State Of California | The Resources Agency of California

Memorandum

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To: Commissioner, Robert Weisenmiller. Presiding Member
Commissioner Karen Douglas, Associate Member
Hearing Officer Raoul Renaud

From: California Energy Commission - **Alan Solomon**
1516 Ninth Street **Siting Project Manager**
Sacramento, CA 95814-5512

Subject: **Palen Solar Power Project (09-AFC-7) Staff Rebuttal Testimony – Alternatives and Biological Resources**

In its October 6, 2010 Opening Testimony, the applicant filed testimony related to Biological Resources; additionally, in its October 6, 2010 Opening Testimony, the Center for Biological Diversity filed testimony related to Alternatives and Biological Resources. Staff here provides rebuttal testimony explaining their position and/or proffers some revisions to Conditions of Certification in the hope of resolving concerns that were raised.

Staff is also filing its Updated Staff Exhibit List and is providing all parties with exhibits 304 through 316.

cc: Proof of Service List
Docket 09-AFC-7

PROOF OF SERVICE (REVISED 8/27/10) FILED WITH
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ENERGY COMMISSION STAFF REBUTTAL TESTIMONY
ALTERNATIVES

Rebuttal Testimony of Susan V. Lee and David Vidaver

Center for Biological Diversity

CBD (Bill Powers) states that the RSA uses outdated PV cost assumptions to assert that the PSPP would be a lower cost generation technology than equivalent Distributed PV. This is not accurate. The RSA quotes the 2009 IEPR, which states that solar PV technology has shown dramatic cost reductions since 2007, and is expected to show the most improvement of all the technologies evaluated in the 2009 IEPR model, bringing its capital cost within range of that of natural gas–fired combined cycle units. The RSA includes additional discussion regarding the cost of solar PV, incorporating the CPUC's *Renewables Portfolio Standard Implementation Analysis Preliminary Results.* The RSA states that the cost of distributed solar PV is a continued challenge to an accelerated implementation of distributed solar PV. The RSA does not assert that the PSPP is lower in cost than the equivalent in distributed PV; the Applicant did not provide the cost estimate of the PSPP so the analysis would not be able to compare these numbers.

In several instances, CBD statements regarding the costs of distributed PV ignore the distinction between planning assumptions and estimated production costs and observed prices. It is asserted that commercial rooftop PV prices have been "erroneously assumed" by the CPUC to be over $7/Wac and that "accurate pricing data" ($4/Wac) can be found in Southern California Edison's (SCE) urban solar PV application. Yet a review of the prices of 100 kW – 1 MW California Solar Initiative projects in 2010 indicates that $7 is likely a far more accurate value.[1] SCE's "pricing data" is in fact an estimate of costs and may be influenced by perceived opposition to utility ownership of a share of the project. To date, SCE;s project has resulted in little development (see below).

CBD also alleges that the RSA misstates SCE's rooftop space requirements for its proposed industrial rooftop PV installations. CBD (Mr. Powers) states that SCE's testimony regarding rooftop PV space requirements for distributed PV is approximately half of the square-footage the RSA attributes to the SCE rooftop installation (approximately 150,000 square feet per MWac compared with 600,000 square feet for 2 MW as stated in the RSA). Mr. Powers quotes the SCE application to the CPUC for the Solar Photovoltaic Project, as estimated in March 2008. While the number Mr. Powers quotes may be correct in theory, the RSA considered the *actual* rooftop space SCE has used for its installations, as stated by SCE in the following descriptions:

- SCE's press release for the Fontana project cites the use of a 600,000-square-foot building for 33,000 solar panels for approximately 2 MW[2].
- SCE's second installation, on a rooftop in Chino, cites the use of a 458,000-square-foot building for a 1 MW PV installation[3].

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[1] http://www.californiasolarstatistics.ca.gov/reports/cost_vs_system_size/

[2] Southern California Edison Begins Construction of World's Largest Solar Panel Installation Project. http://www.edison.com/pressroom/pr.asp?bu=&year=2008&id=7083. July, 2008.

- The third installation, also 1 MW, is planned for installation on a 436,000-square-foot facility in Rialto[4].

