# 3 PHYSICAL AND ECOLOGICAL PROCESSES

This section summarizes the existing setting of the Plan Area in terms of surficial geology and processes, ecological processes, and landscape habitat linkages and wildlife corridors.

## 3.1 Data Sources

The existing ecological and biological setting description is based on the best available existing data and information, including the use of aerial imagery, geographic information system (GIS) data sources, resource agency documents, and scientific literature.

The descriptions of ecological processes (Section 3.3) and habitat linkages and wildlife corridors (Section 3.4) are based on a review of relevant scientific literature and data for these topics, which are cited in the descriptions and listed in Section 8.

Elevation range, percent slope, and aspect are derived from digital elevation model (DEM) data (USGS 2007). Landform is derived from the Land Facet tool using DEM data. This data layer classifies areas as ridgelines, plains, valleys, or slopes (USGS 2007).

Soil parent material is derived from statewide surficial geology data from the California Department of Conservation (2000). Soil texture comes from the U.S. Department of Agriculture (USDA) National Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) Database (USDA 2006).

## 3.2 Surficial Geology and Processes

This section describes the surficial geology of the Plan Area and the physical processes that govern soil transport, deposition, and formation. Desert soil conditions are a driving factor in the hydrology and the type and distribution of biotic resources, including plant and animal communities. Because desert ecosystems are water-limited and non-riparian vegetation communities get most of their water from moisture stored in the soil (Miller et al. 2009), the relationships between soil structure, soil hydrology, precipitation patterns, surface water, and groundwater therefore are critical for maintaining a healthy desert ecosystem. Soil structure reflects surficial geology, which refers to the unconsolidated geological surface materials that lie above bedrock. Surficial geology therefore is an important factor in soil hydrology and hence in the type and distribution of local desert vegetation communities and associated ecological processes, as discussed in detail in Section 3.3. Generally, soil structure strongly affects root distribution, which relates to aboveground plant size/biomass and productivity (Fenstermaker et al. 2009).

Table 3-1 summarizes the surficial geology of the Plan Area by parent material. Surficial geology of the Plan Area is also shown on Figure 3-1.

**Table 3-1**
**Surficial Geology in the Plan Area**

| **Parent Material**<br>Geologic Unit Name | **Acres**[1] |
|---|---|
| **Gabbroic** | **44,391** |
| Mesozoic gabbroic rocks | 44,391 |
| **Granitic** | **2,852,464** |
| Cenozoic (Tertiary) granitic rocks | 64,327 |
| Mesozoic granitic rocks | 2,493,229 |
| Paleozoic and Permo-Triassic granitic rocks | 1,438 |
| Precambrian granitic rocks | 197,953 |
| undated granitic rocks | 95,518 |
| **Granitic and Metamorphic** | **109,902** |
| Granitic and metamorphic rocks, undivided, of pre-Cenozoic age | 109,902 |
| **Igneous and Metamorphic** | **438,190** |
| Precambrian igneous and metamorphic rock complex | 438,190 |
| **Metavolcanic** | **368,782** |
| Mesozoic volcanic and metavolcanic rocks; Franciscan volcanic rocks | 134,662 |
| Paleozoic metavolcanic rocks | 221,906 |
| undivided pre-Cenozoic metavolcanic rocks | 12,214 |
| **Mixed Rock** | **189,630** |
| Miocene marine | 189,630 |
| **Sand Dune** | **707,177** |
| Extensive sand dune deposits | 707,177 |
| **Sedimentary** | **14,892,913** |
| Alluvium (mostly Holocene, some Pleistocene) Quaternary nonmarine and marine | 13,683,505 |
| Miocene marine | 71 |
| Miocene nonmarine | 150,323 |
| Oligocene nonmarine | 393 |
| Paleocene marine | 923 |
| Pliocene marine | 41,786 |
| Plio-Pleistocene nonmarine, Pliocene nonmarine | 709,471 |
| Selected large landslide deposits | 4,038 |
| Tertiary nonmarine, undivided | 302,403 |

**Table 3-1**
**Surficial Geology in the Plan Area**

| **Parent Material**<br>Geologic Unit Name | **Acres**[1] |
|---|---|
| **Sedimentary and Metasedimentary** | **1,147,417** |
| Carboniferous marine | 35,068 |
| Cretaceous marine undivided | 49,127 |
| Devonian marine | 19,885 |
| Jurassic marine | 1,021 |
| Limestone of probable Paleozoic or Mesozoic age | 18,750 |
| Paleozoic marine, undivided | 70,583 |
| Permian marine | 10,648 |
| Precambrian rocks, undivided | 806,446 |
| Schist of various types and ages (metasedimentary or metavolcanic | 89,226 |
| Silurian and/or Ordovician marine | 42,924 |
| Triassic marine | 3,739 |
| **Volcanic** | **1,621,158** |
| Quaternary volcanic flow rocks | 143,166 |
| Quaternary pyroclastic rocks and volcanic mudflow deposits | 21 |
| Recent (Holocene) pyroclastic rocks & volcanic mudflow deposits | 2,019 |
| Recent (Holocene) volcanic flow rocks | 58,233 |
| Tertiary intrusive rocks | 123,969 |
| Tertiary pyroclastic rocks And volcanic mudflow deposits | 204,671 |
| Tertiary volcanic flow rocks | 1,089,079 |
| **Water** | **214,978** |
| Water | 214,978 |
| **Grand Total** | **22,587,002** |

**Source**: California Department of Conservation 2010.
[1] Numbers may not total precisely due to rounding.

The majority of the Plan Area is composed of alluvium, which is unconsolidated sediment deposited by streams. Alluvium comprises 61% of the Plan Area. Alluvium is more common in the desert regions of the Plan Area. In the more mountainous areas, alluvium makes up a relatively small portion of the Plan Area.

The other most common surficial geological components in the Mojave Desert are granite substrates (coarse-grained intrusive rock consisting mainly of light silicate minerals), which make up 13% of the area, and volcanic/metavolcanic rocks, which make up 9% of the area. There are still several relatively young (i.e., within the last million years) volcanic

features in the Mojave and Sonoran deserts, including the Cima, Amboy-Pigash, and Turtle Mountain features in San Bernardino County, Pinto Basin-Salton Creek in Riverside County, and Obsidian Buttes in Imperial County, as well as several smaller miscellaneous volcanic features in San Bernardino, Inyo, and Imperial counties (Harden 2004). Sand dune and marine and marine depositions make up relatively small portions of the Plan Area, but still account for substantial acreages in the Mojave and Colorado/Sonoran deserts. Sand dune deposits comprise about 2% (306,542 acres) of the Mojave Desert and about 7% (399,825 acres) of the Colorado/Sonoran Desert. About 807 acres of sand dunes occur east of Sierra Nevada. Marine deposits are a relatively small portion of the Plan Area, comprising just over 7% of the Mojave Desert and about 4% to 5% of the Colorado/Sonoran Desert (including the Salton Sea). Mapped sand dunes and sand resources in the Plan Area cover approximately 1,780,794 acres of the Plan Area based on natural community mapping, surficial geology data, and dune complex mapping (California Department of Conservation 2000; Dean 1978; CDFG 2012d).

