to a depth of 4 ft or the parent material.

Plant samples were collected of all noted species within a 10 or 20 yard radius of each site.[1]

Particle size analysis was performed using a modified Bouyoucos Hydrometer Method. Fifty grams of sieved (#10) soil and 100 ml of Calgon solution (Sodium metaphosphate, $NaPO_3$) was mixed with a motor mixer for 5 minutes. The mixture was then placed in an 1130 ml sedimentation cylinder and diluted with deionized water to the fill line. The solution was plunged and hydrometer readings were taken at 50 seconds and 8 hours. The readings were then used to calculate percent sand, silt, and clay.

Soil pH was measured with a Corning Model 125 pH meter using 10 grams of soil stirred with 20 ml of deionized water.

Calcium, magnesium, potassium, and sodium were analyzed using an extraction solution of 1N ammonium acetate and 10 grams of soil. The diluted solution was processed through an Atomic Absorption Spectrophotometer to get concentrations in mg/L soil.

Phosphorus was tested using 20 grams of soil and a 100 ml solution of sodium bicarbonate solution run through a photoelectric colorimeter.

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[1] These plant samples were not analyzed in this study because they were lost or destroyed by unfavorable weather before identification of each sample could be completed.

Site 1

Site 1 is located approximately ¼ mile east of the intersection of Highway 180 and Cove Avenue (see Appendix 1B). The site is on top a low-lying ridge that was once connected with the foothills to the north but has been separated by a road cut. North of the site the foothills are predominantly used for non-irrigated cattle grazing. Directly to the south is a large Citrus orchard which resides in a thermal belt. This site was historically used for grazing; orchards are a relatively new addition as rising populations, urban sprawl, and economic expansion have intensified agricultural land use.

Figure 1- View from site 1 looking east towards the Sierra Nevada Mountains

The soil at site 1 was formed from residual granitic material, most likely a quartz diorite or granodiorite. The site has a west facing aspect of 096°, a slope of 4°, and an elevation of 642 ft. The area receives ~12.27 in. of precipitation and has a mean annual temperature of ~63.1 F°. Climactic data is from the Orange Cove weather station, COOP # 046476 (see Appendix 2A).

According to the NRCS, the soil is a Fallbrook very rocky sandy loam, 3 to 30 % slopes (see Appendix 3A). This soil unit forms on back slopes and side slopes of hills from weathered quartz diorite. The typical soil profile is 0 to 11 in: sandy loam, 11 to 29 in: sandy clay loam, 29 to 60 in: bedrock. Both topsoil and subsoil from site 1 were sandy loams, with granitic bedrock at a depth of 15 in.

Soil Forming Factors of Site 1

1. Parent Material- Granitic rocks have large grains of highly weather resistant minerals. The dominant minerals are quartz (SiO_2), K-feldspar (orthoclase, $KAlSi_3O_8$ to albite, $NaAlSi_3O_8$), and plagioclase (anorthite, $CaAl_2Si_2O_8$ to albite, $NaAlSi_3O_8$). These minerals contain very few plant essential nutrients and will usually form coarse, sandy soils with high infiltration rates and a relatively low water holding and nutrient capacity. Parent material is most likely the dominant factor controlling soil texture and has a significant effect on available nutrients.
2. Climate- The Central Valley has a Mediterranean climate with hot summers and mild, wet winters. This gives site 1 a 230+ day frost-free period for growing, but only with irrigation. Available water is a limiting factor. The dry period lasts around 6 months each year, but can vary from 4-8 months. Climate is significant in regard to soil texture, depth, and nutrient availability. More moist climates will have higher rates of chemical weathering, lower soil pH, more biological activity, and higher rates of erosion, transportation, and deposition of sediment.
3. Time- Time is the most difficult factor to determine in the study. All five sites form over the same batholith complex. It is not within the scope of this study to accurately determine either absolute age or relative age without further tests. Relative ages of soils may be determined by looking for evidence of erosion or deposition of topsoil. The paleo-landscape of each site would need to be determined to look for landslides or erosion since the last glacial period which would reset soil development.
4. Topography- Site 1 is on the transition between a local summit and shoulder. Prior to the construction of highway 180, it may have received some clay or nutrient deposition from higher up the ridge, but the ridge has such a small inclination of 4° that any underground horizontal nutrient movement in unlikely. There are no visible signs of erosion around

site 1, so soil is staying in place and weathering residually. Soil nutrients are either from direct chemical weathering of parent material, decomposition of overlying vegetation, or human amendments. The east facing aspect provides more shade than a south facing slope; this will reduce evapotranspiration of soil moisture and allow plants to grow longer into late spring and summer. Topography affects, but is not the most significant factor of soil texture, nutrients, and available water.

5. Biological/ Human Factors- Site 1 has a long history of range land and Native Californian use. The warmer climate allows this site to have potentially been occupied or used by Native Californians year round. The current dominant plants are scattered oak trees with exotic annual grasses. Prior to European settlement, native perennials and bunch grasses would have been much more prevalent. These plants have much larger and deeper root systems than annuals. The land immediately surrounding site 1 is not being used for any production; it is in the space between the orchards and the property fence. Current land management practices or fire suppression are most likely leaving nutrients and organic matter locked up in dry, dead plant matter on the soil surface, where it can be transported by wind or water. The climate is not humid enough to support high rates of organic decay. Fire is needed to release nutrients so that they can become available to the soil again. Fires have been shown to increase microbial decomposition and nutrient release (Hart, 2005). Fire suppression is causing a decrease in soil carbon percentages and nutrient availability. The lack of land management at site 1 is most likely the significant factor affecting soil carbon and nitrogen. In conjunction with parent material and climate, biological factors have the most significant effect on nutrient availability.

Site 2

Site 2 is located on the south side of Highway 180, across from the entrance to the Sierra Endangered Cat Haven, 38257 East King’s Canyon Road (see Appendix 1C). It is ~100 ft. downhill of the road, at the foot slope of a hill. Land uphill of site 2 has been occupied by the Endangered Cat Haven since 1993, so that area has been free of grazing and fires for at least 17 years. The site is not currently being grazed because of its proximity to the highway. However, there is evidence of grazing ~20 ft downhill of the site on the other side of a cattle fence.

Figure 2- View from site 2 looking downhill

The soil at site 2 was formed from residual and alluvial granitic material. The parent material of site 2 is a lighter colored granitic rock than site one and is most likely a tonalite; the USDA lists the parent material as a quartz diorite, but the spatial resolution of their maps is too large to be precise at specific sites. The site has a south facing aspect of 194°, a slope of 13° and an elevation of 2468 ft. The area receives ~26.13 in. of precipitation and has a mean annual temperature of ~62.4 F°. Climatic data for this site is from the Auberry, CA weather station, COOP # 040379 (see Appendix 2B). Although this weather station is located miles from the site, it is similar in elevation. Climatic changes in the Southern Sierra Nevada Mountains occur predominantly though changes in elevation, not latitude. The NRCS lists site 2 soils as Auberry coarse sandy loam, 30 to 45% slopes (see Appendix 3B). Similar to site 1, this soil forms on back slopes and side slopes weathered from quartz diorite. The typical soil profile for this unit is 0 to 12 in: coarse sandy loam, 12 to16 in: sandy loam, 16 to 35 in: sandy clay loam, 35 to 42 in:

coarse sandy loam, 42 to 60 in: bedrock. Both topsoil and subsoil from site 2 were sandy clay loams, with granitic bedrock at a depth of 3 ft.

Soil Forming Factors of Site 2

1. Parent Material- Granitic rocks have large grains of highly weather resistant minerals. The dominant minerals are quartz (SiO_2), K-feldspar (orthoclase, $KAlSi_3O_8$ to albite, $NaAlSi_3O_8$), and plagioclase (anorthite, $CaAl_2Si_2O_8$ to albite, $NaAlSi_3O_8$). These minerals contain very few plant essential nutrients and will usually form coarse, sandy soils with high infiltration rates and a relatively low water holding and nutrient capacity. Parent material is most likely the dominant factor controlling soil texture and has a significant effect on available nutrients. Although the texture of site 2 is finer than at site 1, it is still coarse and has a sand content greater than 60% which is a direct reflection of granitic parent material.
2. Climate- Similar to site 1, site 2 has a Mediterranean climate with hot summers and mild, wet winters. The average temperature of site 2 is only .7 F° cooler than site 1, although both the two warmest and two coldest months are slightly warmer for site 2 than site 1. Warm temperatures give site 2 a long growing season of 200+ days. Precipitation at site 2 is more than double that of site 1, allowing for significantly more plant available water. Relative to site 1, the increase in precipitation is due to orographic uplift. Five months receive significant rainfall of over 2.5 in per month. Increased water will allow higher rates of chemical weathering and accumulation of clay particles. Climate is most likely the reason that texture changes from the sandy loam at site 1 to sandy clay loam at site 2. Climate has some effect on soil texture, depth, and nutrient availability but is not the dominate factor.
3. Time- Time is the most difficult factor to determine in the study. All five sites form over the same batholith complex. It is not within the scope of this study to accurately determine either absolute age or relative age without further tests. The paleo-landscape of each site would need to be determined to look for landslides or erosion since the last glacial period which would reset soil development. Relative ages of soils may be determined by looking for evidence of erosion or deposition of topsoil.

4. Topography- Site 2 is situated on a foot slope below highway 180 and above an annual stream drainage. Prior to the construction of highway 180, the site would have received more soil deposited from uphill. The road diverts and channelizes the water flowing downhill. This water is released from a single drainage pipe nearby which has caused a 4 foot deep gully. There are no other signs of erosion around the site. Site 2 is situated on a foot slope and has a slope of 13°, so deposition is most likely faster than erosion. The construction of highway 180 has cut off this site from receiving any additional sediment. Any recent additional soil nutrients are either from direct chemical weathering of parent material, decomposition of overlying vegetation, or human amendments. The road does not affect direct precipitation to site 2, but its drainage channels affect the movement of water underground. This results in a decrease in available water underground in dry months. Site 2 has a south facing slope, which has the highest amount of sunlight and evaporation. Topography affects, but is not the most significant factor in any of the tested soil properties. It does indirectly affect climate and biological factors due to elevation and orographic precipitation, which affects the vegetation regime.
5. Biological/ Human Factors- Site 2 has a long history as modern range land and Native Californian occupation. The warm climate allows this site to have potentially been occupied or used by Native Californians year round. Thick wooded areas dominate in locations with more available water. Dryer patches have exotic annual grasses. Site 2 is located in one of these dryer patches. Current land management practices or fire suppression are most likely leaving nutrients and organic matter locked up in dry, dead plant matter on the soil surface, where it can be transported by wind or water. The climate is not humid enough to support high rates of organic decay. Fire is needed to release nutrients so that they can become available in the soil again. These factors should both lead to a decrease in soil carbon percentages and nutrient availability. Current land use practices or lack thereof, are most likely the significant factor affecting soil and nitrogen. In conjunction with parent material and climate, biological factors have the most significance on nutrient availability.

Figure 3- View uphill from site 3 with Ponderosa pine and Black oak growing together

Site 3

Site 3 is located off of US Forest Service road 13597; ~ 60 ft uphill of the McKenzie Heliport (see Appendix 1D). US Forest Service road 13597 intersects with Highway 180 ~3000 ft. east of Snowline Lodge, 44138 East Kings Canyon Road. Land surrounding the site is mostly undeveloped, widely spaced houses and compounds are the most common buildings. There is little evidence of current grazing on or near the site, possibly do to the nearby residences or steep slopes nearby. The soil at site 3 was formed from residual granitic material. There were no nearby outcrops of the parent material, but the nearby road cut was deep enough to reveal weathered and oxidized granitic parent material beneath the soil. The site has a southeast facing aspect of 220°, a slope of 10° and an elevation of 4425 ft. Accurate climatic data for this site is currently unavailable as no suitable nearby weather stations with a similar elevation and complete data were available for NCDC 1971-2000 monthly normals. The site is on US Forest Service (USFS) land, and is listed under a USFS soil survey instead of a NRCS survey. The

USFS lists site 3 soils as Holland-Hotaw association, moderately steep (see Appendix 3C). These soils form on back slopes and mountain flanks weathered from granite. The typical soil profile for this unit is 0 to 6 in: sandy loam, 6 to 32 in: sandy clay loam, 32 to 36 in: weathered bedrock. Both topsoil and subsoil from site 3 were sandy clay loams, with granitic bedrock at a depth of 3 ft.

Soil Forming Factors of Site 3

1. Parent Material- Granitic rocks have large grains of highly weather resistant minerals. The dominant minerals are quartz (SiO_2), K-feldspar (orthoclase, $KAlSi_3O_8$ to albite, $NaAlSi_3O_8$), and plagioclase (anorthite, $CaAl_2Si_2O_8$ to albite, $NaAlSi_3O_8$). These minerals contain very few plant essential nutrients and will usually form coarse, sandy soils with high infiltration rates and a relatively low water holding and nutrient capacity. Parent material is most likely the dominant factor controlling soil texture and has a significant effect on available nutrients.
2. Climate- Similar to sites 1 and 2, site 3 has a Mediterranean climate with hot, dry summers and cool, wet winters. Winter temperatures for site 3 are significantly colder because it is situated at a higher elevation. The cooler temperature shortens the growing season and increases precipitation due to orographic uplift. A representative weather station with accessible data was not available for site 3, so monthly temperature and precipitation data are missing, as well as an accurate assessment of frost free days. Due to elevation, site 3 will have colder overall temperatures and increased precipitation compared to site 2. Site 3 has the highest percentage of liquid precipitation versus snow compared with sites 4 and 5. Increased water will allow higher rates of chemical weathering and accumulation of clay particles. Frost wedging will increase soil development rates. Climate effects soil texture, depth, and nutrient availability.
3. Time- Time is the most difficult factor to determine in the study. All 5 sites form over the same batholith complex. It is not within the scope of this study to accurately determine either absolute age or relative age without further tests. The paleo-landscape of each site would need to be determined to look for landslides or erosion since the last glacial period which would reset soil development. Relative ages of soils may be determined by looking for evidence of erosion or deposition of topsoil.