As shown by SCE's data, industrial rooftops cannot be completely covered with PV installations, so the rooftop space required is greater than the acreage presented in CBD's statements.

CBD states that the RSA's concerns regarding sufficient PV panel manufacturing capacity are baseless. The RSA does not cite a concern regarding PV panel manufacturing capacity as a reason for eliminating distributed solar PV as an alternative. The RSA states that the RETI Discussion Draft Paper *California's Renewable Energy Goals – Assessing the Need for Additional Transmission Facilities* published with the RETI Final Phase 2A Report (September 2009) includes manufacturing scale-up as a potential concern. However, this concern was not included as a reason for eliminating the alternative. Contrary to this concern, the RSA states that "The rate of PV manufacturing and installation is expected to continue to grow very quickly."

The RSA does express concerns regarding the limited concrete examples of large scale distributed solar projects. Mr. Powers highlights the PG&E and SCE proposals for large scale rooftop solar installations as examples of large scale distributed PV. However, as stated in the RSA, in the two years since SCE proposed the 500 MW urban project, with a goal of installing 500 MW in five years, it has only installed 3 MW. One additional MW was proposed in March 2010.

The CBD also suggests that an alternative site should have been considered in the Westlands Water District CREZ to reduce the environmental impacts that would occur at the PSPP Site. First, the PSPP as currently defined could not be located at the Westlands Water District CREZ because the Westlands CREZ does not have adequate insolation for a solar thermal plant (the solarity there is adequate only for solar photovoltaics). A solar PV project could be located in the Westlands Water District CREZ, and solar projects are now being considered by a development group at Westlands. While the Westlands CREZ is a potential alternative site that could be considered, we are not required to consider all possible alternatives. CEQA requires consideration of a reasonable range of alternatives that meet the CEQA screening criteria [see CEQA Guidelines Section 15126 (a)]. CEQA does not require consideration of <u>all</u> potential alternatives to a proposed project. The consideration of alternatives is based on the goal of reducing or eliminating the significant impacts of the project as proposed. We believe that the RSA presents an adequate range of alternatives.

CBD contends that (a) substantial amounts of rooftop space are available for development, (b) more than 13,000 MW of distributed PV can be developed with minimal investment in distribution infrastructure and at a price of $0.16 - $0.20/kW, and, as a result, distributed PV can replace utility-scale solar thermal projects as a component of the state's efforts to attain a renewable energy standard of 33%.

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[3] Second Rooftop in Southern California Edison's Massive Solar Panel Installation Program Now Generating power in Chino. http://www.edison.com/pressroom/pr.asp?bu=&year=2009&id=7286. October, 2009.

[4] Third Installation in Southern California Edison's Large Solar Power Project to Take Place in Rialto. http://www.edison.com/pressroom/pr.asp?bu=&year=0&id=7369. March, 2010.

It is true that large amounts of rooftop space exist in IOU service territories. This does not mean that they are suitable for solar PV development, nor that development of all suitable roof space is possible. CBD cites a Black and Vetch study[5] that indicates a (screened) potential of 11,500 MW of distributed PV on large rooftops, but this assumes 100% participation in a development program. Subsequent estimates of "easy to interconnect MW" by the same author assumed a 33% participation rate, and yield 3,200 MW.[6]

CBD's claim that 13,000 MW of distributed PC can be easily developed with minimal investment in distribution infrastructure is subject to dispute. The CPUC has devoted a stakeholder proceeding, the Renewable Distributed Energy Collaborative (Re-DEC), to study issues associated with achieving high levels of distributed PV. Presentations and discussion at Re-DEC workshops and in the CPUC Long-term Procurement proceeding indicate that 6,000 MW is a more realistic number.[7]

CBD's claim that large amounts of privately developed distributed PV would be forthcoming at a (adjusted MPR) price of $0.169 is subject to dispute. A recent study[8] commissioned by the CPUC for consideration in its Long-term Procurement proceeding, concluded that the levelized cost of energy of distributed PV in California, while depending upon technology and location, would likely be above $0.169. The study estimated levelized costs of energy (LCOE) for four solar technologies in four California locations. 5 -20 MW ground mounted fixed tilt located in the Mojave Desert had an LCOE of $0.168. The remaining technology-location pairs had LCOEs of $0.175/kWh (2-5 MW ground mounted fixed tilt, Mojave Desert) to $0.29/kWh (0.5 – 2 MW rooftop, North Coast). Of the estimated 6,000 "easy to interconnect MW" less than 200 MW fell into the lowest cost category, roughly 4,500 MW had an estimated LCOE of more than $0.20/kWh.

