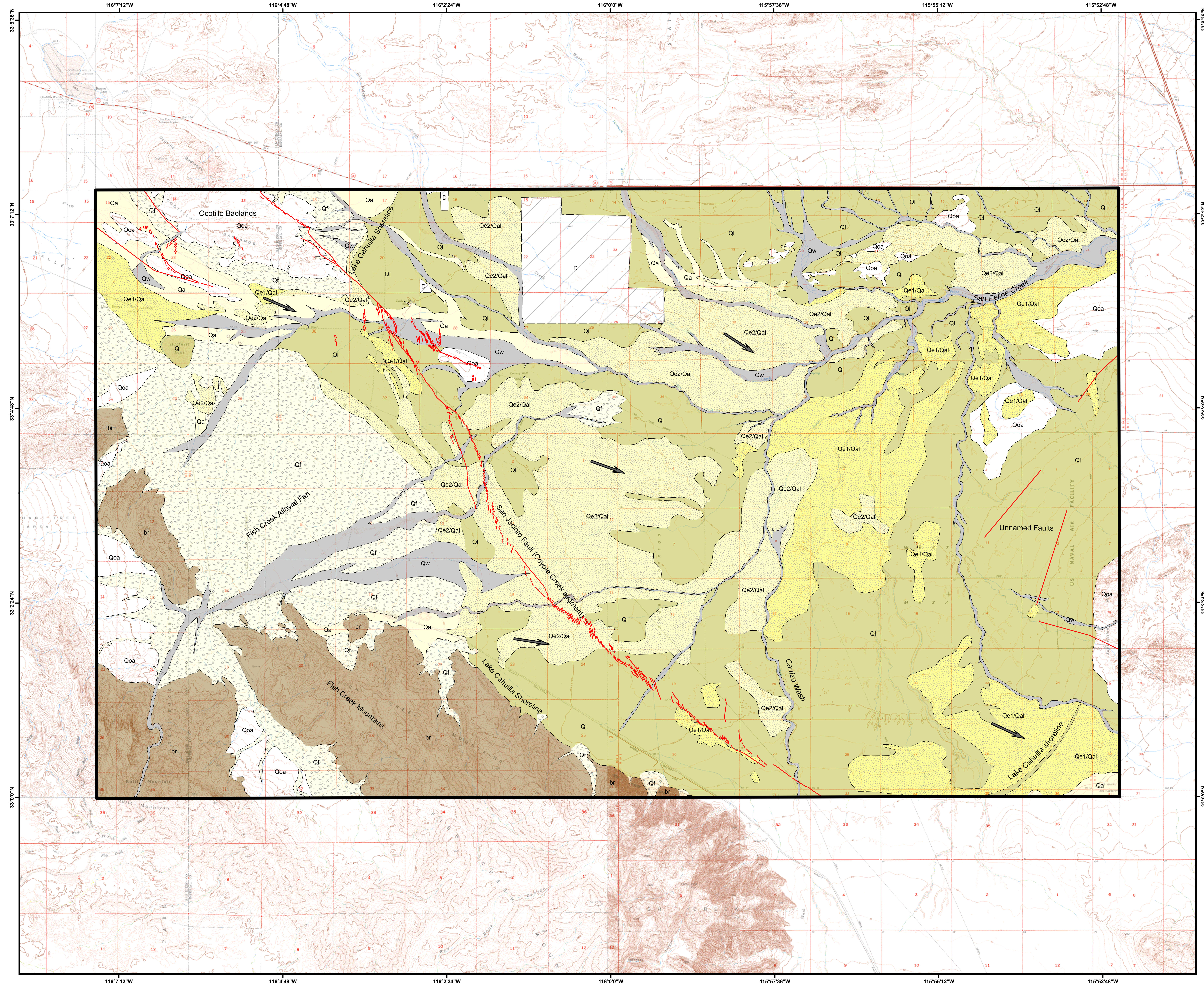
PLATE 3



PROJECT OVERVIEW

Eolian deposits are recognized as areas of higher biological value because they support specific natural communities and wildlife habitats. In response to potential increased land use from renewable energy projects in California where eolian deposits and processes are present, the California Department of Fish and Wildlife (CDFW) and the State and Federal Renewable Energy Action Team have designated sand dunes and their associated processes as areas of higher biological value for inclusion into a Habitat Conservation Plan / Natural Community Conservation Plan. This plan is known as the Desert Renewable Energy Conservation Plan (DRECP, http://www.drecp.org/). The Department of Conservation's California Geological Survey (CGS) provided CDFW with technical assistance on Eolian System Mapping under the Cooperative Endangered Species Conservation Fund (Section 6) Grant Program (Agreement Number P1382002). This project addresses the need for map-based information that identifies the presence of active eolian deposits and their source areas. The San Felipe Dunes area is one of several priority areas that are part of the DRECP, identified as Development Focus Areas.