Miller et al. (2009) identify three fundamental geomorphic processes that shape the surficial geology of desert systems and transportation and deposition of substrates: (1) aeolian (wind transported); (2) fluvial, alluvial, and lacustrine (water-transported); and (3) mass-wasting (gravity-transported). Miller et al. (2009) outlined the relationship between substrate deposit types and depositional process: alluvial fans are formed through fluvial and debris flow processes; aeolian dunes and sheets are formed through aeolian processes; playas and axial valley washes are formed through fluvial, lacustrine, and aeolian processes; hillslope materials are formed through mass-wasting; and wetland deposits are formed through fluvial and aeolian processes. Surficial deposits vary on several factors related to these depositional processes, including particle size, cohesiveness, bulk density, lateral and vertical heterogeneity, and degree of sorting (Miller et al. 2009). These geomorphic processes are common to both the Mojave Desert and Colorado/Sonoran Desert ecoregions of the Plan Area.

### 3.2.1 Aeolian Processes

Wind systems are particularly important in arid and semiarid environments where sparse vegetation enables wind energy to more directly affect the soil surface (Breshears et al. 2003). The deposition of aeolian sediments is one of the major processes that shape the desert landscape, including desert pavement and dune systems (BLM 2002a; Miller et al. 2009), and therefore is discussed here as well as Section 3.3.2.

Aeolian systems are determined by the interactions of three main factors: sediment supply, sediment availability (i.e., its ability to be transported by the wind), and the transport capacity of the wind (Kocurek and Lancaster 1999). Miller et al. (2009) describe aeolian-

driven soil formation, or pedogenesis, as a process that "proceeds by progressive infiltration of fine-grained aeolian materials (dust), chemical deposition, and weathering within sediment deposits…" (p. 232). This process results in a soil layering or "horizonization" that strongly affects soil permeability and moisture-holding capacity and becomes more pronounced over time. Aeolian processes facilitate the formation of desert pavements, which are closely packed rock surface substrates created through wind and water erosion that generally have very low permeability and moisture available to plants (Miller et al. 2009). Increased runoff from these soils can also promote erosion and the development of surface drainages and dissection of the soil deposits (Miller et al. 2009).

Sand dune systems form where winds are consistently strong enough to lift and carry fine sand grains and where there is little or no vegetation that serves to stabilize the soil (Harden 2004). Sandy alluvium in dry washes and alluvial fans are the sources for these materials and strong winds generally blowing east to west transport the sands to areas where the winds decrease at the mountain front and deposit the sand (Harden 2004). The Algodones Dunes in the Colorado/Sonoran Desert of the southeastern area of the Plan Area, for example, formed from the sandy delta of the Colorado River and currently extend about 43 miles from the southwest portion of the Salton Sea to the Mexican border and reach heights of over 300 feet.

### 3.2.2 Fluvial, Alluvial, and Lacustrine Processes

As described previously, the majority of the surficial geology of the Mojave and Colorado/Sonoran deserts and east of Sierra Nevada is alluvium that has resulted from fluvial processes and over geological time scales that deposit materials (i.e., alluviation) from the mountains to the alluvial fans at the base of the mountains. Desert fluvial processes generally relate to the drainage system of slopes and channels. Although these processes are generally considered to occur over long periods of time, severe flooding events related to thunderstorms can cause alluvial fan flash flooding and large debris flows that can alter the landscape over very short time periods. Generally, the size of an alluvial fan is proportional to the size of the drainage network for the fan (Harden 2004).

Lacustrine processes are most prominent in desert dry lakes or playas, which generally are low spots in drainage basins that capture sediments and surface water, and which also may be influenced by groundwater; technically such areas are base-level plains in desert drainage basins (Cooke and Warren 1973) (see hydrology discussion in Section 2.1.4). Several prominent playas in the Plan Area are listed in Section 2.1.3 and playas are also discussed in Section 2.1.4 in context of hydrology. Playas are characterized by large flat areas dominated by fine-grained sediments. Due to the fine-grained sediments, playas are relatively impermeable. Surface water is removed by infiltration and evaporation and groundwater is removed by

evaporation and evapotranspiration (evaporation and transpiration by vegetation). During wet periods, surface water may accumulate, facilitating lacustrine sedimentation. Overall, the hydrologic characteristics of a playa are affected by climate, basin floor conditions, soil and vegetation, and water salinity (which affects evaporation rates).

### 3.2.3 Mass-Wasting Processes

Mass wasting refers to the downslope movement of rock, regolith (rock and mineral fragments), and soil under the direct influence of gravity (Lutgens and Tarbuck 1992). Mass wasting processes include creep, slides, and debris flows. Slides are sudden downslope movements of rocks and sediments. Debris flows are dense, fluid mixtures of rock, sediments, and water. Mass wasting in the many major and smaller mountain ranges in the Plan Area occurs primarily as rock falls and rock slides on the steeper slopes. Intense monsoonal rains and earthquakes are likely primary causes of rockfalls and rockslides on steep, mountain slopes in the Plan Area. Creep, on the other hand, is a slow, continuous downslope movement primarily related to freeze/thaw or wet/dry cycles (Lutgens and Tarbuck 1992; California Department of Conservation 2007).

## 3.3 Ecological Processes

Sections 2.1 and 3.2 described the existing physical setting of the Plan Area and the physical processes that shape the landscape, including climate, the overall geomorphology of the Plan Area (i.e., mountain ranges, plateaus, valleys, and basins) and the main geomorphic processes affecting surficial geology and hydrology (i.e., aeolian, fluvial, alluvial, lacustrine, and mass wasting). The physical setting and processes influence the existing biological/ecological setting through the ecological processes described in this section. The ecological processes and factors that influence these processes are environmental gradients, substrates, soil biota, carbon and nutrient cycling, and fire. Other ecological processes that are not specifically addressed in this section include population dynamics, structural complexity, evolution, and ecological succession.