Even if 13,000 MW of distributed PV were developed, the resulting energy (28,500 GWh, charitably assuming a 25% capacity factor) would be roughly half that needed (approximately 54,000 GWh) to meet a 33% renewable energy standard under "moderate" load growth assumptions. 6,000 MW of distributed PV would yield 13,100 GWh, less than one-fourth of what is needed. In either case, renewable technologies other than distributed PV are needed to achieve the standard.

As noted above, there is strong evidence that policymakers do not believe that distributed PV can serve as a substitute for all central station solar thermal development. The CPUC has approved long-term power purchase agreements between IOUs and the developers of central station solar thermal projects, totaling 3,700 MW, another 2,400 MW of projects are pending approval.

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[5] E3 and Black & Veatch, *Summary of PV Potential Assessment in RETI and the 33% Implementation Analysis*, presentation at Re-DEC Working Group Meeting, December 9, 2009, p. 24. Online at: http://www.cpuc.ca.gov/PUC/energy/Renewables/Re-DEC.htm

[6] Black and Veatch, *LTPP Solar PV Performance and Cost* Estimates, presented at the Workshop on Planning Standards, June 18, 2010. Available at http://www.cpuc.ca.gov/PUC/energy/Procurement/LTPP/ltpp_history.htm

[7] Ibid.

[8] Ibid.

Energy Commission Staff Rebuttal Testimony – BIOLOGICAL RESOURCES

Rebuttal Testimony of Andy Collison, Carolyn Chainey-Davis, Sara Keeler, and Susan Sanders

This testimony responds to Center for Biological Diversity (CBD) Testimony.

Sufficiency of Surveys (CBD Testimony Page 3). CBD states that the RSA fails to adequately identify all of the on-site resources, evaluate the impacts to those resources and propose adequate mitigation. CBD asserts that a project of this size should involve many seasons of surveys to thoroughly document all of the resources that occur on the site. CBD notes that failure to conduct sufficient surveys prior to construction of the project also effectively eliminates the most important function of surveys - using the information from the surveys to avoid and minimize harm caused by the project and reduce the need for mitigation, and quantify the appropriate amount and type of mitigation.

> **Staff Response:** Staff agrees that multiple years of surveys are often necessary in desert environments to adequately identify resources that may be affected by proposed projects. The Applicant conducted two consecutive years of biological surveys at the Project site, including one season of surveys during a normal or wetter rainfall year. The surveys were professional, thorough, conducted by qualified biologists, and met agency protocols.
>
> Staff concluded in its assessment that additional fall surveys were warranted because the region has a uniquely 'tropical' warm desert climate influenced by the addition of monsoonal summer rains; a contrast to the dry summer Mediterranean climate that characterizes the rest of California. Staff specified additional fall surveys in **BIO-19** (Section B). The final botanical report is required no less than 30 days prior to the start of ground-disturbing activities.
>
> Staff agrees that avoidance is the most effective mitigation and should always be the first consideration; consequently several alternatives were considered that were specifically designed to minimize impacts through avoidance, and staff has concluded that those alternatives would result in significantly less impacts to many sensitive resources.
>
> It is important to note that although the Project site is "relatively undisturbed", *i.e.*, relative to agricultural lands, it has been significantly impaired hydrologically by the construction of I-10 and diversion of the numerous smaller ephemeral washes into three primary washes via a network of collector ditches (south of I-10). The loss of flows, sediment (and seed) transport, and the loss of wash-dependent vegetation along the smaller washes has had severe biological consequences in terms of

habitat value and function for many species. This is reflected in the near absence of rare plants within the solar facility site. The most valuable habitat on site, located in the northern and northeastern portions of the project, would be largely avoided by the reconfigured alternatives proposed by the Applicant.