4. Topography- Site 3 is situated on a back slope on the spine of a ridge with a slope of 10°. There are no other signs of erosion around the site. Slope increases significantly to the northwest and southeast, which will increase drainage speed and prevent site 3 from retaining significant groundwater. Any recent additional soil nutrients are either from direct chemical weathering of parent material, decomposition of overlying vegetation, or human amendments. Site 3 has a southwest facing slope, which has a high amount of sunlight and evaporation. Topography affects, but is not the most significant factor in soil properties. It does indirectly affect climate and biological factors due to elevation and orographic precipitation, which affects the vegetation regime.
5. Biological/ Human Factors- Site 3 has a shorter history of historical grazing and Native Californian use than sites 1 and 2. Being just above the snowline would have limited this site to only three seasons of active use by Native Californians. Site 3 lies in the ecotone between black oak (*Quercus velutina*) dominated woodland and ponderosa pine (*Pinus ponderosa*) dominated forest. Prior to European settlement, the understory of this region would have been cleared by fire on a regular basis. Current land management practices of fire suppression are most likely leaving nutrients and organic matter locked up in dry, dead plant matter on the soil surface, where it can be transported by wind and water. The modern understory is dominated by highly invasive species such as thistles (*Asteraceae spp*.) and forget-me-nots (*Myosotis spp*.). Both of these species thrive in areas of intense human disturbance (Steinmaus, oral comm.). The climate is not humid enough to support high rates of organic decay. Temperatures in the summer months are too high and the soil is too dry to afford rapid decay, while winter months are moist and the cold suppresses microbial activity. Fire is needed to release nutrients so that they can become available in the soil again. These factors should both lead to a decrease in soil carbon percentages and nutrient availability. Current land use practices are most likely the significant factor affecting soil carbon and nitrogen levels. In conjunction with parent material and climate, biological factors have the most significance on nutrient availability.

Figure 4- View uphill from site 4 of forest understory

Site 4

Site 4 is located in Indian Basin; ~500 ft southwest of the intersection of Highway 180 and Hume Lake road (see Appendix 1E). It is on the south side of the meadow, across from Princess Meadow Campground. Site 4 and the land surrounding the site are contained within the Sequoia National Forest. The main use of this land is seasonal recreation such as hiking and camping. Cattle grazing is occurring in the southern half of the meadow.

The soil at site 4 was formed from residual granitic material. Rock outcrops of the parent material were plentiful nearby. The site has a northwest facing aspect of 315°, a slope of 17° and an elevation of 5853 ft. The area receives 42.07 in. of precipitation and has a mean annual temperature of 46.4 F°. Climatic data is from the Grant Groove weather station, COOP # 043551 (see Appendix 2C). The site is on US Forest Service (USFS) land, and is listed under a USFS soil survey instead of a NRCS survey. The USFS lists site 4 soils as Shaver-Chaix association, moderately steep (see Appendix 3D). The site properties and soil depth most closely resembles the Chaix unit. These soils form on back slopes and mountain flanks weathered from granite. The typical soil profile for this unit is 0 to 7 in: sandy loam, 7 to 25 in: coarse sandy loam, sandy loam, 25 to 30 in: weathered bedrock. Both topsoil and subsoil from site 4 were sandy loams, with weathered granitic bedrock at a depth of 2 ft.

Soil Forming Factors of Site 4

1. Parent Material- Granitic rocks have large grains of highly weather resistant minerals. The dominant minerals are quartz (SiO_2), K-feldspar (orthoclase, $KAlSi_3O_8$ to albite, $NaAlSi_3O_8$), and plagioclase (anorthite, $CaAl_2Si_2O_8$ to albite, $NaAlSi_3O_8$). These minerals contain very few plant essential nutrients and will usually form coarse, sandy soils with high infiltration rates and a relatively low water and nutrient capacity. Parent material is most likely the dominant factor controlling soil texture and has a significant effect on available nutrients.
2. Climate- Similar to sites 1, 2, and 3, site 4 has a Mediterranean climate regime with warm summers and cold, wet winters. The average temperature of site 4 is significantly cooler at 46.4°. The summer winter temperature range is also smaller. The frost free period is only ~140 days. Precipitation at site 4 is more than triple that of site 1, allowing for significantly more plant available water. Increased precipitation is due to orographic uplift. Five months receive significant precipitation in the form of snow and rain of over 4.0 in per month. Increased water will allow higher rates of chemical weathering and accumulation of clay particles. Climate is not a significant factor affecting soil texture or nutrient availability because site 4 has the coarsest texture and lowest nutrients. Site 5 has the same general climate, although some microclimatic differences may occur, and has a much finer texture and higher levels of available nutrients.
3. Time- Time is the most difficult factor to determine in the study. All five sites form over the same batholith complex. It is not within the scope of this study to accurately determine either absolute age or relative age without further tests. The paleo-landscape of each site would need to be determined to look for landslides or erosion since the last glacial period which would reset soil development. Relative ages of soils may be determined by looking for evidence of erosion or deposition of topsoil. Site 4 is situated

on a toe slope at the edge of a basin, so there is an uphill source for deposition of new soil material. A slope of 17° and exposed bare soil underneath the forest canopy suggest a potential for erosion for the site. Site 4 has the lowest nutrient values and the second shallowest depth to bedrock. This shows that site 4 is receiving minimal to no colluvial parent material. Site 4 has the coarsest soil texture and extremely low nutrient values which suggest that this is the youngest soil, because it has not had enough time to chemically weather the granitic parent material. Climate and topography affect time for both sites 4 and 5. During winter the soil is covered and insulated by a thick snowpack, which reduces the time each year for soil to develop. The cold winters and persistent snow through spring significantly shorten the frost free period to only ~140 days. This effectively decreases soil development speed due to decreases in microbial activity.

4. Topography- Site 4 is situated on a toe slope south of highway 180. The soil should receive colluvial parent material from uphill, however shallow soil depth and minimal soil development suggest that the site is receiving minimal to no material from off site. There are no signs of erosion around the site, so the soil is developing over the residual granitic parent material. Any soil nutrients are either from direct chemical weathering of parent material, decomposition of overlying vegetation, or human amendments. Site 4 has a northwest facing slope, which receives relatively low amounts of sunlight and evaporation. This should result in longer periods of plant available water; however the slope, coarse soil texture and shallow depth to bedrock are causing water to flow away from the site faster than it accumulates. Topography, along with time, may be the most significant factors affecting the extremely low nutrient values and coarse soil texture of site 4. Without the deposition of new material from colluvial or fluvial sources, site 4 will continue to have extremely low fertility.
5. Biological/ Human Factors- Site 4 has a long history of modern range land and Native Californian occupation. Although winter snow would limit the use of this site to late spring through fall, it was an important summer location for Native Californians. As the name Indian Basin suggests, this was a heavily used area for Native Californians and several stone mortars can be observed on rock outcrops very close to the site. Site 4 lies in a ponderosa pine (*Pinus ponderosa*) dominated forest. Prior to European settlement, the understory of this region would have been cleared by fire on a regular basis. Current

land management practices or fire suppression are most likely leaving nutrients and organic matter locked up in dry, dead plant matter on the soil surface, where it can be transported away by the water. There is a thin layer of dried pine needles covering the entire understory. The climate is too cold in winter and too dry in summer to support high rates of organic decay. Fire is needed to release nutrients so that they can become available in the soil again. These factors should both lead to a decrease in soil carbon percentages and nutrient availability. Nutrient availability and recycling is crucial for vegetative health in site 4 due to the low nutrient values and shallow depth. In conjunction with topography and time, biological factors have the most significance on nutrient availability.

Site 5

Site 5 is located off of US Forest Service road 13S55, in Stump Meadow (see Appendix 1F). It is ~150 yds east of a sign titled “Regenerating a Giant”. US Forest Service road 13S55 intersects Highway about 2 mi to the south, a couple of miles before the road to Hume Lake. Site 5 and the land surrounding the site are contained within the Sequoia National Forest. Stump Meadow is part of the larger Converse Basin. The main use of this land is cattle grazing and seasonal recreational use. Cattle grazing was occurring on the site at the time the samples were taken.

The soil at site 5 was formed from residual granitic material. There were no nearby outcrops of the parent material to confirm this; the parent material was inferred from the US Forest Service soil report for the site. The site has a west facing aspect of 278°, a slope of 8° and an elevation of 6054 ft. The area receives 42.07 in. of precipitation and has a mean annual temperature of 46.4 F°. Climatic data is from the Grant Groove weather station, COOP # 043551 (see Appendix 2). The site is on US Forest Service (USFS) land, and is listed under a USFS soil survey instead of a NRCS survey. The USFS lists site 5 soils as Shaver-Chaix association, moderately steep (see Appendix 3E). The site properties and soil depth most closely resembles the Shaver unit. These soils form on back slopes and mountain flanks weathered from granite. The typical soil profile for the Shaver unit is 0 to 43 in: fine sandy loam, 43 to53 in: gravelly sandy loam, gravelly coarse sandy loam, gravelly fine sandy loam, 53 to 57 in: weathered bedrock. Site 5 is unique in the study area for two seasons. First, the soil is deep enough that the parent material was not reached with the auger, so the subsoil sample goes to a depth of 4+ ft without hitting a root limiting layer. Secondly, site 5 has two separate subsoil samples. Subsample A is 6 to 30 in and the subsoil B is 30 to 48+ in. The last 4 in of subsoil A contain medium size (up to 3 in long) pieces of redwood buried in the soil. The pieces may be remnants of trees that were logged during the 14 years of intensive harvesting that began around 1897 by the Sanger Lumber Company. If that is true, then current topsoil might be a very recent deposition and buildup in the last 100 years. All three soil samples from site 5 were sandy clay loams.

Figure 5- View of Stump Meadow from site 5

Soil Forming Factors of Site 5

1. Parent Material- Granitic rocks have large grains of highly weather resistant minerals. The dominant minerals are quartz (SiO_2), K-feldspar (orthoclase, $KAlSi_3O_8$ to albite, $NaAlSi_3O_8$), and plagioclase (anorthite, $CaAl_2Si_2O_8$ to albite, $NaAlSi_3O_8$). These

minerals contain very few plant essential nutrients and will usually form coarse, sandy soils with high infiltration rates and a relatively low water holding and nutrient capacity. Parent material is most likely the dominant factor controlling soil texture and has a significant effect on available nutrients.

2. Climate- Similar to all other sites, site 5 has a Mediterranean climate regime with warm summers and cold, wet winters. The average temperature of site 5 is significantly cooler than the first three at 46.4°. The summer winter temperature range is also smaller. The frost free period is only ~140 days. Precipitation at site 5 is more than triple that of site 1, allowing for significantly more plant available water. Increased precipitation is due to orographic uplift. Five months receive significant precipitation in the form of snow and rain of over 4.0 in per month. Increased water will allow higher rates of chemical weathering and accumulation of clay particles. Climate is probably not a significant factor affecting soil texture or nutrient availability because site 4 has the same general climate, although some microclimatic differences may occur, and has a much coarser texture and lower levels of available nutrients.
3. Time- Time is the most difficult factor to determine in the study. All five sites form over the same batholith complex. It is not within the scope of this study to accurately determine either absolute age or relative age without further tests. Relative ages of soils may be determined by looking for evidence of erosion or deposition of topsoil. The paleo-landscape of each site would need to be determined to look for landslides or erosion since the last glacial period which would reset soil development. Site 5 is situated on a toe slope at the edge of a basin, so there was an uphill source for deposition of new soil material, the small slope indicates the ground has stabilized and is receiving less deposited material today. A slope of 8° and extensive vegetative cover underneath the forest canopy suggest minimal potential for erosion for the site. In theory, site 5 should be a relatively young soil due to accumulation of new parent material from farther uphill. Site 5 has the some of the highest nutrient values, the deepest depth to bedrock, and the finest soil texture. These suggest that the soil is older than the other sites. In particular compared to site 4, which has the most similar characteristics and climate to site 5 but has the most significantly different nutrient values. Therefor site 5 is older than site 4 and/or it is receiving fine grained material and nutrients from colluvial or fluvial

sources. Stump Meadow has a more rounded, U-shaped cross-section compared with Indian Basin; this suggests that Stump Meadow has had more time to develop slope equilibrium. Climate and topography affect time for both sites 4 and 5. A thick snowpack insulates the soil, reducing the amount of time each year for soil development. The cold winters and persistent snow through spring significantly shorten the frost free period to only ~140 days. This effectively decreases soil development speed due to decreases in microbial activity.

4. Topography- Site 5 is situated on a toe slope west of a forest service road. Site 5 is located the farthest away from highway 180 compare to other sites. The presence of buried wood pieces is evidence of accumulating soil material. There are no signs of erosion around the site, so the soil is developing from deposited material over the residual granitic parent material. Soil nutrients are either deposited from uphill material or from direct chemical weathering of parent material, decomposition of overlying vegetation, or human amendments. Site 5 has a west facing slope, which receives lower amounts of sunlight and evaporation than south facing slopes. This should result in longer periods of plant available water. This was observed in the field as site 5 was the only site with moist soil during collection on August 1st. The soil may be moist due to its proximity to the water table. Topography, along with time, may be the most significant factors affecting the high nutrient values and fine soil texture of site 5. The deposition of additional material from colluvial or fluvial sources has given site 5 the highest fertility of the soils in this study. Topography also influences climate due to significant decrease in temperatures and an increase in precipitation due to orographic effects.
5. Biological/ Human Factors- Site 5 has a long history of cattle grazing and Native Californian land use. Although winter snow would limit the use of this site to late spring through fall, it was an important summer location for Native Californians. Although there was no direct evidence of Native Californian inhabitance, it is likely that the area was used for food collecting and as hunting grounds. Prior to European settlement, the understory of this region would have been cleared by fire on a regular basis. Converse Basin is the largest grove of Giant Sequoias (Sequoiadendron giganteum) in the world. Stump meadow refers to the large amount of huge stumps scattered throughout the meadow. These stumps are remnants of the logging which occurred at the beginning of

the 20th century. Site 5 is unique because there is a complete account of the land use practices in Stump Meadow dating back to 1868.

Charles Porter Converse bought the basin in 1868. The Converse Sequoia Grove was harvested over a 14 year period. The Kings River Lumber Company initially harvested few sequoias. The company changed its name to the Sanger Lumber Company in 1897 and built the Converse Mill to increase the harvesting of sequoias. The Converse Mill burned to the ground on November 11, 1905; in December of that year the property was sold to the Hume Bennet Lumber company. The company focused on milling trees which were already downed because only a few trees were left standing. Due to the downing of so many trees, the water table of stump meadow rose, preventing the regeneration of sequoias. In 1929, the Converse fire burned much of the logging debris which allowed for the regeneration of sequoias which sprouted shortly after the fire. In 1935 the land was sold to the USDA Forest Service. Due to depression and war, the land was left alone during the 1930's and 40's. In 1955 the McGee fire cleared thickets of brush and most of the remaining logging debris. This created ideal growing conditions for young sequoias and since then the forest service has planted thousands of sequoias (*Sequoiadendron giganteum*), sugar pine (*Pinus Lambertiana*), and Jeffrey pine (*Pinus jeffreyi*).