### 3.3.1 Environmental Gradients

Generally, the vegetation types and patterns in the desert regions are directly related to these physical features and processes, which create the various environmental gradients in the Plan Area. A discussion of the natural communities and vegetation types in the Plan Area is provided in Section 4. An environmental gradient is a spatial shift in physical and ecological parameters across a landscape, such as changes in topography, climate, land cover types, or natural communities. Environmental gradients are influenced by factors such as temperature, precipitation, wind, and solar exposure that vary with physical factors

such as elevation, latitude, slope, and aspect. For example, the hotter, drier, and flatter desert lowlands are associated with relatively low plant species richness and diversity and are dominated by low, shrubby species such as creosote (*Larrea tridentata*) and burro-weed (*Ambrosia dumosa*) (Baldwin et al. 2002). As elevation and precipitation increases, vegetation communities include more woody species, such as Joshua tree (*Yucca brevifolia*) and conifers such as pinyon pines (*Pinus* spp.) and junipers (*Juniperus* spp.). The composition of desert vegetation also varies with seasonal precipitation patterns. Most herbaceous annuals germinate and bloom in association with winter rains, but some species respond to ephemeral summer rains (Baldwin et al. 2002). Insolation is defined as incident solar radiation and corresponds to the amount of solar resource available per unit area. It is usually expressed as kilowatt-hours per square foot per day (kwhrs/ft$^2$-day) and can be summed over an area to give an estimate of the gross energy potential in that area. The Plan Area has very high insolation values ranging from between 7 and 7.5 kilowatt-hours per square meters per day (kwhrs/m$^2$-day) (CEC 2005).

As described in Section 2.1.5, the Plan Area ranges in elevation from below sea level to approximately 8,700 feet above MSL (Figure 3-2). The majority of the site is at the middle elevation range of approximately 1,500 to 3,500 feet above MSL. A large portion of the Plan Area is relatively flat as opposed to moderately sloped or steep. The Plan Area supports a relatively even distribution of aspects, but notably proportionally very little (1%) of the Plan Area is entirely "flat" (i.e., without aspect).

### 3.3.2 Substrates

Substrate is also an important factor in local desert vegetation communities and normal soil hydrology, and this factor is critical for maintaining and restoring native communities. Generally, soil structure strongly affects root distribution, which relates to aboveground plant size/biomass and productivity (Fenstermaker et al. 2009). Because desert ecosystems are water-limited, the relationship between precipitation patterns, soil structure, and soil hydrology therefore is critical for maintaining a healthy desert ecosystem. The surficial geology and processes associated with ecological processes in substrates are described in Section 3.2. Key factors in how substrates influence ecological processes include:

- Water infiltration into the upper soil horizon;
- Water storage capacity of lower soil horizons;
- Nutrient availability for plants; and
- Direct effects of aeolian sand deposition on plants and animals.

Several different soil surface textures occur in the Plan Area. The acreage of each soil texture type is listed in Table 3-2. Very gravelly sandy loam (soil composed of sand, silt, and clay), unweathered bedrock, and loamy sand are the most common soil textures in the Plan Area. Figure 3-3 depicts the distribution of the various soil textures in the Plan Area.

**Table 3-2**
**Soil Textures Mapped in the Plan Area**

| Soil Texture | Acres[1] |
|---|---|
| clay | 301,069 |
| clay loam | 64,590 |
| coarse sand | 6,372 |
| coarse sandy loam | 870,715 |
| cobbly fine sandy loam | 86,511 |
| cobbly sand | 59,858 |
| extremely gravelly sandy loam | 1,605,679 |
| fine sand | 831,201 |
| fine sandy loam | 479,338 |
| gravelly loam | 9,977 |
| gravelly loamy coarse sand | 195,042 |
| gravelly sand | 47,049 |
| gravelly sandy loam | 113,681 |
| loam | 16,910 |
| loamy fine sand | 732,231 |
| loamy sand | 4,533,157 |
| sand | 1,160,311 |
| sandy loam | 1,051,236 |
| silt loam | 1,727 |
| silty clay | 223,372 |
| silty clay loam | 691,959 |
| unweathered bedrock | 4,189,988 |
| very channery loam | 21,790 |
| very cobbly fine sandy loam | 5,064 |
| very cobbly loamy sand | 38,886 |
| very cobbly sandy loam | 7,297 |
| very fine sandy loam | 210,943 |
| very gravelly coarse sand | 388,477 |
| very gravelly fine sandy loam | 38,879 |
| very gravelly loam | 51 |
| very gravelly loamy fine sand | 12,591 |

**Table 3-2**
**Soil Textures Mapped in the Plan Area**

| Soil Texture | Acres[1] |
|---|---|
| very gravelly loamy sand | 347,300 |
| very gravelly sandy loam | 3,231,473 |
| very gravelly silt loam | 455 |
| weathered bedrock | 822,033 |
| *Not Mapped* | 187,800 |
| **Total** | **22,585,015** |

**Source**: USDA 2006.
[1] Numbers may not total precisely due to rounding.

Substrate is also an important factor in local desert vegetation communities and normal soil hydrology, and this factor is critical for maintaining and restoring native communities. Generally, soil structure strongly affects root distribution, which relates to aboveground plant size/biomass and productivity (Fenstermaker et al. 2009). Because desert ecosystems are water-limited, the relationship between precipitation patterns, soil structure, and soil hydrology therefore is critical for maintaining a healthy desert ecosystem.

Baldwin et al. (2002) summarize the general relationships between vegetation communities and general substrate types. Lower elevation bedrock substrates, for example, support plant species such as brickellbush (*Brickellia arguta*), brittlebush (*Encelia farinosa*), hedgehog cactus (*Echinocereus engelmannii*), and arrow-leaf (*Pleurocoronis pluriseta*). Washes support more deep-rooted shrubs that are tolerant of flash-floods, including catclaw (*Senegalia greggii*), desert-willow (*Chilopsis linearis*), white burrobrush (*Ambrosia salsola*), mesquite (*Prosopis glandulosa*), palo verde (*Cercidium* spp.), ironwood (*Olneya tesota*), and smoke tree (*Psorothamnus spinosus*). Playas, salt flat, and basins where water collects may support highly alkaline or saline conditions that are unsuitable for plant growth, but the margins of these features support tolerant plants such as saltbushes (*Atriplex* spp.) and greasewood (*Sarcobatus vermiculatus*).

A critical feature of soil hydrology is the infiltrability of the soil, which is the maximum rate water can infiltrate a given soil under atmospheric conditions (Miller et al. 2009). Sand deposition increases water infiltration, dilutes soil nutrient concentrations, reduces soil surface stability, and restricts the soils' water- and nutrient-holding capacity (Belnap et al. 2008). However, infiltration generally decreases with the increasing age of a soil deposit and degree of soil development. As described in Section 3.2.1, an important characteristic of desert substrates is the formation of desert pavement and accumulation of desert varnish on alluvial piedmonts (i.e., the areas lying at the base of mountains), which occurs progressively over a long time period as the soil is stabilized (i.e., the process of pedogenesis).