This map of San Felipe Dunes was developed by CGS to assist in identifying components of the eolian system, including active areas of deposition, source areas, and zones of sand transport. This 48,000 scale map is based on new mapping by CGS of Quaternary age surficial deposits that form the interpretive source in the identification of eolian deposits, sources, and zones of transport for the San Felipe Creek study area. Depending on the geomorphic setting, eolian processes range from primary to secondary (Blair and McPherson, 1994). Within the regional zone of transport, eolian sand accumulates as dunes, sand sheets, and sand ramps. Eolian processes are primary where thick deposits accumulate, develop dune forms, and influence the geomorphology of the landscape. Where these eolian sand accumulations attain sufficient thickness (> 1.5 m) they are typically portrayed as eolian deposits on geologic maps. However, complex interactions occur locally on the landscape between source and deposition areas. Eolian sand is transported across playa lakes, playa fringe, alluvial fans, alluvial washes, and along bedrock divides. In these geomorphic settings, the primary processes acting on the landscape are gravity-driven flow of water and gravity-induced slope movements (e.g. translational failures and rockfalls). Along playa margins and piedmont landforms, transported eolian sediment interacts with vegetation and topographic irregularities that act as baffles, causing eolian sediment to deposit as thin sand sheets superimposed on these geomorphic surfaces. In the presence of vegetation, sand sheets are typically thin, relatively planar, and lack dune form (Cooke et al., 1993).

To address this complexity, CGS used a hybridized mapping nomenclature that identifies both the primary geomorphic process and the secondary processes superimposed on those features that are specific to eolian systems. Using an original surficial geologic nomenclature of Bedrossian et al. (2012), CGS developed a hybrid geologic nomenclature to identify the presence of eolian veneers. For example, an undifferentiated Quaternary alluvial fan (Qf) within an active eolian transport corridor, may be overlain by a veneer eolian sand. In order to represent the superimposition of this secondary process on the landscape, the map unit is termed Qe/Qal. Conversely, the designation Qe is used singularly when the map unit attained an estimated thickness of > 1.5 m. In addition to the hybridized mapping nomenclature, CGS used aerial photographic interpretation and field observations of deposit thickness, texture, and soil development in order to attribute map units with their relative state of activity. The relative state of activity is identified by observing the relative degree of soil development, including consolidation and pedogenic horizon development. Where eolian deposits have formed during past episodes of activity (late Quaternary), but have been stabilized by soil development, the land surface may have relatively lower reflectance, or albedo. Active eolian surfaces typically present features that suggest fresh scour of existing soil and vegetation, or deposition of eolian sand over pre-existing land cover. These surfaces have a relatively high albedo. In this map area, where observations suggested a period of stability, eolian deposits are designated as Qe1. Where observations suggest relatively recent activity, eolian deposits are designated as Qe2.

This map, along with others developed as part of this study to address eolian system processes, is regional in nature and should not be used as a substitute for detailed studies in any specific area. It is intended for regional planning efforts and may be used as the framework to identify regional eolian processes and to guide future studies. For additional discussion regarding San Felipe Creek study area and other mapped areas, please refer to the project report (Lancaster and Bedrossian, 2014).

San Felipe Dunes

The San Felipe Dunes study area is located on the western edge of the Imperial Valley and Colorado Desert geomorphic province, east of the Peninsular Ranges in San Diego and Imperial Counties. The Colorado Desert is a low lying barren desert basin dominated by the Salton Trough and Salton Sea (CGS, 2002). The area is characterized by isolated prehistoric shorelines and lake deposits from the ancient Lake Cahuilla generally found at elevations of about +12-14 m above sea level (Waters, 1993). The study area is bounded by a series of hills to the west and south. The Ocotillo Badlands occur in the northwest part of the field area and are a series of low barren hills largely devoid of vegetation and dissected by numerous alluvial washes and gullies. The Superstition Hills in the southeast of the study area have a similar appearance. To the southwest are the Fish Creek Mountains which rise abruptly from the valley and reach an elevation of over 700 m. The Coyote Creek segment of the San Jacinto Fault Zone trends northwest to southeast through Lower Borrego Valley and San Felipe Dunes area (Bryant, 2005) and was the source for the 1968 M6.6 Borrego Mountain earthquake and 1987 M6.6 Superstition Hills and M6.2 Elmore Ranch earthquakes. Mesozoic and older age rocks composed of granite, quartz diorite, and gneiss make up most of Fish Creek Mountains to the west of the study area (Dibblee and Minch, 2008).