The climate is too cold in winter and too dry in summer to support high rates of organic decay. Fire is needed to release nutrients so that they can become available in the soil again. Current land management practices of fire suppression have had the smallest effect on site 5 due to 2 major fires in the last 82 years. These fires, aided by massive debris buildup from logging, are most likely the reason why site 5 has the highest levels of organic carbon, nitrogen, and calcium as well some of the highest values of other nutrients. Soil nitrogen levels spike after fires in areas with high fuel loads (Hart, 2005). Site 5 has the highest nitrogen levels, which is from the Converse and McGee fires releasing it back into the soil. In conjunction with topography and time, biological factors have the most significance on nutrient availability.

Results

Sample	**P.S.A**	**Texture**	**pH**	**Ca (mg/L)**	**Mg (mg/L)**	**K (mg/L)**
K1T	69-16-15	Sandy Loam	5.55	852.5	120	177.5
K1s	69-13-18	Sandy Loam	5.64	1032.5	177.5	197.5
K2T	60-22-18	Sandy Clay Loam	5.96	1597.5	47.5	85
K2s	59-24-17	Sandy Clay Loam	6.09	1987.5	40	82.5
K3T	51-30-19	Sandy Clay Loam	5.8	1700	107.5	320
K3s	49-24-27	Sandy Clay Loam	5.52	1155	107.5	325
K4T	71-17-12	Sandy Loam	4.45	117.5	0	112.5
K4s	77-12-11	Sandy Loam	4.54	110	0	87.5
K5T	57-25-18	Sandy Clay Loam	4.87	2150	167.5	197.5
K5sA	60-21-19	Sandy Clay Loam	4.75	2105	180	150
K5sB	50-26-24	Sandy Clay Loam	4.91	1897.5	165	137.5
Sample	**Na (mg/L)**	**Ca:Mg**	**P (ppm)**	**N%**	**C%**	**C:N**
K1T	42.5	7.104	1	0.075	0.896	11.97
K1s	67.5	5.817	1	0.044	0.647	14.75
K2T	30	33.63	1	0.091	1.383	15.19
K2s	30	49.688	0.5	0.044	0.783	17.71
K3T	47.5	15.814	0.5	0.122	2.056	16.83
K3s	52.5	10.744	0	0.038	0.753	19.65
K4T	35	0	2	0.054	1.807	33.33
K4s	42.5	0	1.5	0.045	1.311	29.25
K5T	40	12.836	0.5	0.202	4.063	20.16
K5sA	87.5	11.694	1	0.107	3.669	34.36
K5sB	60	11.5	1	0.073	2.104	28.78

Figure 6- Particle Size Analysis, Texture, pH, Exchangeable Cations, Carbon, and Nitrogen

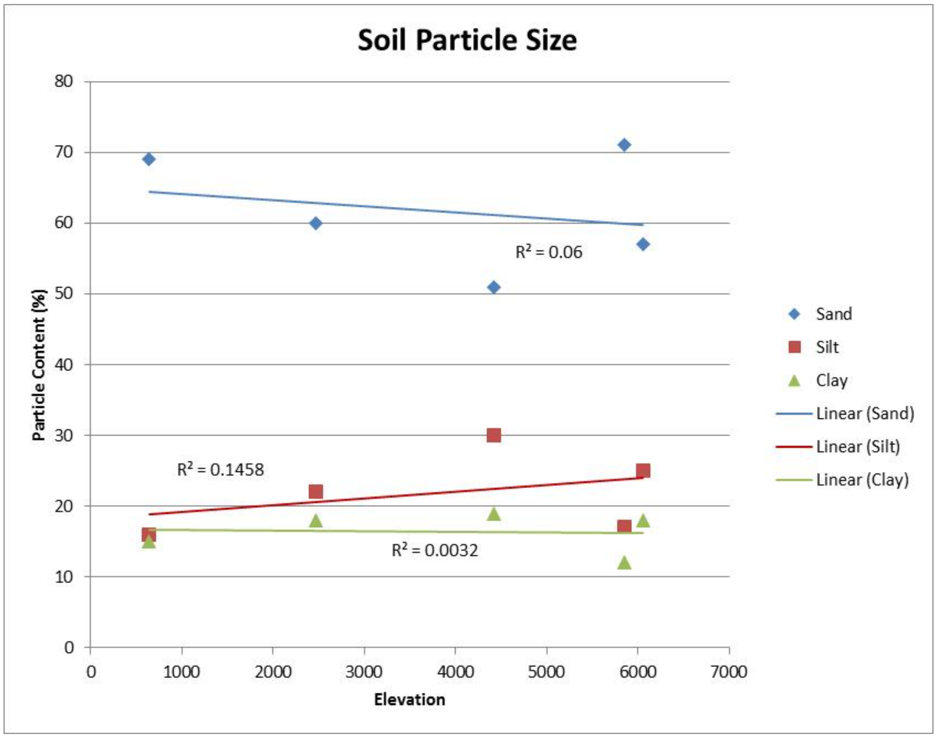


Figure 7- Distribution of particle size in soils as elevation increases

Texture

Particle size analysis showed that textures throughout this study were consistently coarse. All samples except one have sand contents greater than or equal to 50% (Fig 6). These textures are indicative of a coarse grained parent material that is highly resistant to physical and chemical weathering. The essential minerals of the granitic parent materials are all listed as hard (6) to very hard (7) on the Mohs scale of relative hardness of minerals (Mottana 278). As weathering rates increase, sand content will decline and clay content will increase. Sand content decreases almost linearly from sites 1 to 3 as elevation increases (Fig 7). Sand content increases again somewhere after an elevation of 4,500 ft. The abrupt change in textural trend implies a significant change in weathering rates above this elevation. Dahlgren (1997) found that evidence of clay translocation and accumulation in soils abruptly stopped about 5250 ft.

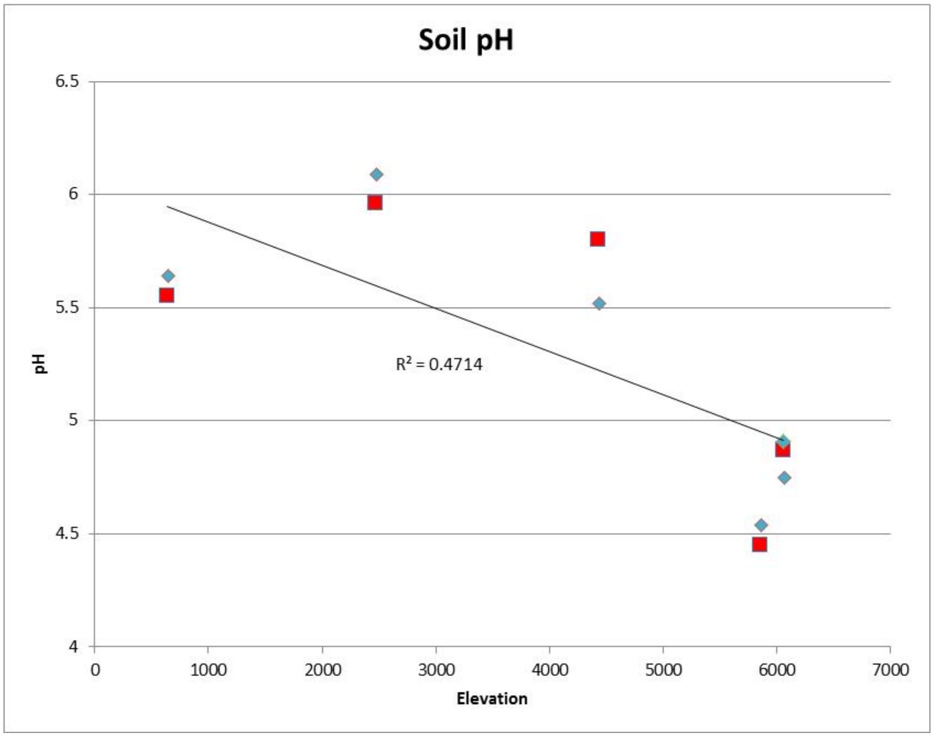
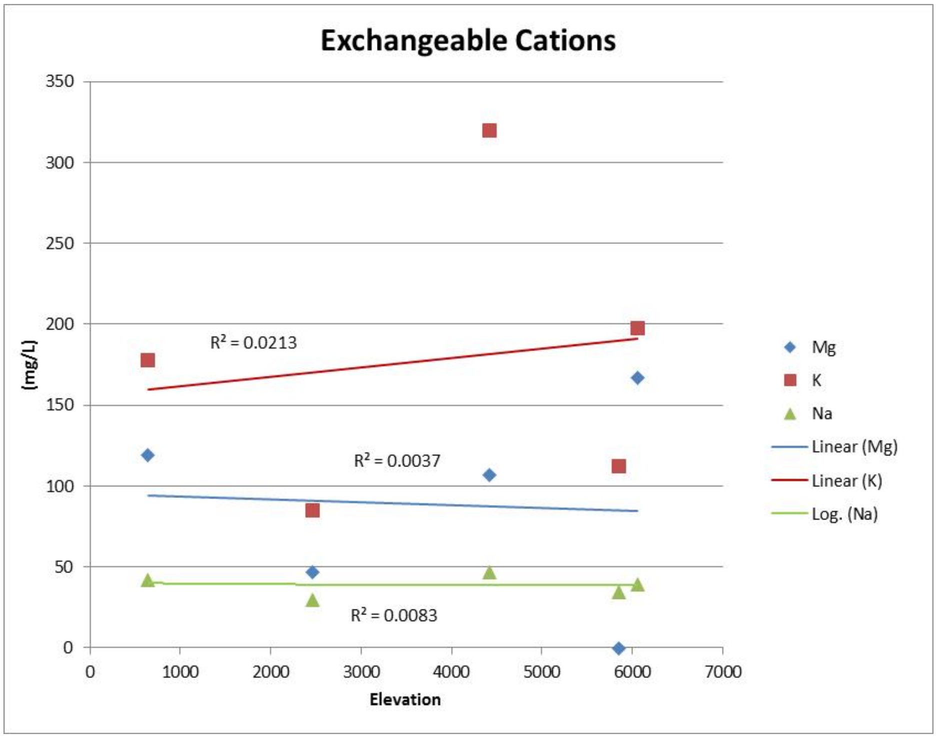


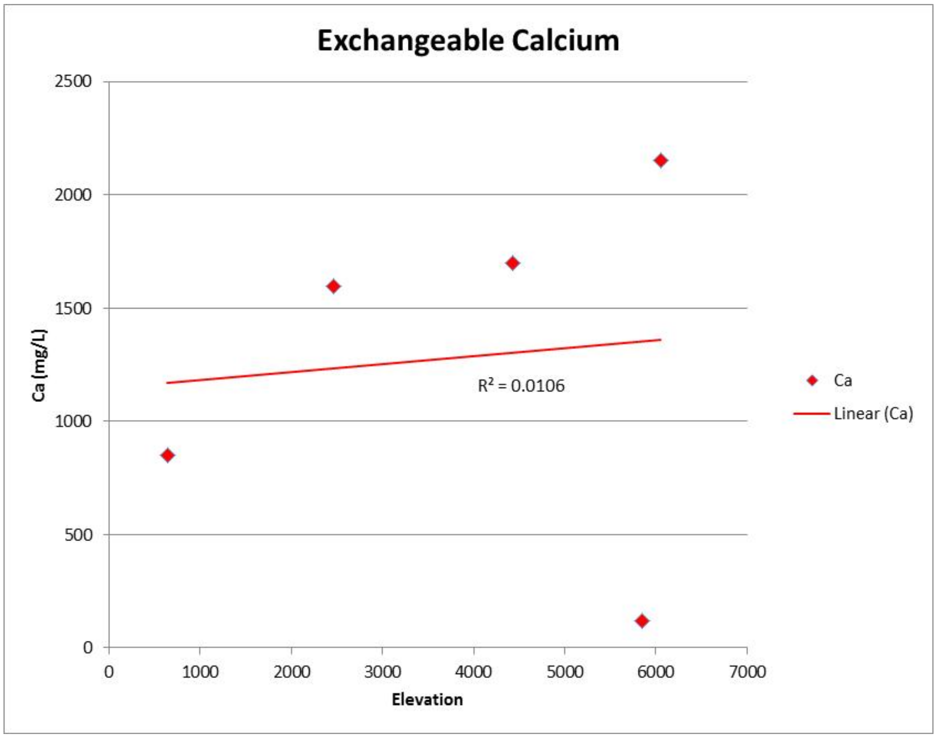
Figure 8- pH values along an elevational transect. Yellow diamonds indicated topsoil pH and orange squares indicate subsoil pH. The trendline is for topsoil pH

pH

The pH values are acidic overall, ranging from 4.45 to 6.09 (Fig 8). The values increased from site 1 (642 ft.) to site 2 (2468 ft.) then decreased with increasing elevation. There is a steep decrease of over 1.5 units between site 3 (4425 ft.) and sites 4 and 5 (~6000 ft.) The pH values decrease with elevation, except between sites 1 and 2, where pH increases slightly.



A



B

Figure 9- Exchangeable cations at each of the 5 sites. Magnesium, potassium, and sodium are shown in A; calcium in shown in B

Exchangeable Cations

All soils have the same trend in exchangeable cations with calcium being the highest (Fig 9B), followed by potassium, magnesium, and sodium (Fig 9A), respectively. The one exception of this is site 4, which had a zero value for magnesium. The nonexistent magnesium in site 4 may reflect a change in parent material or a lack of deposition at the site. Calcium has much higher values then other cations. With the exception of site 4, calcium increases with elevation in a near linear trend. Potassium, magnesium, and sodium do not follow any linear trends, however they all decrease between sites 1 (642 ft.) and 2 (2468 ft.) and between sites 3 (4425 ft.) and 4 (5853 ft.); then increase between sites 2 (2468 ft.) and 3 (4425 ft.) and between sites 4 (5853 ft.) and 5 (6054 ft.). These trends may reflect the composition of the granitic parent material having high percentages of anorthite ($CaAl_2Si_2O_8$) and orthoclase ($KAlSi_3O_8$) compared to albite ($NaAlSi_3O_8$). These trends differ from those found in Dahlgren (1997), in which magnesium was the second dominant cation at low elevations, and potassium became second dominant above 5250 ft.