Horizonization, which becomes more pronounced with age, strongly affects soil permeability and moisture-holding capacity. The collection of silt and sand in the Av horizon (a distinct, fine-grained soil horizon that forms the topmost mineral layer of soil and has many vesicles or large pores throughout) through aeolian processes, for example, facilitates the formation of desert pavement, which generally has very low permeability (as little as 1%) and moisture available to plants (Miller et al. 2009). The decreased infiltration in older deposits is also related to higher runoff rates, which causes erosion and the formation of surface drainages and deposit dissection (Miller et al. 2009). Generally, in the Eastern Mojave, perennial plant cover decreases with the age of the deposit and formation of desert pavement and varnish (Miller et al. 2009).

While development of the Av horizon can decrease infiltration of the water, development of the underlying B horizon (i.e., subsoil) can also strongly affect soil hydrology. The accumulation of loam, sandy clay loam, and clay loam in the B horizon enhances soil structure and the number of micropores, which increases the retention and water storage capacity of the soil (Belnap et al. 2008; Miller et al. 2009). The finer soils have lower permeability and bind water more tightly to soil particles by capillary force (Miller et al. 2009).

In addition to available moisture related to soils structure, plant species composition is also influenced by the nutrient-rich deposition of fine silt and clay particles that alter soil fertility (Belnap et al. 2008). Aeolian dust contributes to the formation of soils and supplies sediments with essential nutrients, including the following elements: phosphorus, magnesium, sodium, potassium, molybdenum, and calcium (Reynolds et al. 2001).

In addition to aeolian-related soil and vegetation interactions that occur over long time periods of soil development, aeolian processes can have more direct and immediate physical impacts on the ecosystem. Sand deposition that can occur during a single wind event can cause either complete or partial plant burial. Airborne dust that collects and accumulates on leaves and stems of desert plants can cause a reduction in physiological performance that may eventually reduce plant growth and seedling establishment (Belnap et al. 2008). Sand inputs can also affect, either negatively or positively, animal species' ability to burrow into the soil (Belnap et al. 2008). Consequently, areas with active aeolian systems, such as sand dunes, generally include plant and animal species able to adapt to rapid changes in substrate (Belnap et al. 2008).

Although plant and animal community types and distributions are strongly determined by the physical processes discussed above, plant and animals also exert an influence on soil development, structure and hydrologic and chemical properties such as infiltrability, organic material, and chemical nutrients through bioturbation (i.e., the mixing of sediment by the burrowing, feeding, or other activity of living organisms). Bioturbations may occur from

plant rooting and burrowing by insects, rodents, and reptiles. Titus et al. (2002), for example, found that microsites with perennial shrubs in a creosote–burro-weed community in the Mojave Desert and small mammal burrows had higher levels of nutrients, and non-vegetated sites (washes, plant interspaces) had very low levels of nitrogen and phosphorus.

### 3.3.3 Soil Biota

Soil biota is another important factor in desert ecosystem processes (Belnap et al. 2008). Soil surface biota or biological soil crusts are related to soil stabilization, nutrient cycling, and local hydrology. Biological soils crusts in the Mojave Desert consist primarily of cyanobacteria, which cover most soil surfaces, and soil surfaces at higher elevations also support lichens and mosses (Belnap et al. 2008). Biological soil crusts serve important soil stabilization functions that influence biological resources, including aggregating soil particles and reducing their susceptibility to wind and water erosion; roughing the soil surface, which traps dust and increases capture of mineral nutrients; and enhancing retention of wind- and waterborne organic material and seeds (Belnap et al. 2008). Subsurface soil biota include bacteria, fungi, protozoa, nematodes, and microarthropods (Belnap et al. 2008). An important function of subsurface biota is the breakdown of plant litter and roots, which makes the nutrients of these materials available to other plant and animal organisms (Belnap et al. 2008).

### 3.3.4 Carbon and Nutrient Cycling

Carbon and nutrients cycling are important factors in desert ecosystems. Carbon cycling in desert systems occurs from dead plant material, with aboveground decomposition likely occurring from abiotic process (e.g., release of gas when soils are wetted) and belowground decomposition occurring from the biotic process of respiration by plant roots and soil organisms (Belnap et al. 2008). Biological crusts can be significant sources of carbon in arid and semi-arid environments, especially in areas between vascular plant species where biological soil crusts can reach 100% cover. In addition, soil organisms, which are sources of carbon for other organisms, are relatively more diverse and abundant in soils with a biological soil than soils without a biological crust.

Nitrogen is made available to plants in the Mojave Desert mainly by prokaryotes (organisms lacking a discrete nucleus separated from the cytoplasm), dominated by the cyanobacterium *Nostoc* (Belnap et al. 2008). Nitrogen fixation is controlled by moisture and temperature in association with physiological activity by the cyanobacterium (Belnap et al. 2008).

Phosphorus, which can be a vegetation-limiting nutrient in deserts, is made available by the weathering of primary material such as apatite (Belnap et al. 2008). Generally, phosphorus is

unavailable for uptake by soil biota and plants because of its relative insolubility (due to its reaction with carbonates, iron oxide, and other compounds), but exudates (fluid that filters from the circulatory system) of cyanobacteria, bacteria, fungi, and plant roots can increase phosphorus availability and uptake by dissolving these compounds (Belnap et al. 2008).

Other important nutrients affecting plant productivity include potassium; calcium; magnesium; sodium; and micronutrients, including copper, iron, zinc, and manganese.

Potassium, which is essential for plants, is fairly evenly distributed throughout the soil profile in desert regions (Belnap et al. 2008). Too much calcium can limit plant growth by forming calcium carbonate to the depth of water infiltration (e.g., in playas) and creating a solid layer of calcrete (or caliche, a calcium-rich hardpan) that inhibits plant roots and water flow (Belnap et al. 2008). Too much calcium can also inhibit the bio-availability of other important nutrients such as phosphorus, magnesium, and micronutrients by reducing their solubility. Magnesium, which can be depleted fairly rapidly from soils, interacts strongly with other cations such as potassium and sodium and plant productivity can be affected by the ratio of magnesium to other cations (positively charged ions) (Belnap et al. 2008). Sodium is beneficial to plant productivity in small amounts, but because it is the most easily leached cation and forms alkaline crusts on the surface, many desert plants have adaptive mechanisms for managing high sodium levels (Belnap et al. 2008).

The micronutrients of copper, iron, zinc, and manganese are also important to plant productivity, but typically have low biologically available concentrations in the Mojave Desert and also react with carbonate compounds that result in low solubility and bio-availability (Belnap et al. 2008).