Mitigation Ratio (CBD Testimony Page 3). CBD states that the proposed 1:1 mitigation required in **BIO-12** (Desert Tortoise Compensatory Mitigation) results in a net decrease in habitat for desert tortoise and other species that rely on this mitigation (golden eagle, special status birds, badger, kit fox, rare plants). BD recommends a minimum 2:1 to avoid a net decrease in habitat.

Staff Response: The recommended compensatory mitigation ratio of 1:1 for impacts to desert tortoise reflects staff's consultation with desert tortoise experts at USFWS, CDFG, and BLM as to what an appropriate level of compensatory mitigation should be for the quality of the habitat impacted by the Project. The mitigation lands acquired for compensation would be managed in a fashion that promotes increased reproduction and survival of desert tortoise, which would also have corollary benefits for the other sensitive species listed by CDB. As described in the RSA (p. C.2-100) once a management plan for compensatory mitigation lands is developed and approved by the appropriate resource agencies, enhancement actions such as fencing, road closure, weed control, and habitat restoration would benefit desert tortoise and the special status wildlife species that co-occur with desert tortoise. The goal of these activities is to increase the carrying capacity of the acquired lands for desert tortoise and increase their population numbers by enhancing survivorship and reproduction.

In consultation with USFWS, CDFG, and BLM, staff has concluded that mitigation at a 5:1 ratio (critical habitat) and at a 1:1 ratio (outside critical habitat) through land acquisitions or an assessed financial contribution based on the final construction footprint would mitigate for habitat loss within the Project Disturbance Area for the Palen Project. This mitigation is consistent with measures in Incidental Take Permits issued by CDFG for Projects in the region, and with requirements described in the NECO plan.

Mitigation Plan Effectiveness (CBD Testimony Page 3). CBD asserts that it is impossible to adequately evaluate effectiveness of mitigation since plans are not available for review. CBD states that many of the plans proposed by staff to adequately minimize or mitigate impacts are either not provided in the RSA or anywhere else or are draft plans that lack specific details in order to evaluate their effectiveness. CBD recommends that the Energy Commission put in place a public process that enables public input on the plethora of mitigation plans that are being proposed as conditions of certification for this (and other) proposed projects.

Staff Response: Staff agrees that mitigation plans must contain an adequate level of specificity, performance standards, monitoring and reporting requirements to ensure that the mitigation will be effective. Staff developed *81 pages* of highly detailed mitigation measures with clear performance standards and verification requirements (RSA, C.2-253-334). Many draft mitigation plans were submitted by the Applicant, and are contained in the Project data request responses and, thus, were available for public review. Staff's analysis included a review of the draft mitigation plans and data responses; the "final plan" specified in many conditions reflects staff's review of the adequacy of the draft plans, and any additional specificity, performance standards, or monitoring and reporting requirements that staff concluded were necessary to minimize the Project's impacts or to address any Project changes. Where onsite (or adjacent) avoidance is required, the measures are also site-specific. Staff consulted the REAT agencies and other experts in the development of these measures.

In accordance with CEQA, staff crafted measures that included avoidance and minimization of impacts, performance standards for off-site mitigation through preservation or restoration, and monitoring and management verifications, while coordinating with the appropriate agencies. Also in accordance with CEQA, staff provided, in elaborate detail, mitigation measures to satisfy the specific and strict performance criteria in its recommended conditions of certification, and included mechanisms for ensuring implementation.

Staff agrees with CBD that public disclosure of the final plans would further the Energy Commission's goals for public participation and transparency, and would help assure all parties that public resources are being protected. All plans filed in compliance with these and all other conditions are available for public review upon request.

Desert Tortoise Translocation (CBD Testimony, Page 3)

CBD discusses the unacceptably high levels of mortality associated with desert tortoise translocation on projects such as Fort Irwin, and notes that the Independent Science Advisory committee for the Desert Renewable Energy Conservation Plan (DRECP), stated: "the advisors do *not* recommend translocation of desert tortoise as effective mitigation or conservation action, in part because translocated tortoises suffer high mortality rates." CBD also states that Condition of Certification **BIO-10** requires only that a translocation and relocation plan be developed in the future, denying them the opportunity to review and comment on the plan. CBD also notes that regarding **BIO-9** (1), the desert tortoise fencing along Interstate 10 needs to be installed prior to any desert tortoise relocation or translocation. Desert tortoises are known to make

long distance movements after being moved and having a fence in place may help to minimize mortality.