Cation exchange capacity (CEC) should vary seasonally in higher elevations as potassium has increased conductivity in warmer temperatures and sodium conductivity increases in colder temperatures (Blank, 2010). This could potentially create very low CEC values in winter due to the relatively low sodium values and high CECs in the summer due to the high potassium values.

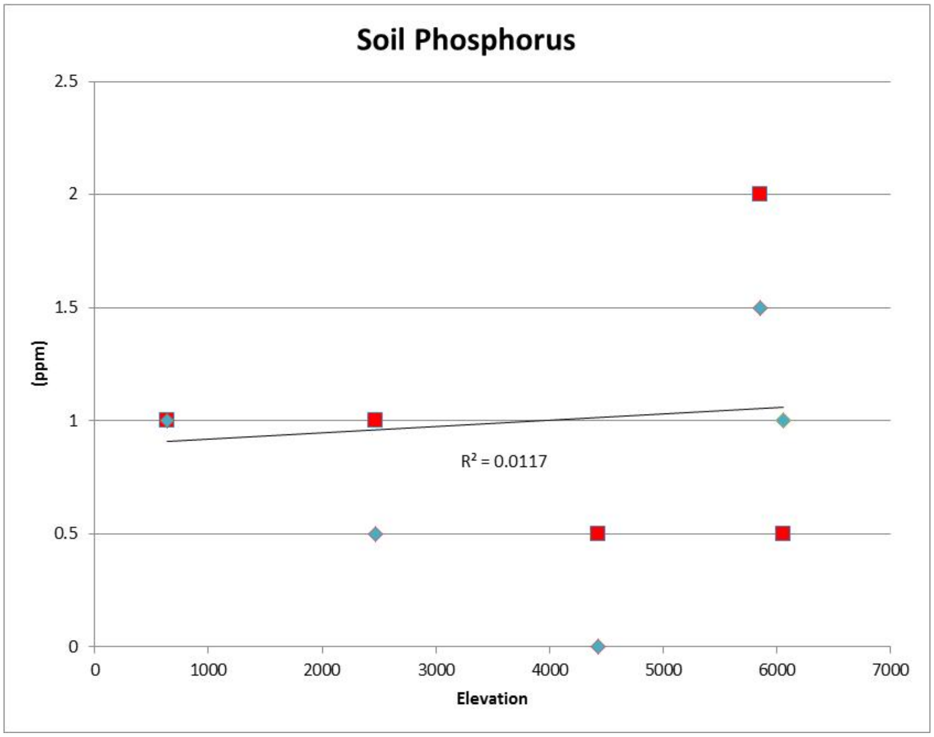
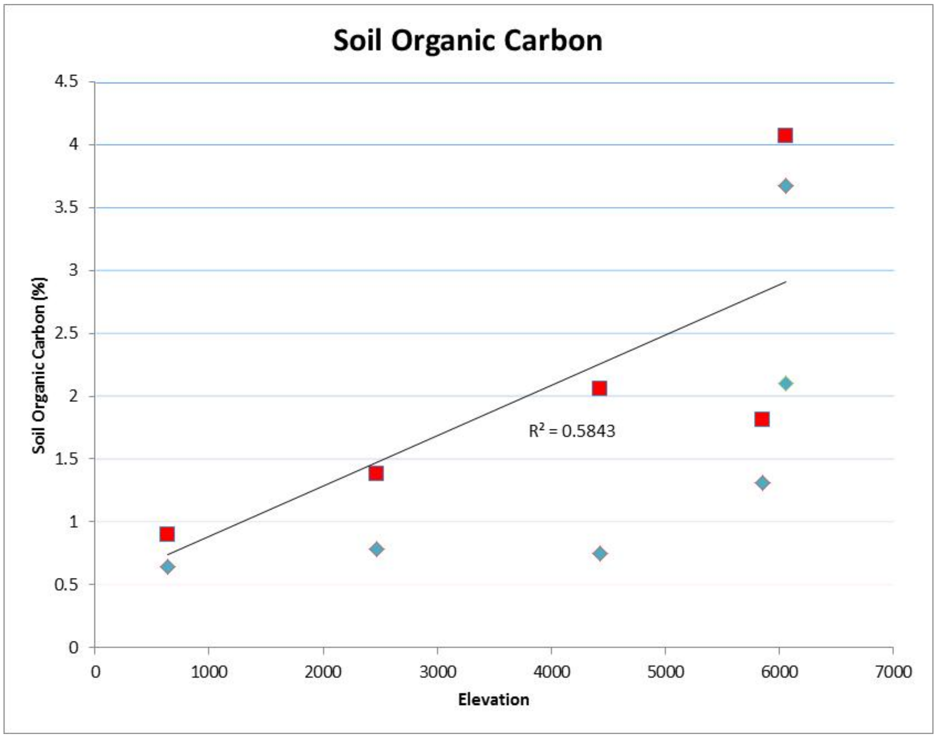


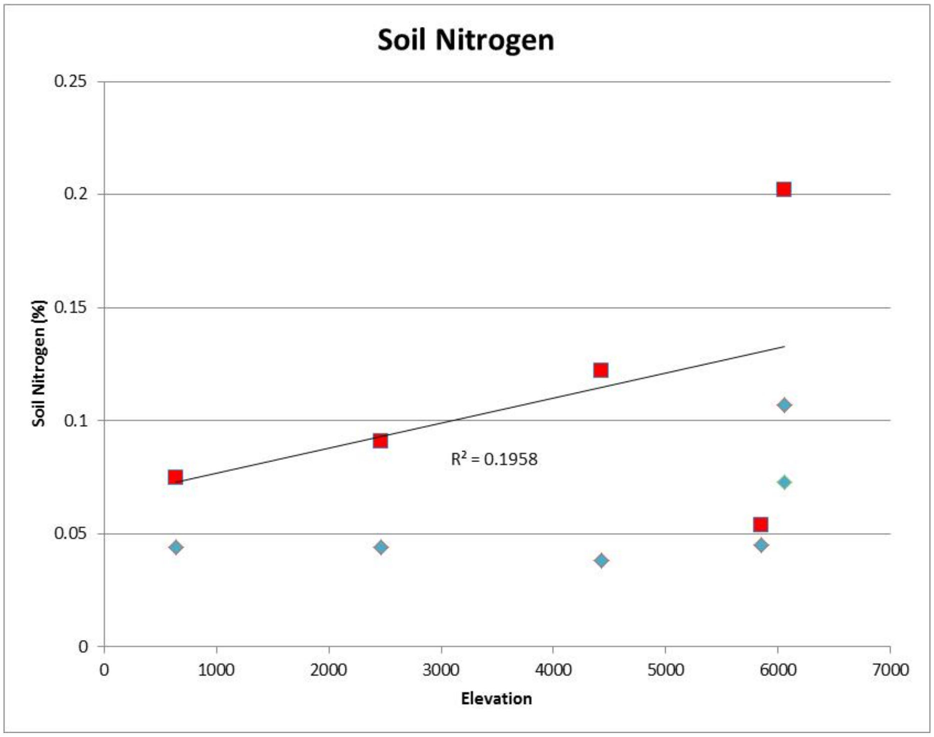
Figure 10- Soil Phosphorus at each of the 5 sites. Red squares indicate topsoil phosphorus levels while blue diamonds indicate subsoil phosphorus levels

Phosphorus

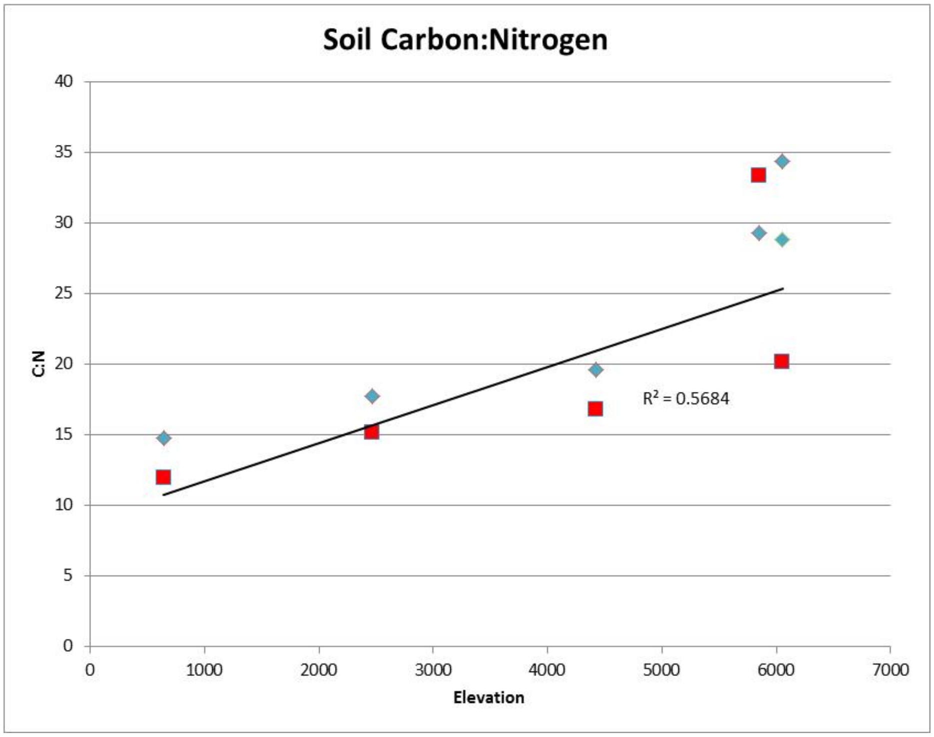
Soil phosphorus levels were extremely low in all study areas. All sites except site 4 had 1 part per million (ppm) or less phosphorus (Fig 10). Site 4 has 2 ppm in the topsoil and 1.5 ppm in the subsoil. While these levels are still very low, they are surprising because site 4 has the lowest values some other nutrients.


Soil Organic Carbon
Soil Organic Carbon (%)
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
R² = 0.5843
0
1000
2000
3000
4000
5000
6000
7000
Elevation

A


Soil Nitrogen
Soil Nitrogen (%)
0.25
0.2
0.15
0.1
0.05
0
R² = 0.1958
0
1000
2000
3000
4000
5000
6000
7000
Elevation

B



C

Figure 11- Soil Carbon and nitrogen at each of the 5 sites. Carbon is shown in A, Nitrogen in B, and C:N in C. Red squares represent topsoil levels, blue diamonds represent subsoil levels. Trendlines are for topsoil only in A and B.

Organic Carbon and Nitrogen

Organic carbon levels vary due to several factors including soil properties, vegetative litter, climate, and erosion (Dahlgren, 1997). Dahlgren (1997) assumes that soil organic concentrations in the southern Sierra Nevada Mountains are near steady state due to little variance in climate since the last glacial period. In this study we assume that land use/land cover change and changes in vegetative composition since European contact may have had an effect on organic carbon levels; most likely reducing soil carbon due to accumulation of fuel loads and the reduction in plant root mass by invasion of European annual grasses.

Soils in this study showed a near linear increase in organic carbon from just under 1% (.89) to over 4% (4.06) (Fig 11A) with the exception of site 4 (5853 ft.) which showed a drop to less than 2% (1.81). This is most likely due to less vegetative cover at site 4.

Conclusion

Numerous factors contribute to soil development. This study has examined the 5 major soil forming factors, parent material, climate time, topography, and biological activity to determine which of these has the greatest effect on soil at each site. Date shows that no one single factor is controls soil development across the study area. Changes in elevation which affect climate can have significant effect on soil development (Dahlgren, 1997), but these effects are only for certain soil properties. The data in this study do not support these claims. There is some correlation with elevation and soil properties, but elevation is not a reliable predictor of soil development. Each site has individual characteristics affecting the development of soil. Rather than one or two factors controlling soil development across the study area, all five are interacting to create unique soil properties.

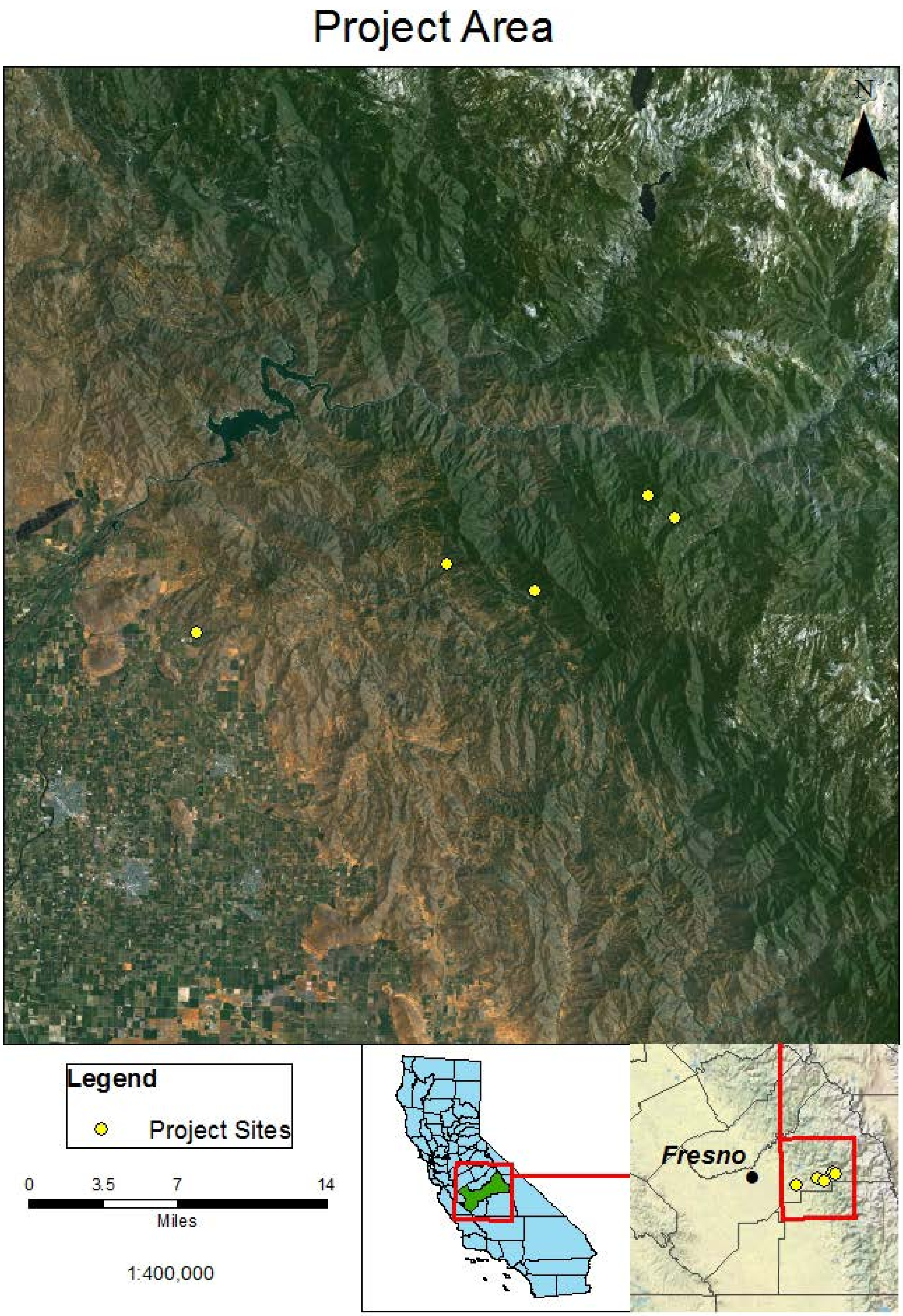
No single factor dominates the soil development of sites 1 and 2. Site 2 has a wetter climate, resulting in slightly more soil development and a different vegetative community. However, both sites could be classified as various compositions of oak woodland. Land use and land cover change have had the biggest influence as these two sites are highly disturbed by modern humans. Fire suppression and invasive annuals have created an excessive fuel load, resulting in lower nutrient values in the soil.