### 3.3.5 Fire

Fire has been historically infrequent in the southwestern deserts but has increased in frequency and extent in recent decades, generally as a result of increased fuel provided by the invasion of non-native annual grasses, such as red brome (*Bromus rubens*) and buffelgrass (*Pennisetum ciliare*) (Brooks and Matchett 2006; Abella 2010). Most of the fires recorded from 1911 to 2009 within the Plan Area occurred along its western boundary (CAL FIRE 2009). It has been estimated that between 1980 and 1990, about 38 square kilometers (9,390 acres) of the Mojave Desert burned every year (Pavlik 2008). Brooks and Minnich (2007) indicate that between 1980 and 2001, the Mojave Desert had an annual fire frequency of 2.1 fires per 1,000 square kilometers, the Sonoran Desert had an annual fire frequency of 0.6 fires per 1,000 square kilomenters, and the Colorado Desert had an annual fire frequency of 2.2 fires per 1,000 square kilometers. Within the Plan Area, the largest

acreages burned in the years 1999, 2005, 2006, and 2007 (CAL FIRE 2009), indicating a trend of increased fire sizes/frequency.

Non-native plant invasions may alter the fire regime by changing the frequency, intensity, extent, type, or seasonality of fire (Brooks and Matchett 2006). Repeated fires are typically followed by dominance of bromes (*Bromus* spp., red brome in particular) capable of carrying fire again soon after burning. This can result in a repeated invasive plant/fire regime where increased fire frequency and conversion of native vegetation communities to invaded landscapes develops into a positive feedback loop, setting the stage for even more frequent, intense widespread fires and increased conversion of the native landscape (Brooks and Matchett 2006).

Increased fire in the desert ecosystem has severe consequences because the plant communities and desert species were not exposed to frequent and large-scale fires during their evolutionary history and thus are not fire adapted, as are some other communities such as chaparral (Pavlik 2008). These changes are most evident in the middle elevation shrublands dominated by creosote bush, Joshua tree, and blackbrush (*Coleogyne ramosissima*). Creosote bush, for example, does not stump-sprout like some chaparral species (Pavlik 2008). Fire has also decimated large numbers of Joshua trees in areas of Joshua Tree National Park. Fire readily kills Joshua trees and they rarely resprout. In addition, Joshua trees often require protection in the form of shading by existing vegetation or nurse plants for reproduction, making regeneration of new individuals slow since it takes time for the nurse plants to become established following fire (Abella 2010).

Some desert wildlife species, such as Agassizi's desert tortoise (*Gopherus agassizii*), are also especially vulnerable to fire because they do not have behavioral avoidance responses to severe events (e.g., deep burrow systems and quick escape). On the other hand, the effects of fire may be beneficial in certain cases. Early successional communities may provide habitat favorable for some wildlife species, such as Merriam's kangaroo rat (*Dipodomys merriami*), which forages in open areas. Studies have shown increased abundance of this species after a fire in Sonoran Desert upland habitat (Abella 2010).

Compared to other areas of the Mojave Desert, the middle elevation shrublands are more susceptible to increased fire size following years of high rainfall, which causes an increase in the biomass of non-native annual grasses, especially red brome, that produce continuous fuel-beds. Further, native desert annuals do not typically flourish following fire (i.e., they are not "fire-followers"). At lower elevations, the background cover of native perennial fuels is already very low, which lessens the impact of the ephemeral fuels. At higher elevations, native woody fuels dictate fire regimes so fire size does not vary so much with rainfall (Brooks and Matchett 2006).

Fire functions differently than other forms of disturbance in the desert. Abella (2010) found in the Mojave and Sonoran deserts that perennial cover generally rebounded faster after fire compared to land-clearing disturbances in addition to differences in post-disturbance species composition. Although fire affects soil's physical and chemical properties, soils may still remain more intact following fire compared to land-clearing disturbances in which soils are removed or heavily compacted. In addition, roots and seeds are not necessarily entirely removed by fire, but are often removed after land-clearing disturbances. Thus, the residual propagules may enhance plant reestablishment after fire relative to establishment following other types of disturbance (Abella 2010). However, fires can sterilize soils by killing mycorrhizal fungi (Pavlik 2008).

## 3.4 Landscape Habitat Linkages and Wildlife Corridors

Natural environments are typically heterogeneous and form a mosaic across a landscape. Terrestrial wildlife species typically occupy favorable patches within a landscape matrix and may move between these patches through less favorable habitats. However, terrestrial wildlife species are more likely to follow pathways between habitat patches that contain elements of their preferred habitat (Rosenberg et al. 1997). Disjunct habitat patches that are used by terrestrial wildlife to negotiate through landscape mosaics have been likened to "stepping-stones," and some researchers (e.g., Bennett 2003) have suggested that in some cases and for some species, stepping-stone habitat is as effective as continuous corridors.

There is a distinction between short-term individual movements, such as foraging within an organism's home range, long-term dispersal (one-time emigration and immigration events between populations), and migration (seasonal or periodic movements). Corridors and habitat linkages may allow for both long- or short-term movements, dispersal, and migration depending on the life history requirements and ability of a particular species to travel through a landscape. Wildlife movement and population connectivity also may be examined at three spatial scales: (1) landscape habitat linkages, (2) wildlife corridors, and (3) wildlife crossings.

Landscape habitat linkages (or simply "linkages") are large open space areas on a landscape scale that contain natural habitat and provide a connection between at least two larger adjacent open spaces or habitat areas. Linkages are defined as providing a large enough area to at least support a natural habitat mosaic and viable populations of smaller terrestrial species, such as rodents, smaller carnivores (e.g., raccoons [*Procyon lotor*], skunks, fox, and weasels [*Mustela* spp.]), passerine birds, amphibians, reptiles, and invertebrates and allowing for gene flow through diffusion of populations over a period of generations, as well as allowing for jump dispersal for some species between neighboring

habitats. Linkages can form large tracts of natural open space and serve both as "live-in" or "resident" habitat and as connections to the larger landscape (e.g., large core habitat areas).

Wildlife corridors are linear landscape elements that provide for species movement and dispersal between two or more habitats, but do not necessarily contain sufficient habitat for all life history requirements of a species, particularly reproduction (Rosenberg et al. 1995, 1997). For this reason, while corridors may provide for dispersal of most species, they may not provide for the diffusion of populations over a longer time scale. The main prerequisite for corridors is that they increase animal movement between habitat patches. The mechanisms related to the efficacy of corridors are varied and species-specific (Soulé and Gilpin 1991; Beier and Loe 1992; Rosenberg et al. 1995; Haddad and Tewksbury 2005).

Wildlife crossings are locations where wildlife must pass through physically constrained environments (e.g., roads, development) during movement within home ranges or during dispersal or migration between core areas of suitable habitat. Such crossing can occur within a landscape habitat linkage or within a wildlife corridor. Development and roads may transect or interrupt an existing natural crossing, creating dangerous or impassable barriers that impede the natural movement of a species and possibly subject it to higher risks of injury and mortality from adverse human interactions, such as increased vehicle collisions at roadways where no safe wildlife passage is provided (Meese et al. 2007).