There are several semi-consolidated and structurally deformed Pliocene and Pleistocene sedimentary formations exposed in the low lying hills that surround the San Felipe Creek study area. These formations are also sometimes exposed in the cuts along the San Felipe Creek wash and tributary washes. Much of the study area is covered by very young, late Holocene or historic fluvial, lacustrine and eolian deposits. At least six times in the last 1,000 years the Colorado River has rerouted from its present course to flow north into the Salton Depression. These prehistoric episodic lakes are collectively known as Lake Cahuilla. The Colorado River Delta essentially forms a dam across the Salton Depression approximately 12 m above sea level. These relatively frequent lake filling events during the late Holocene has created conspicuous shoreline features throughout the study area where the Lake Cahuilla was at its maximum elevation of 12 m above sea level. For example, in the Superstition Hills there is a wave cut bench; west of the Superstition Hills the former shoreline developed an arcuate sandy beach ridge; and, at the base of the Fish Creek Mountains are several beach deposits and wave cut platforms. Holocene age alluvial fans and alluvial washes mimic the Pleistocene flow regime and locally cover (or are inset into) deposits of Pleistocene age. The youngest deposits overly the ~300 year old Lake Cahuilla lacustrine deposits.

The climate of the region is extremely arid and dry with average annual temperatures reported for the adjacent Borrego Springs ranging between 2.7° and 41° C (NOAA weather station 040986). According to NOAA, the average annual rainfall is approximately 76 mm. While most of the rain falls during the winter months, the most intense rainfall occurs during summer thunderstorms. The principal watersheds that convey sediment to the study area are San Felipe Creek and Carrizo Wash. The San Felipe Creek watershed drains mountains and valleys to the west and northwest and is roughly 1,020 km^2 in area, has a maximum elevation of 2,619 m msl, and a mean annual rainfall of 120 mm (USGS, 2012). The Carrizo Wash watershed extends into Mexico and is approximately 1,230 km^2 in area, with a maximum elevation of 1,901 m msl. Both San Felipe Creek and Carrizo Wash are fairly well confined up to the point they enter the study area. The most prominent alluvial fan that supplies sediment to the study area is the Fish Creek fan, originating from drainages in the Fish Creek and Vallecito Mountains immediately west of the study area. This watershed has an area approximately 178 km^2 with a mean annual precipitation of about 170 mm, and a maximum elevation of 1,583 m. Numerous smaller drainages issue from the Fish Creek Mountains as well as isolated badlands that bound the valley to the north and south.

Interpretation and Description of Map Units

Along the zones of sand transport, active dunes and sand sheets are punctuated by eolian sand accumulations that have been stabilized due to a period of inactivity. These stabilized coppice dunes and sand sheets typically have a silty crust mantling the surface and are locally undergoing abrasion and deflation. While these stabilized areas suggest a period of inactivity, their short-lived exposure on the earth's surface (less than 300 years) does not lend itself to soil development to the degree that would allow us to infer the period of inactivity. However, given the complexity of drainage patterns in the San Felipe basin and the interaction between active alluvial fans and washes to the west and northwest, it is likely that dune and sand sheet stabilization occurs in response to alternating episodes of sedimentation and quiescence. Strong interactions occur between alluvial fan and alluvial wash systems with active coppice dune and sand sheet distribution. Areas of active distributary flow appear to form the most prominent sources of eolian sand. In contrast, at several locations the lack of active eolian deposition down-wind of incised alluvial wash systems suggests that narrow channels with steep banks tend to inhibit down-wind eolian sand entrainment and transport.

To provide a regional perspective, CGS reviewed hourly wind data from the CIMIS weather station about 27 km northwest of the study area in Borrego Springs (CIMIS #207; DWR, 2014). Additionally, CGS observed leeward tails on coppice dunes both in the field and from aerial photographs. Hourly wind data from 2005 to 2014 was summarized using wind velocity threshold of 10kts, which depending on grain size, is close to the general threshold considered to mobilize and transport sand. Our review of the regional wind data, field observations and review of aerial photography indicate:

- 84% of the hourly wind data above 10 kts are from the north (from between 349° and 11° azimuth), with wind between azimuth 270° and 349° for about 12% of the period of record.
- Measured trends of leeward tails on coppice dunes and linear dunes in the study area suggest an average drift direction of 118° azimuth (or from azimuth 298°)

The local orientations suggest a more westerly wind regime is operative in the study area than the regional wind data from Borrego Springs would indicate. We interpret these local data to be a better indicator of transport direction than the regional data.