Site 3 showed some of the highest rates of soil development based on texture and nutrient availability. Climate and elevation are dominating factors at this site. Due to this site being near the snow line, it receives the highest percent of precipitation in liquid form as opposed to snow. This maximizes the amount of time each year for water to infiltrate the soil and increase development. Higher elevation sites become blanketed with snow which insulates the soil temperature from fluctuations above and below freezing; which causes frost wedging and greatly increases mechanical weathering. Since the snow only melts in spring, this effectively reduces the time that water is infiltrating the soil and leeching (Dahlgren, 1997). Fluctuations above and below freezing temperature will be the most common at site 3, allowing for increased weathering due to frost wedging.

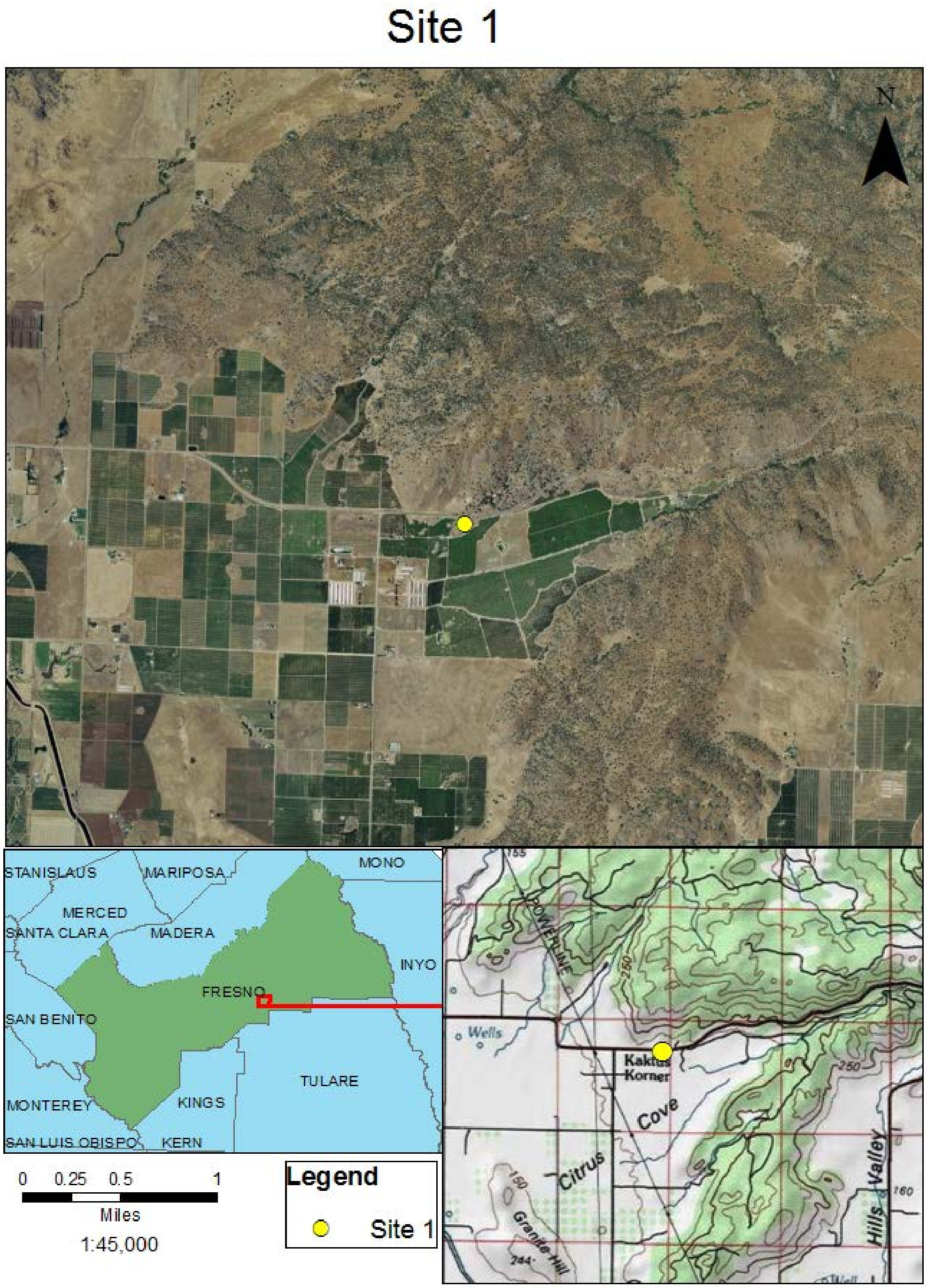
Topography is a dominant factor controlling the soil development at site 4. The site is high enough above the local water table to be completely dry during summer and the slope is steep enough to prevent deposition. Parent material may also be a significant factor. Having no magnesium in the soil at site 4 indicates that there is no magnesium in the parent material as well as none being deposited at the site. As a plant essential nutrient, magnesium may be lowering the potential vegetative cover of the site by being a limiting nutrient.

The dominating soil forming factors for site 5 are topography and biological activity. Site 5 is in a depositional environment which provides it with fine sediment and nutrients. The site is close to the water table providing moisture for increased vegetative and microbial growth. Site 5 has burned more recently than any other site. Although the burns are fairly recent, sufficient time has passed to allow the nutrients and carbon to infiltrate back into the soil. This is most likely the reason that site 5 has high levels of organic carbon and calcium.

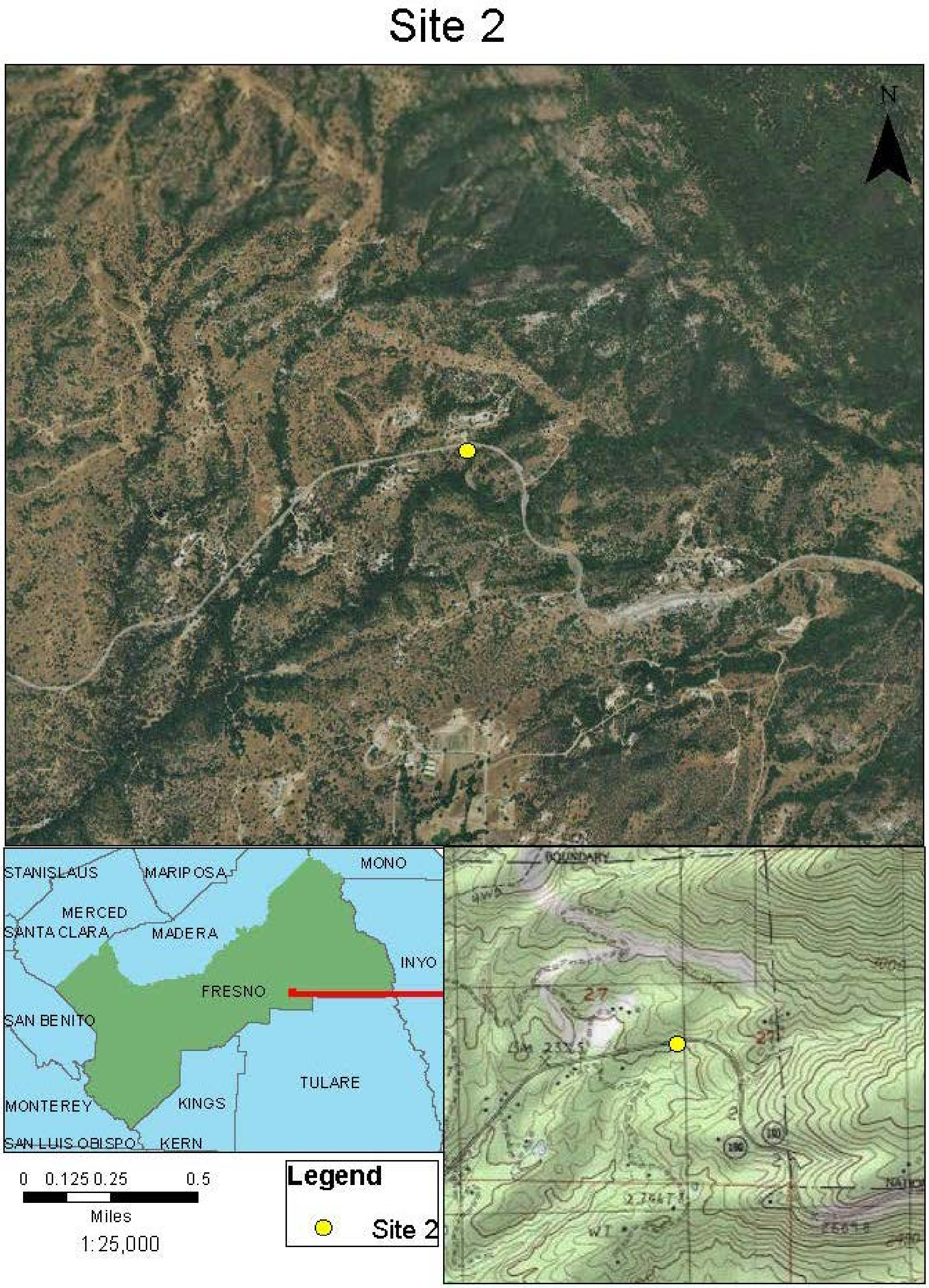
Appendix 1- Project Maps &Site Maps



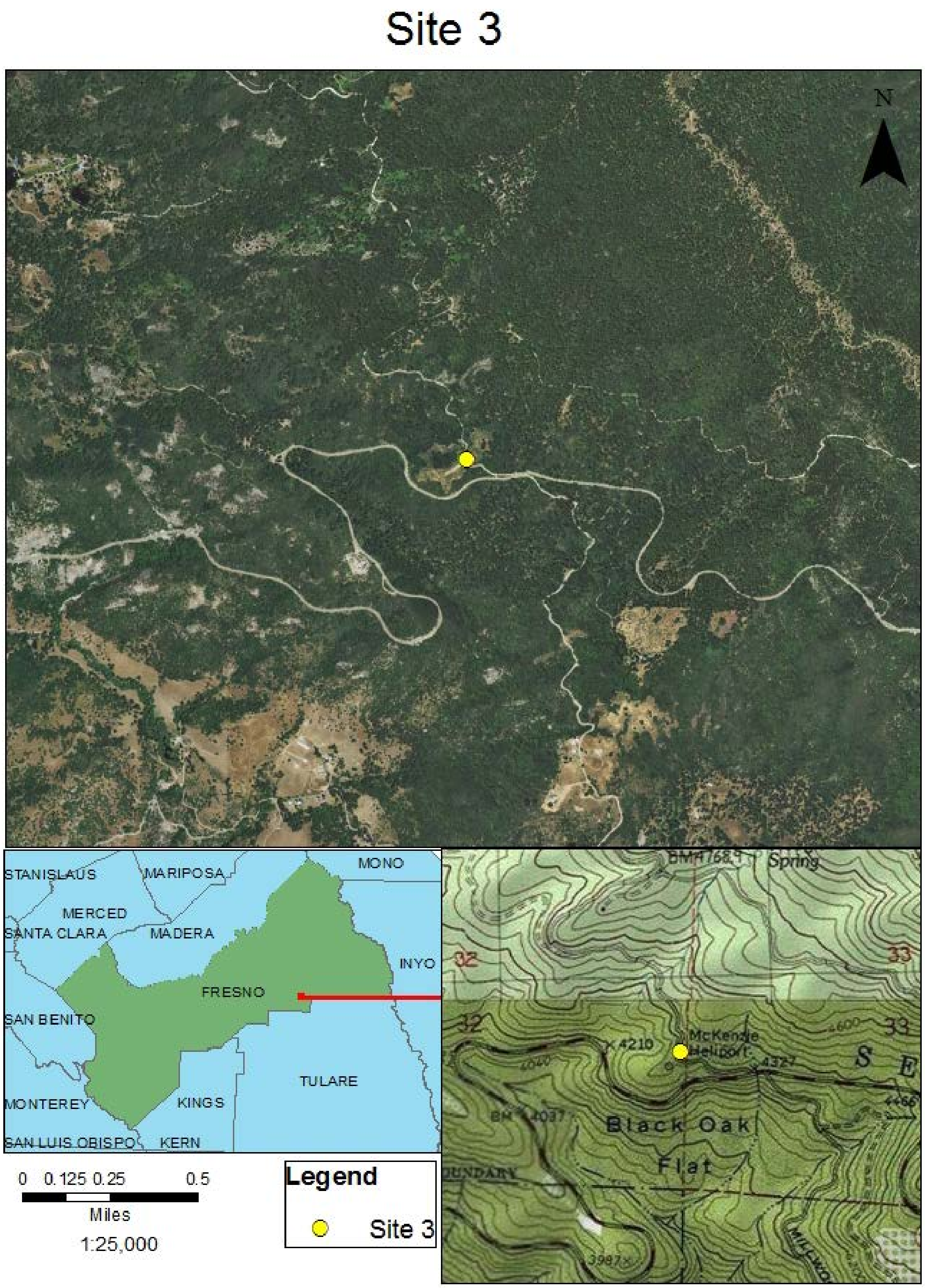
1A- Project Area


Site 1
N
STANISLAUS
MARIPOSA
MONO
MERCED
SANTA CLARA
MADERA
INYO
FRESNO
SAN BENITO
TULARE
MONTEREY
KINGS
SAN LUIS OBISPO
KERN
0 0.25 0.5 1
Miles
1:45,000
Legend
Site 1
Wells
Kaktus Korner
Citrus Cove
Granite Hill
Hills Valley
POWERLINE
250
150
244
160