### 3.4.1 Data Sources and Methods

Potential landscape-level habitat linkages and wildlife movement corridors in the Plan Area have been identified in the California Desert Connectivity Project (Penrod et al. 2012), the California Essential Habitat Connectivity Project (Caltrans 2010), the South Coast Missing Linkages Project (Beier et al. 2006; South Coast Wildlands 2008), and A Linkage Design for the Joshua Tree–Twentynine Palms Connection (Penrod et al. 2008).

### 3.4.2 Description of Linkages and Corridors

***The California Desert Connectivity Project*** (Penrod et al. 2012) provides a comprehensive and detailed habitat connectivity analysis for the California deserts. The Connectivity Project included both least-cost corridor habitat permeability models for four focal species (American badger [*Taxidea taxus*], kit fox [*Vulpes macrotis*], bighorn sheep [*Ovis canadensis*], and Agassizi's desert tortoise) and identification of a Desert Linkage Network using "land facet" methods based on the approach described by Beier and Brost (2010). The land facet method is designed to identify "swaths" of habitat of fairly uniform physical conditions that will interact with uncertain climate changes to maintain habitat for species and species' movement (Penrod et al. 2012). Each identified linkage consists of a corridor for each land facet and a corridor for high diversity of land facets and should support movement of species associated with that facet

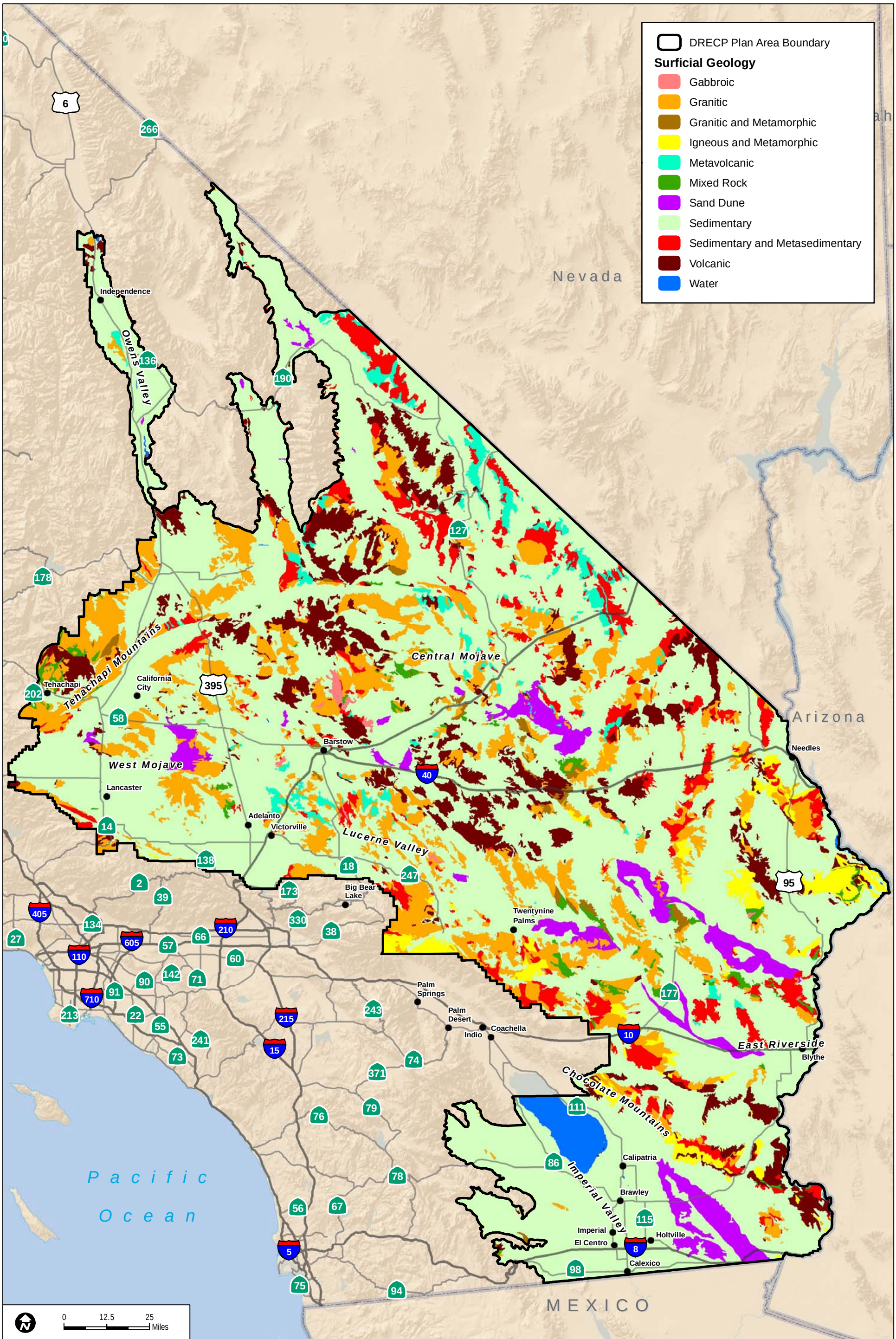
(Penrod et al. 2012). The Connectivity Project identified 23 "crucial" linkage planning areas within the Plan Area that are each defined by a pair of "landscape blocks" that should remain connected. The landscape blocks identified by Penrod et al. (2012) include Sierra Nevada, China Lake North Range, China Lake South Range, Kingston-Mesquite Mountains, Mojave National Preserve, Edwards Air Force Base, Twentynine Palms and Newberry-Rodman, San Gabriel and San Bernardino mountain ranges, Joshua Tree National Park, Stepladder-Turtle Mountains, Whipple Mountains, Palen-McCoy Mountains, Chocolate Mountains, East Mesa, and Picacho. Each of these landscape blocks is linked to another landscape block by one or more linkages that meet certain criteria defined by Penrod et al. (2012). Finally, Penrod et al. (2012) conducted habitat suitability, patch size, and configuration analyses for 44 focal species, including 12 mammals, 8 birds, 9 reptiles, 1 amphibian, 5 lepidoptera (insects), and 9 plants, to evaluate the configuration and extent of potentially suitable habitat in the linkage network. The reader is referred to Penrod et al. (2012) for a detailed discussion of the linkage network identified by the Connectivity Project.

***The California Essential Habitat Connectivity Project*** (CEHC) (Spencer et al. 2010) was coarser in scale than the Connectivity Project or South Coast Missing Linkages (SCML). The CEHC Project did not use focal species to identify areas needing connection; rather, it used indices of environmental integrity and other biological inputs to identify large "Natural Landscape Blocks" and "Essential Connectivity Areas" throughout California. These are particularly useful in identifying important areas to conserve outside of conservation priority areas not already conserved or mapped by other efforts.