Active Eolian Deposits

Qe2/Qal — Active windblown deposits consisting primarily of sand sheets superimposed on alluvial or Lake Cahuilla deposit typically < 1.5 m in thickness. Sand is predominantly fine- to medium-grained. Dry color is typically very pale brown 10YR 8/2 to 10YR 7/3. These deposits often accumulate as coppice dunes around *Prosopis glandulosa* (mesquite) and *Larrea tridentata* (creasote bush).

Potentially Active Eolian Deposits

Qe1/Qal — Stabilized eolian deposits consisting of sand sheets and coppice dunes overlying alluvial and Lake Cahuilla deposits. Geomorphic position suggests these deposits are less than 300 years old because they postdate Lake Cahuilla deposits. May locally include active eolian deposits. Fine to medium grained sand locally stabilized with a thin brittle crust that is developed on the surface of the deposit. Dry soil color is typically very pale brown 10YR 8/2 to 10YR 7/3.

Active Eolian Sources

Qw — Alluvial wash deposits consisting of unconsolidated fine- to coarse- grained sand and gravel with silt, dry soil color is brownish yellow 10YR 6/6; bar and swale morphology. No soil profile development.

Qf — Alluvial fan deposits of latest Pleistocene and Holocene age (undifferentiated). Unconsolidated to slightly consolidated sand and gravel, fine- to coarse- grained; includes cobbles, and boulders. Surfaces exhibit bar and swale morphology where traversed by active alluvial washes (Qw). Dry soil color is yellowish brown 10YR 5/4.

Ql — Lacustrine deposits of former Lake Cahuilla. As mapped, these deposits are composed of fine sand, silt, and clay lake bed deposits as well as sand and gravel beach ridge deposits that occur along the former shoreline.

Qa — Alluvial valley deposits of late Pleistocene and Holocene age. Composed of sand and gravel; surfaces exhibit minor bar a swale morphology, locally mantled by eolian deposits.

Other Map Units

Qoa — Alluvial deposits of Pleistocene age. Comprised of alluvial fan deposits capped by a gravel lag or desert pavement as well as the Pleistocene Ocotillo and Brawley formations.

D — Areas with inactive sand transport/deposition resulting from anthropogenic modification of the land surface. In the map area, these include farms and residences.

br — Bedrock (undifferentiated). This map unit is comprised primarily of Mesozoic granitic rocks and Tertiary volcanic and sedimentary rocks.

Contact between map units, approximately located. May be gradational where local variations in map unit thickness exist.

Quaternary faults compiled by Bryant (2005).

Predominant transport direction. Inferred from geomorphic interpretation of dune crest orientations.

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Projection: Universal Transverse Mercator, Zone 11 North, North American Datum of 1983

Topographic base from U. S. Geological Survey Borrego Mountain 7.5-Minute Quadrangle, 1960; Contour Interval 40ft. U. S. Geological Survey Shell Reef 7.5-Minute Quadrangle, 1959; Contour Interval 20ft. U. S. Geological Kane Springs NW 7.5-Minute Quadrangle, 1998; Contour Interval 10ft. U. S. Geological Survey Harper Canyon 7.5-Minute Quadrangle, 1959; Contour Interval 40ft. U. S. Geological Survey Borrego Mountain SE 7.5-Minute Quadrangle, 1958; Contour Interval 40ft. U. S. Geological Survey Harpers Well 7.5-Minute Quadrangle, 1998; Contour Interval 10ft. U. S. Geological Survey Kane Spring 7.5-Minute Quadrangle, 1992; Contour Interval 10ft. U. S. Geological Survey Arroyo Tapiado 7.5-Minute Quadrangle, 1997; Contour Interval 40ft. U. S. Geological Survey Carrizo Mountain NE 7.5-Minute Quadrangle, 1957; Contour Interval 40ft. U. S. Geological Survey Plaster City NW 7.5-Minute Quadrangle, 1956; Contour Interval 20ft. U. S. Geological Survey Superstition Mountain 7.5-Minute Quadrangle, 1956; Contour Interval 20ft.

N

Map Scale: 1:48,000

2.5 1.25 0 2.5 Miles

5 2.5 0 5 Kilometers

EOLIAN SYSTEM MAP OF THE SAN FELIPE DUNES AREA

A Project for the California Department of Fish and Wildlife
By the California Geological Survey

By: Peter Holland, CEG and Jeremy T. Lancaster, CEG