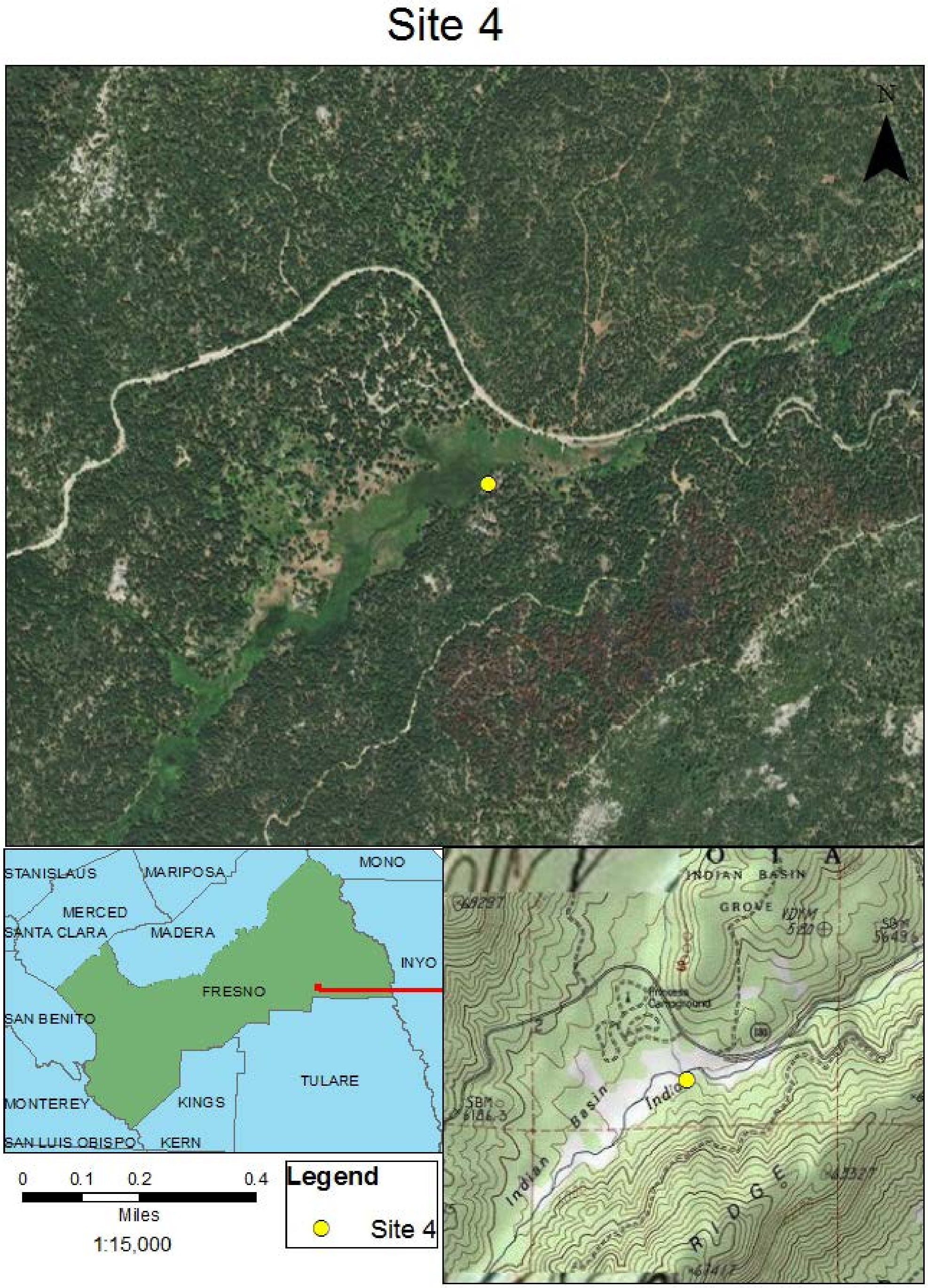
1B- Site 1


Site 2
N
STANISLAUS
MARIPOSA
MONO
MERCED
SANTA CLARA
MADERA
INYO
FRESNO
SAN BENITO
TULARE
MONTEREY
KINGS
SAN LUIS OBISPO
KERN
0 0.125 0.25 0.5
Miles
1:25,000
Legend
Site 2

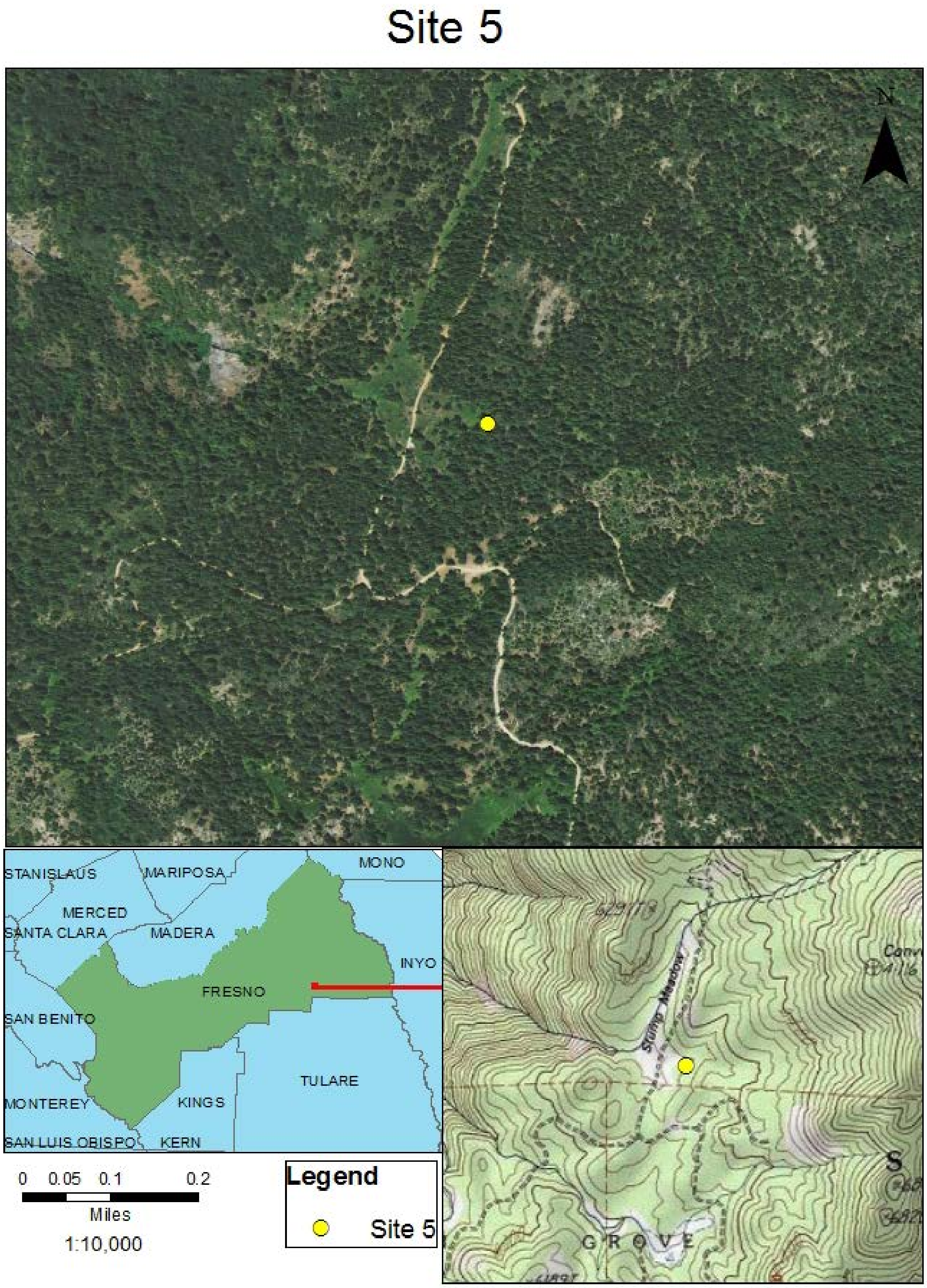
1C- Site 2


Site 3
N
STANISLAUS
MARIPOSA
MONO
MERCED
SANTA CLARA
MADERA
INYO
FRESNO
SAN BENITO
TULARE
MONTEREY
KINGS
SAN LUIS OBISPO
KERN
0 0.125 0.25 0.5
Miles
1:25,000
Legend
Site 3
Spring
32
33
4210
McKenzie Heliport
4327
Black Oak Flat
4037
3987

1D- Site 3

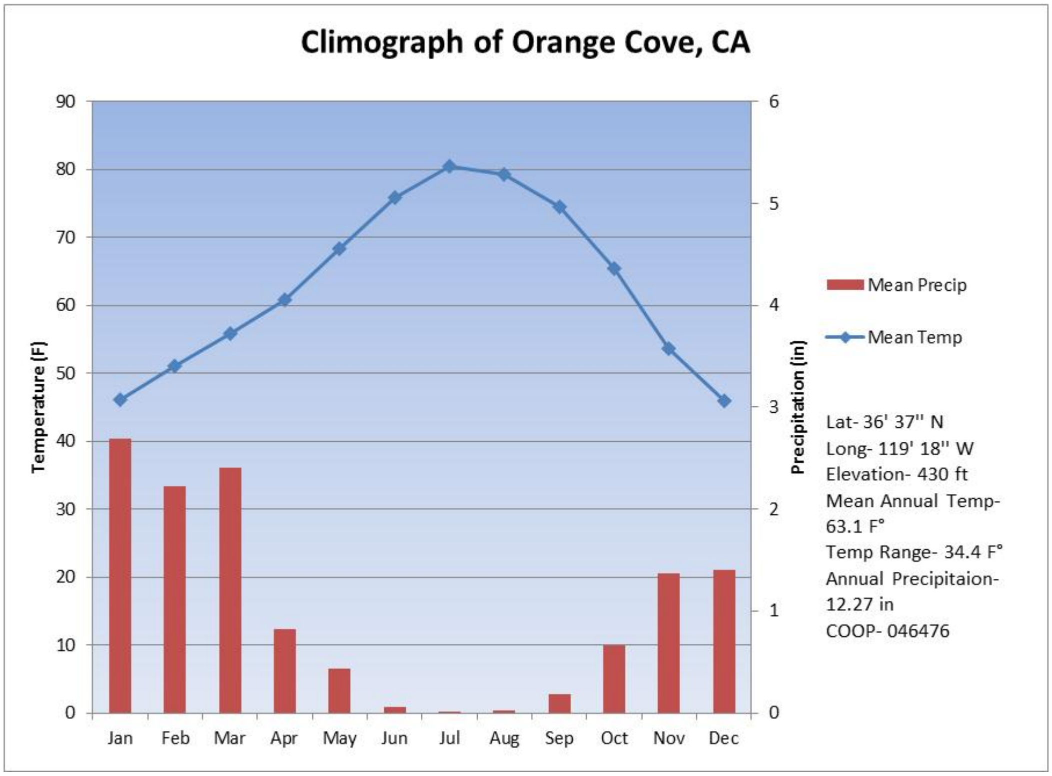

Site 4
N
STANISLAUS
MARIPOSA
MONO
MERCED
SANTA CLARA
MADERA
INYO
FRESNO
SAN BENITO
TULARE
MONTEREY
KINGS
SAN LUIS OBISPO
KERN
INDIAN BASIN
GROVE
Indian Basin
RIDGE
0 0.1 0.2 0.4
Miles
1:15,000
Legend
Site 4

1E- Site 4

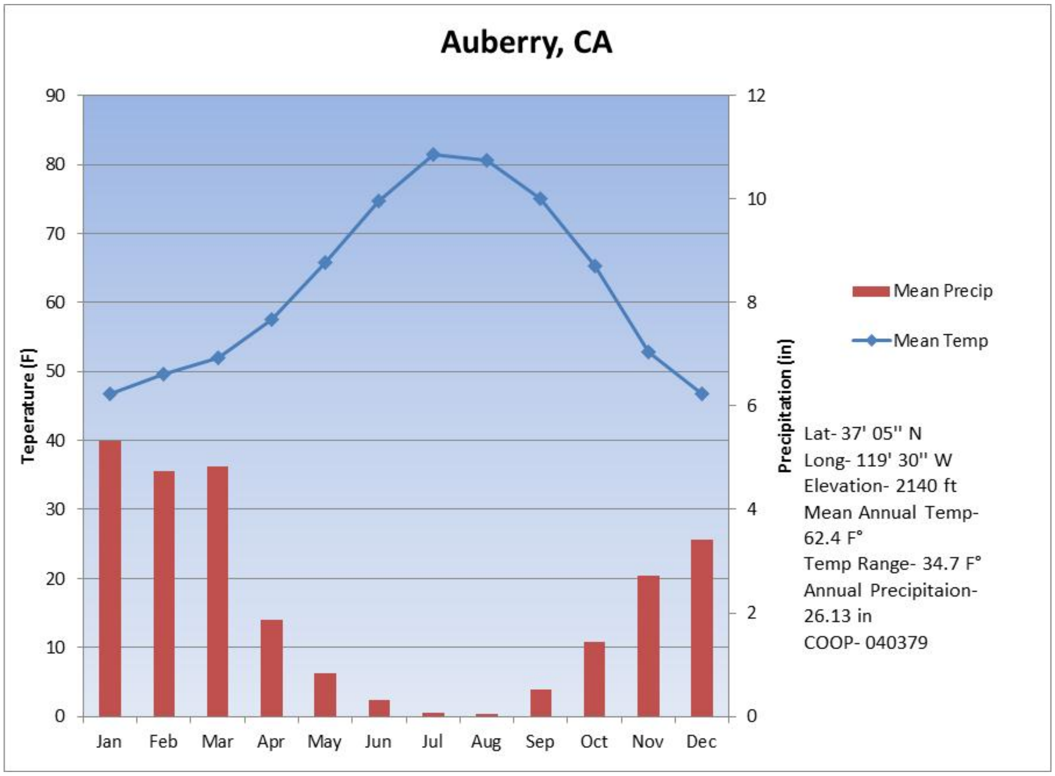

Site 5
N
STANISLAUS
MARIPOSA
MONO
MERCED
SANTA CLARA
MADERA
INYO
FRESNO
SAN BENITO
TULARE
MONTEREY
KINGS
SAN LUIS OBISPO
KERN
0 0.05 0.1 0.2
Miles
1:10,000
Legend
Site 5
GROVE