***The SCML Project*** (Beier et al. 2006; South Coast Wildlands 2008) preceded the Connectivity Project (Penrod et al. 2012), which expanded the geographic area from California's South Coast Ecoregion across California's deserts, as discussed above. The SCML Project developed several linkage designs that connected portions of the South Coast Ecoregion with the Mojave and Sonoran deserts, and thus several linkage designs prepared for SCML are partly within the Plan Area and should be incorporated. The Connectivity Project was designed to be complementary to SCML, using similar analytical tools, and the SCML information was incorporated into Penrod et al. (2012) and noted as a "previous linkage design."

***A Linkage Design for the Joshua Tree–Twentynine Palms Connection*** (Penrod et al. 2008) identified the Joshua Tree–Twentynine Palms Connection, which lies in an ecological transition zone between the Mojave and Sonoran deserts. This linkage connects Joshua Tree National Park with the Marine Corps Air Ground Combat Center (MCAGCC) at Twentynine Palms. As with the SCML information, this information was incorporated into Penrod et al. (2012) and noted as a previous linkage design.

Figure 3-4 shows identified habitat connectivity areas within the Plan Area based on these various projects.




Sources: CEC (2010), USGS (2010), ESRI (2010), CA Geological Survey (2011)

**FIGURE 3-1**

**Surficial Geology**

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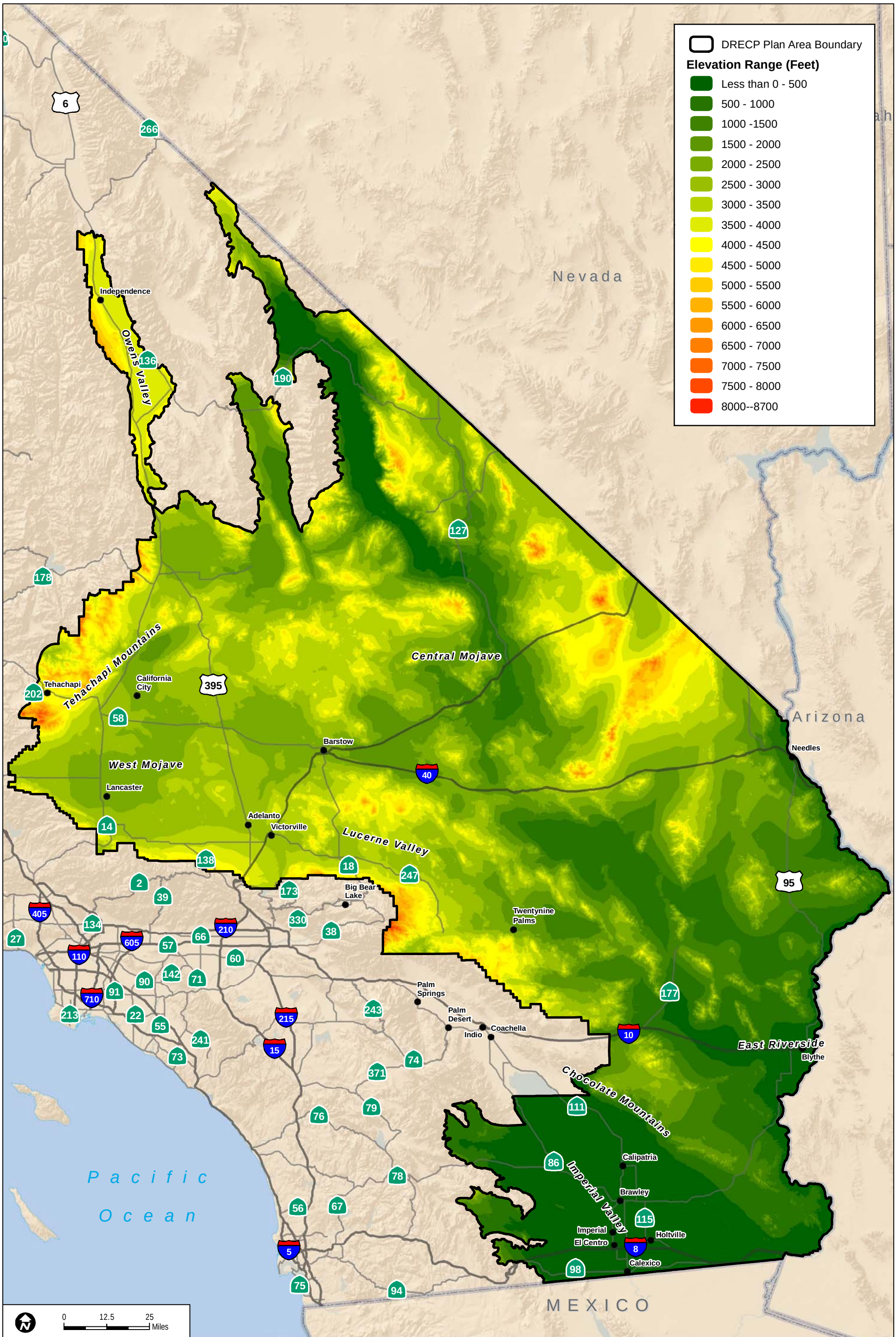


Sources: CEC (2010), USGS (2010), ESRI (2010), CA Geological Survey (2011)