1F- Site 5

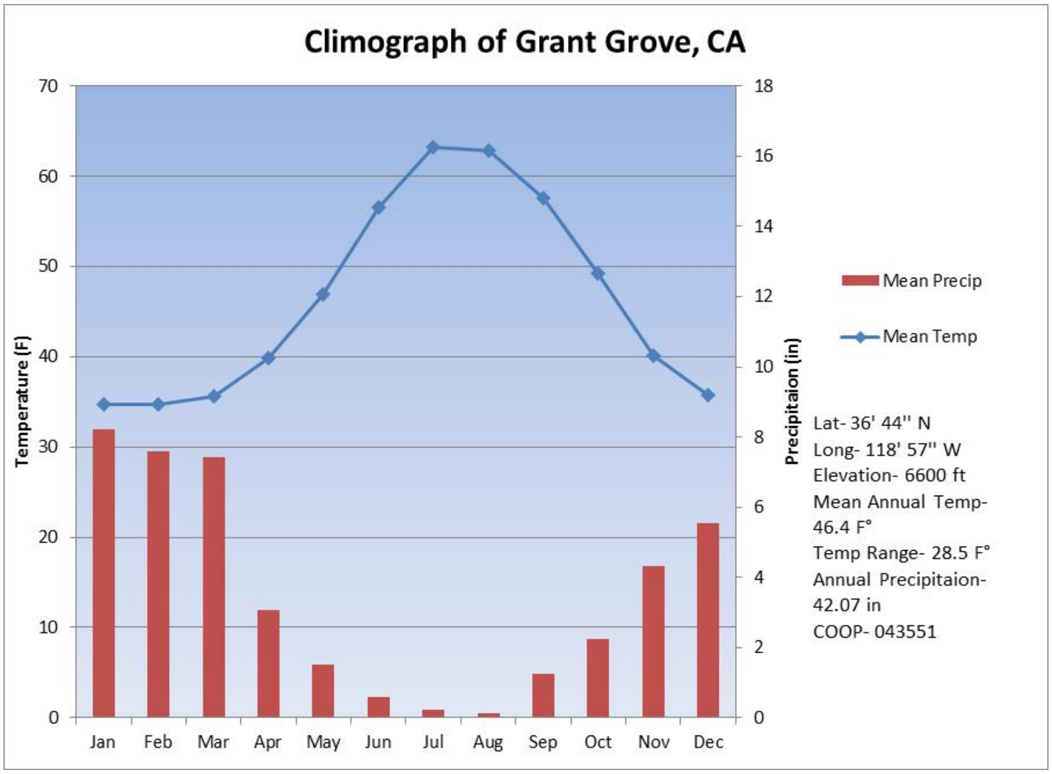
Appendix 2- Climatic Data



2A- Orange Cove climograph

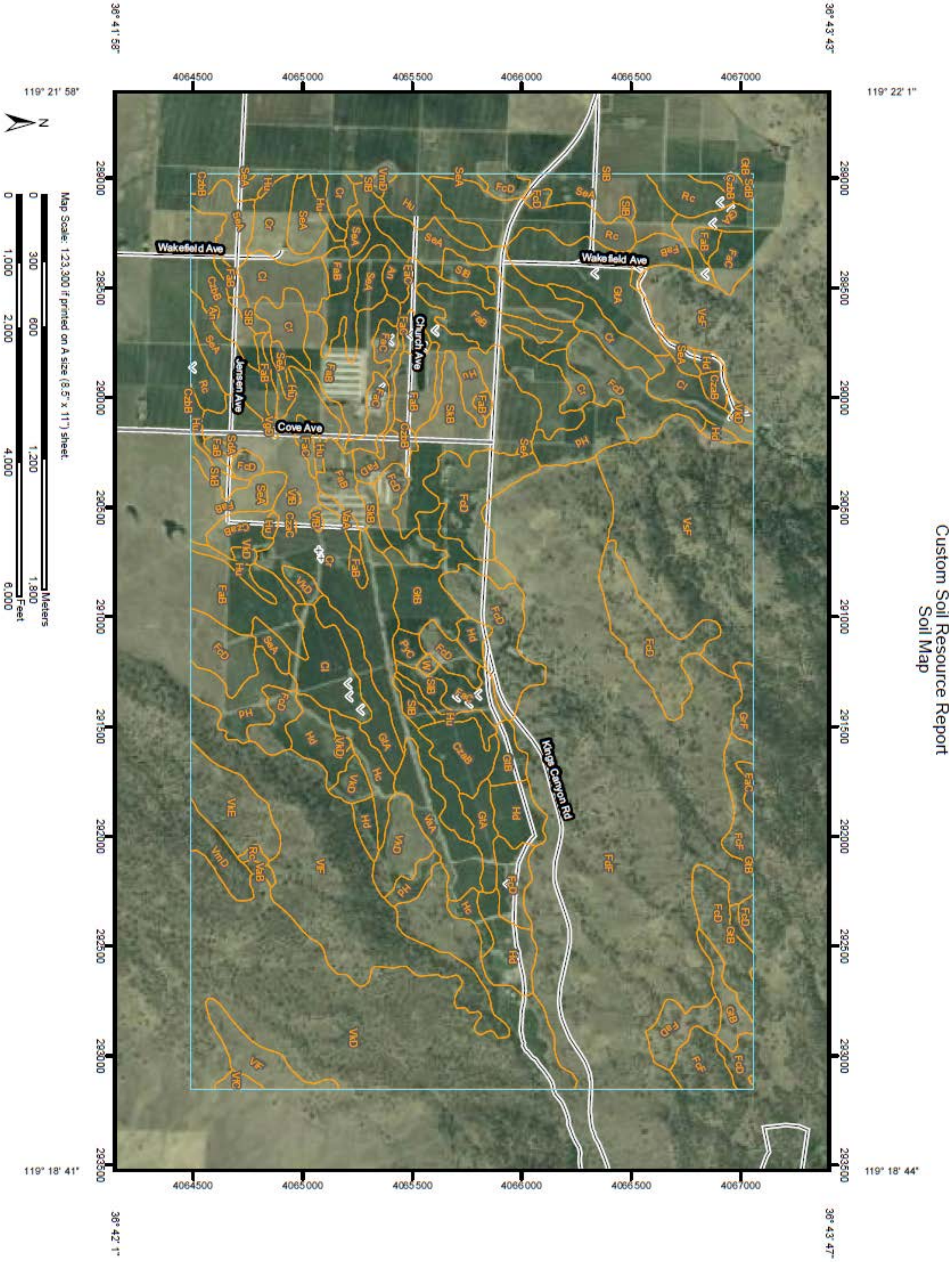


2B- Auberry climograph



2C- Grant Grove climograph

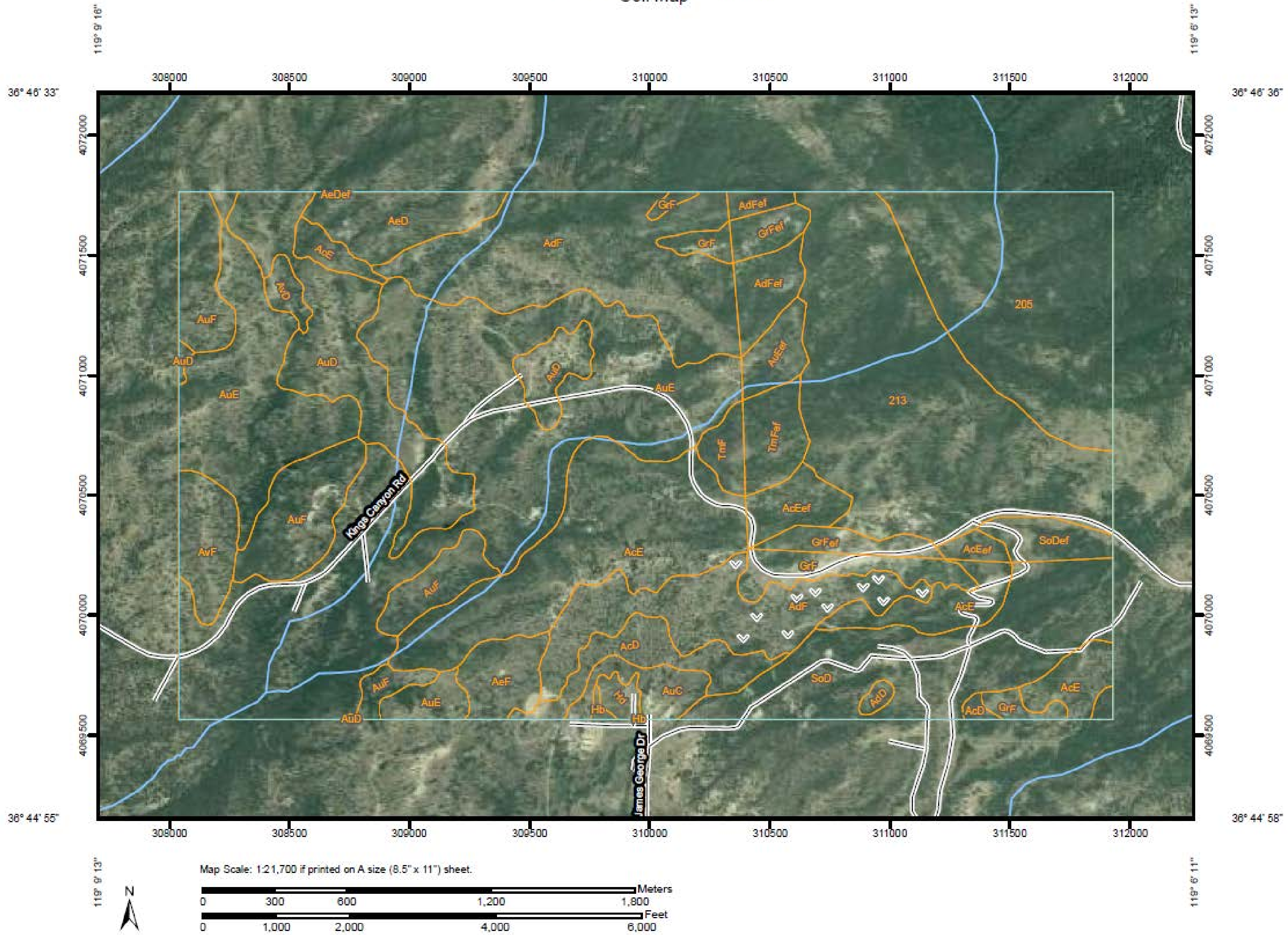
Appendix 3- Soils Maps



3A- Site 1 Soil Map and Units

- An—Alamo clay
- Cl—Chino sandy loam
- Cr—Chino loam
- CzaB—Cometa sandy loam, 3 to 9 percent slopes
- CzaC—Cometa sandy loam, 9 to 15 percent slopes
- CzbB—Cometa loam, 2 to 9 percent slopes
- FaB—Fallbrook sandy loam, 3 to 9 percent slopes
- FaC—Fallbrook sandy loam, 9 to 15 percent slopes
- FaD—Fallbrook sandy loam, 15 to 30 percent slopes
- FcD—Fallbrook very rocky sandy loam, 3 to 30 percent slopes
- FcF—Fallbrook very rocky sandy loam, 30 to 70 percent slopes
- FdF—Fallbrook very rocky sandy loam, shallow, 30 to 70 percent Slopes
- GrF—Granitic rock land
- GtA—Greenfield sandy loam, 0 to 3 percent slopes
- GtB—Greenfield sandy loam, 3 to 9 percent slopes
- Hc—Hanford sandy loam
- Hd—Hanford sandy loam, benches
- Hu—Hildreth clay
- PyC—Porterville cobbly clay, 3 to 15 percent slopes
- Rc—Ramona loam
- SdA—San Joaquin sandy loam, shallow, 0 to 3 percent slopes
- SdB—San Joaquin sandy loam, shallow, 3 to 9 percent slopes
- SeA—San Joaquin loam, 0 to 3 percent slopes
- SkB—Sesame sandy loam, 3 to 9 percent slopes
- SlB—Sesame loam, 3 to 9 percent slopes
- VaA—Visalia sandy loam, 0 to 3 percent slopes
- VaB—Visalia sandy loam, 3 to 9 percent slopes
- VfB—Vista coarse sandy loam, 3 to 9 percent slopes
- VfC—Vista coarse sandy loam, 9 to 15 percent slopes
- VgD—Vista coarse sandy loam, shallow, 9 to 30 percent slopes
- VkD—Vista very rocky coarse sandy loam, 3 to 30 percent slopes
- VkE—Vista very rocky coarse sandy loam, 30 to 45 percent slopes
- VlF—Vista very rocky coarse sandy loam, shallow, 30 to 70 percent slopes
- VmD—Vista extremely rocky coarse sandy loam, 3 to 30 percent slopes
- VsF—Vista-Fallbrook extremely rocky coarse sandy loams, 30 to 70 percent slopes
- W—Water

Custom Soil Resource Report
Soil Map

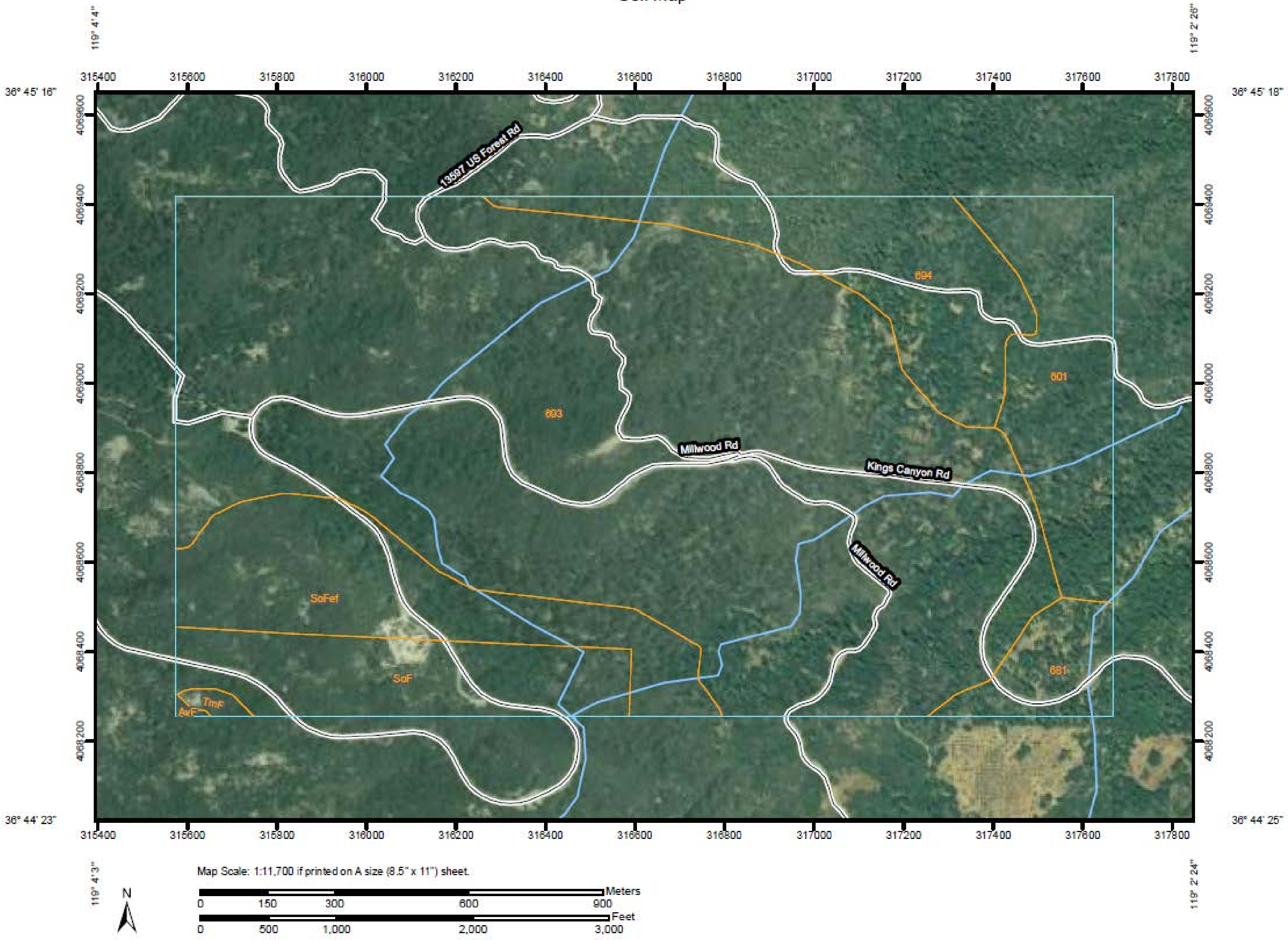


Map Scale: 1:21,700 if printed on A size (8.5" x 11") sheet.

3B- Site 2 Soil Map and Units

- AcD—Ahwahnee coarse sandy loam, 15 to 30 percent slopes
- AcE—Ahwahnee coarse sandy loam, 30 to 45 percent slopes
- AdD—Ahwahnee very rocky coarse sandy loam, 3 to 30 percent slopes
- AdF—Ahwahnee very rocky coarse sandy loam, 45 to 70 percent slopes
- AeD—Ahwahnee very rocky coarse sandy loam, shallow, 3 to 30 percent slopes
- AeF—Ahwahnee very rocky coarse sandy loam, shallow, 30 to 70 percent slopes
- AuC—Auberry coarse sandy loam, 9 to 15 percent slopes
- AuD—Auberry coarse sandy loam, 15 to 30 percent slopes
- AuE—Auberry coarse sandy loam, 30 to 45 percent slopes
- AuF—Auberry coarse sandy loam, 45 to 70 percent slopes
- AvD—Auberry very rocky coarse sandy loam, 3 to 30 percent slopes
- AvF—Auberry very rocky coarse sandy loam, 45 to 70 percent slopes
- GrF—Granitic rock land
- Hb—Hanford coarse sandy loam, hard substratum
- Hd—Hanford sandy loam, benches
- SoD—Sierra very rocky sandy loam, 3 to 30 percent slopes
- TmF—Tollhouse extremely rocky coarse sandy loam, 30 to 70 percent slopes
- VaB—Visalia sandy loam, 3 to 9 percent slopes
- 205—Chualar family-Rock outcrop complex, 50 to 75 percent slopes
- 213—Auberry-Cieneba-Rock outcrop complex, 30 to 50 percent slopes
- AcEef—Ahwahnee coarse sandy loam, 30 to 45 percent slopes
- AdFef—Ahwahnee very rocky coarse sandy loam, 45 to 70 percent slopes
- AeDef—Ahwahnee very rocky coarse sandy loam, shallow, 3 to 30 percent slopes
- AuEef—Auberry coarse sandy loam, 30 to 45 percent slopes
- GrFef—Granitic rock land
- SoDef—Sierra very rocky sandy loam, 3 to 30 percent slopes
- TmFef—Tollhouse extremely rocky coarse sandy loam, 30 to 70 percent slopes

Soil Map

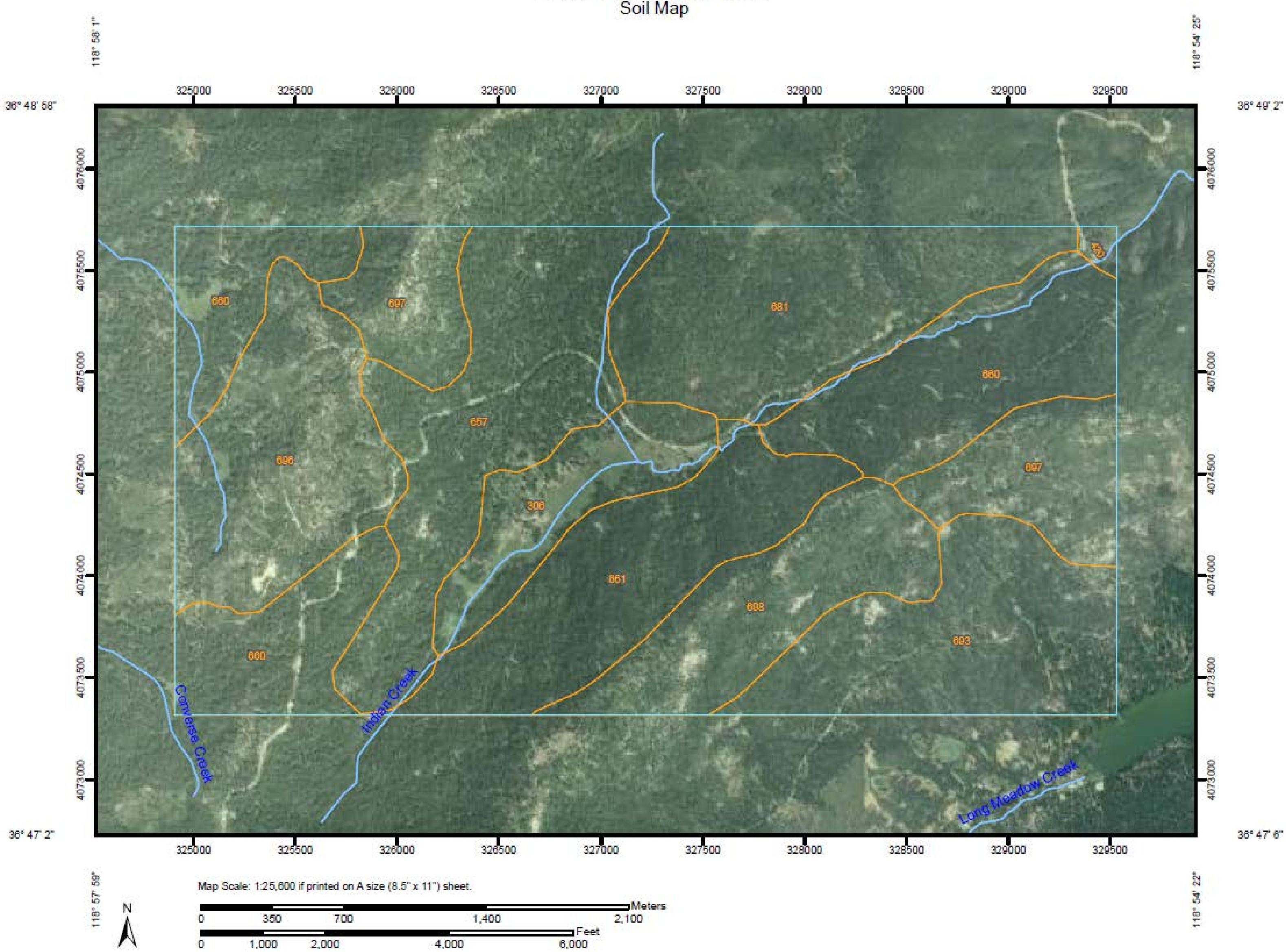


Map Scale: 1:11,700 if printed on A size (8.5" x 11") sheet.

3C- Site 3 Soil Map and Units

- AvF—Auberry very rocky coarse sandy loam, 45 to 70 percent slopes
- SoF—Sierra very rocky sandy loam, 45 to 70 percent slopes
- TmF—Tollhouse extremely rocky coarse sandy loam, 30 to 70 percent slopes
- 601—Brownlee family-Hotaw variant complex, 30 to 50 percent slopes
- 681—Boomer-Crozier-Rock outcrop complex, 5 to 40 percent slopes
- 693—Holland-Hotaw association, moderately steep
- 694—Holland-Hotaw association, steep
- SoFef—Sierra very rocky sandy loam, 45 to 70 percent slopes

Soil Map

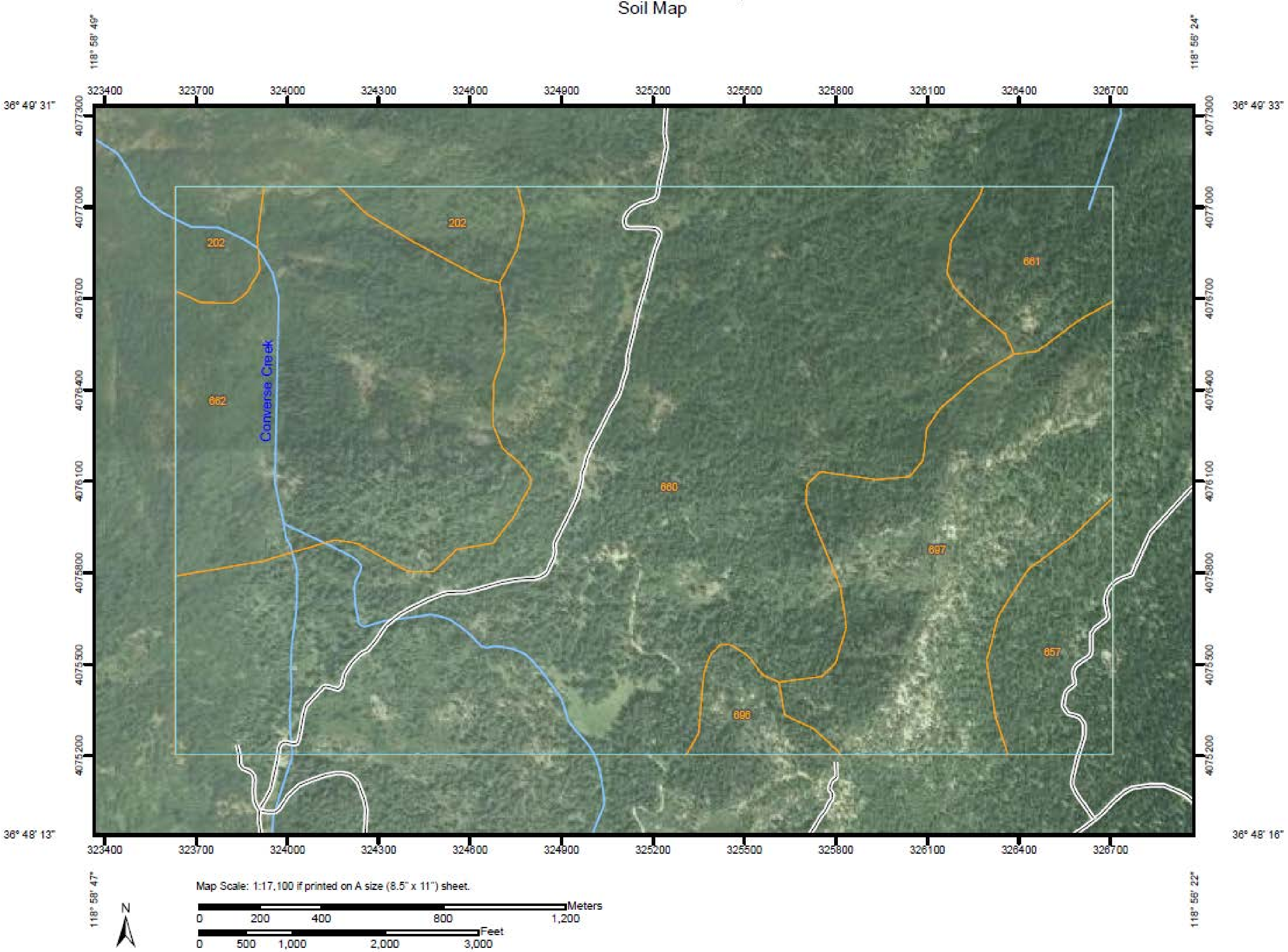


Map Scale: 1:25,600 if printed on A size (8.5" x 11") sheet.

3D- Site 4 Soil Map

- 306—Monache variant, drained, warm-Junipero family association, gently sloping
- 420—Rock outcrop-Cieneba complex, 50 to 75 percent slopes
- 657—Chaix-Dome-Holland association, moderately steep
- 660—Shaver-Chaix association, moderately steep
- 661—Shaver-Chaix association, steep
- 681—Boomer-Crozier-Rock outcrop complex, 5 to 40 percent slopes
- 693—Holland-Hotaw association, moderately steep
- 696—Chaix-Rock outcrop-Dome complex, 10 to 30 percent slopes
- 697—Chaix-Rock outcrop-Dome complex, 30 to 50 percent slopes
- 698—Chaix-Rock outcrop-Dome complex, 50 to 75 percent slopes

Custom Soil Resource Report
Soil Map



3E- Site 5 Soil Map

- 202—Cieneba-rock outcrop complex, 50 to 75 percent slopes
- 657—Chaix-Dome-Holland association, moderately steep
- 660—Shaver-Chaix association, moderately steep
- 661—Shaver-Chaix association, steep
- 662—Shaver-Chaix association, very steep
- 696—Chaix-Rock outcrop-Dome complex, 10 to 30 percent slopes
- 697—Chaix-Rock outcrop-Dome complex, 30 to 50 percent slopes

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