**FIGURE 3-2**
**Topography**

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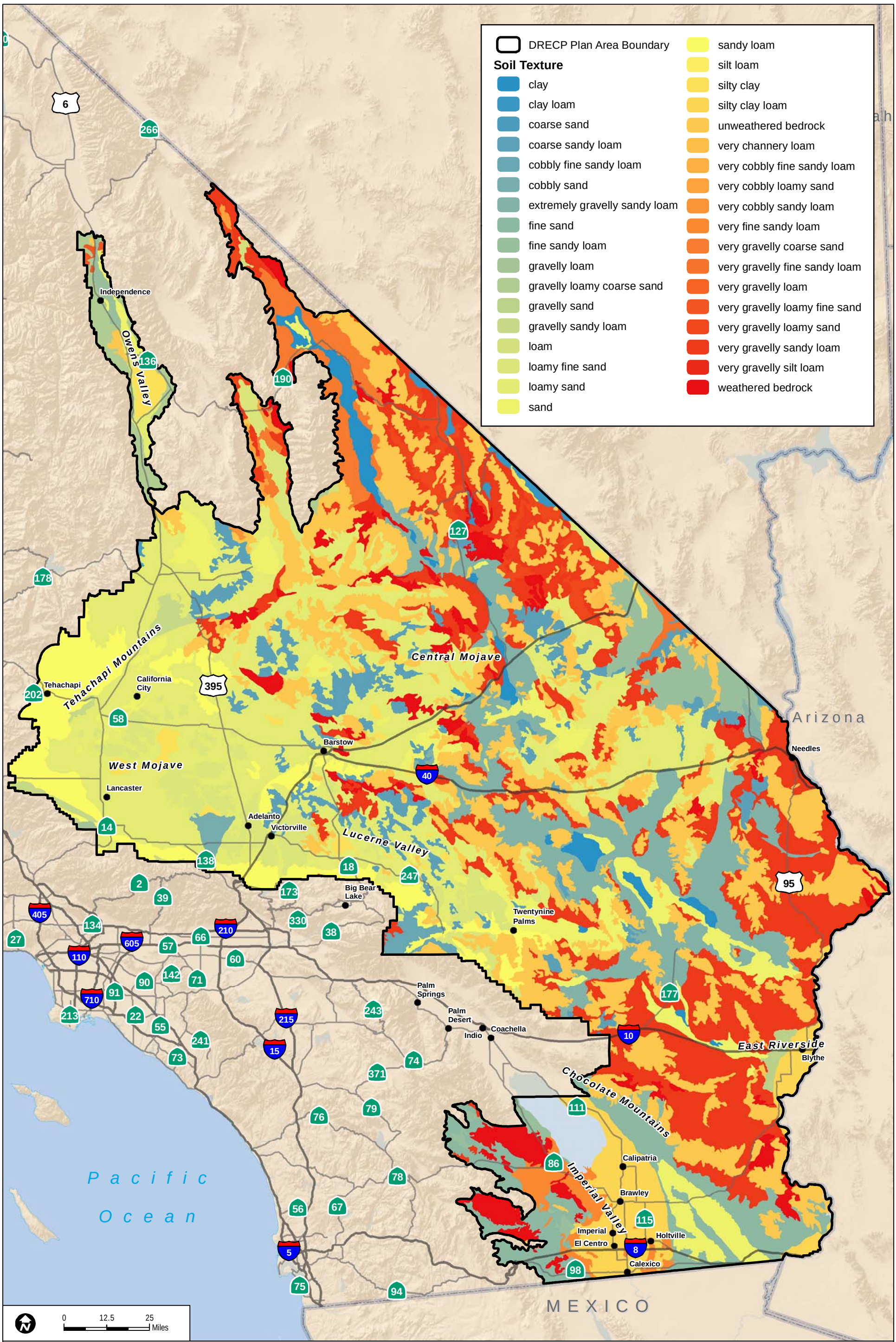


Sources: CEC (2010), USGS (2010), ESRI (2010), USDA (2008)

**FIGURE 3-3**

**Soil Textures**

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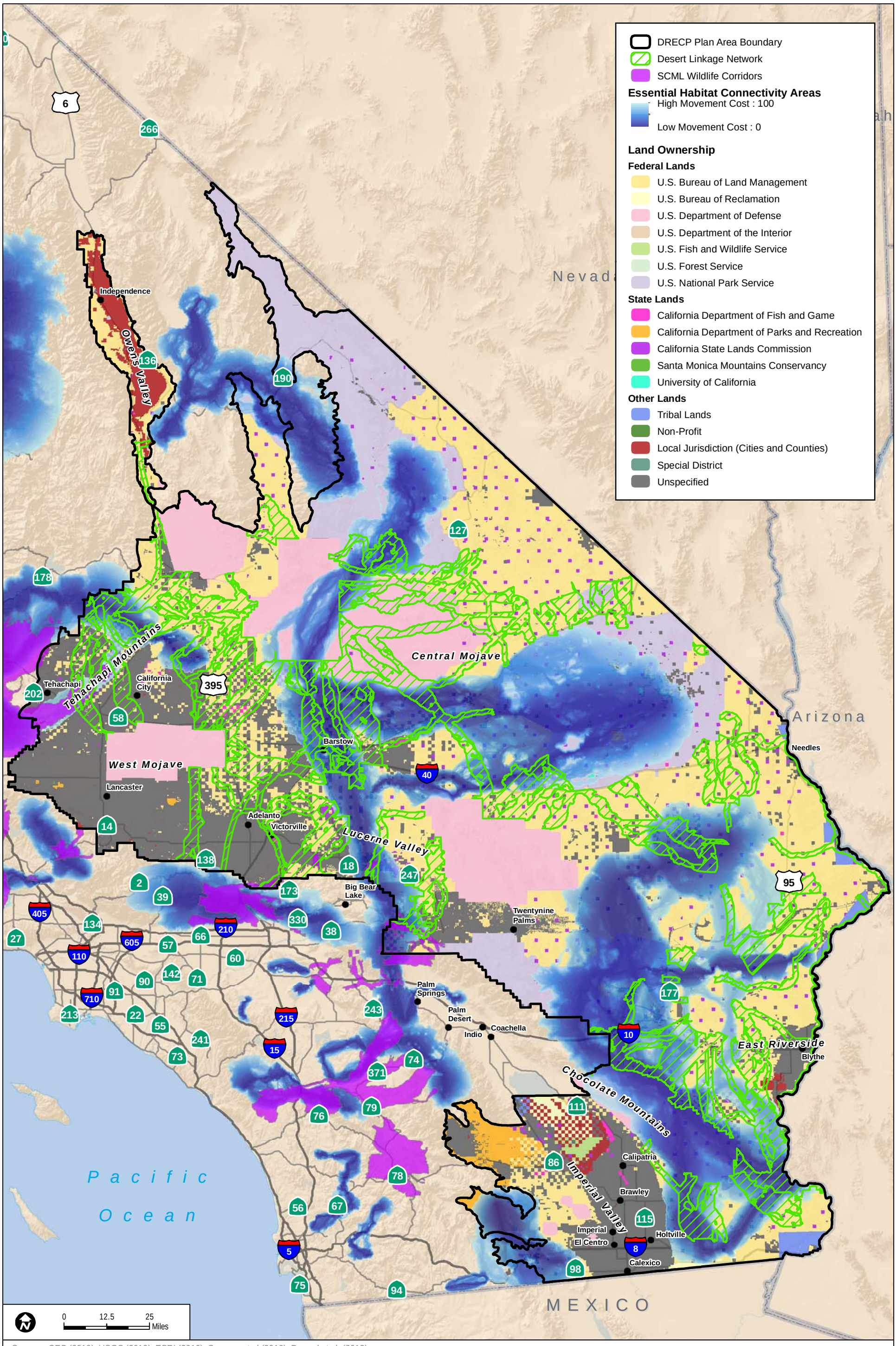


Sources: CEC (2010), USGS (2010), ESRI (2010); Spencer et al (2010); Penrod et al. (2012)

**FIGURE 3-4**

**Habitat Connectivity Areas**

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