> **Staff Response**: Staff's analysis in the RSA fully considered the risks and uncertainties associated with desert tortoise translocation, and addressed this topic in the RSA (p. C.2 – 25). Condition of Certification **BIO-10** requires the applicant to develop a translocation plan that meets the approval of BLM, USFWS, CDFG and the Energy Commission staff, and requires details on how the translocation will: relocate/translocate all desert tortoises from the project site to nearby suitable habitat; minimize impacts on resident desert tortoises outside the project site; minimize stress, disturbance, and injuries to relocated/translocated tortoises; and assess the success of the translocation effort through monitoring. Staff believes that **BIO-10** provides an adequate level of specificity, performance standards, monitoring and reporting requirements to ensure that the translocation plan will include all appropriate measures to minimize harm to translocated tortoise and to those at the recipient site. Furthermore, based on the Applicant's survey results, which found no desert tortoise on the Project site, and on consultation with desert tortoise experts at CDFG, BLM, and USFWS, staff believe that it is likely no tortoise will be detected during clearance surveys, and that no tortoise will need to be translocated.
>
> With respect to the DRECP Independent Science Advisors recommendation that translocation not be used as a mitigation measure, staff agrees. Unlike recovery actions such as habitat restoration, fencing, or land acquisition, translocation should not be considered as compensatory mitigation for project impacts, but rather is a necessary avoidance and minimization measure to avoid take of desert tortoise during project construction and operation.
>
> Staff does not agree that the requirement in **BIO-9** for desert tortoise fencing along I-10 should be required before translocations can occur. Staff developed the timing for the fences installation in consultation with CDFG, USFWS and BLM, and does not believe that the risk of a long-distance movement by a translocated desert tortoise to I-10 warrants immediate construction of a fence along I-10.

Desert Tortoise DWMA Connectivity (CBD Testimony, Page 5)

CBD comments that the RSA does not discuss that the area is specified for Desert Wildlife Management Area (DWMA) *connectivity*, and asserts that the proposed 1:1 mitigation is inadequate because it does not take into consideration the importance of this specific location in the WHMA for DWMA connectivity as identified in the NECO plan. CBD comments that at minimum, a 2:1 mitigation ratio needs to be implemented to truly off-set the impacts to this important linkage zone. CBD also states that the identified "probable" linkage area in the

RSA (Biological Resource Figure 6) includes another proposed large-scale industrial solar project – Desert Sunlight, which has a DEIS currently out for public review.

> **Staff Response**: Staff does not agree that the RSA failed to consider the issue of DWMA connectivity in their analysis. On page C.2-176 of the RSA, staff described in some detail how the Project would contribute to loss of desert tortoise connectivity between the Chuckwalla and Chemehuevi DWMAs and critical habitat areas. In consultation with BLM, staff identified probable desert tortoise linkages between the Chuckwalla and Chemehuevi critical habitat areas and DWMAs in **Biological Resources Figure 6**. These linkages were identified based on a review of vegetation and landform data (NECO datasets and Project-specific survey data), and from the USGS habitat model. Staff's review of connectivity corridors described by the Science and Collaboration for Connected Wildlands Desert Linkages Habitat Connectivity Study (www.scwildlands.org) also indicates that some of the areas depicted in **Biological Resources Figure 6** are important linkages for desert tortoises. The linkages depicted in that figure represent areas of the best habitat quality for tortoises between the DWMAs and critical habitat, and therefore represent the most probable linkages and most important areas to protect to maintain connectivity between the Chemehuevi and Chuckwalla DWMAs. Staff does not believe that because a solar project has been proposed within one of the linkages depicted in **Biological Resources Figure 6** the entire broad swath of the linkage has been rendered as unusable. The RSA also noted that with the linkages depicted in **Biological Resources Figure 6,** additional linkages through areas of lower quality habitat could be restored and may also be important for long-term connectivity between the Chemehuevi and Chuckwalla DWMAs.
>
> With implementation of proposed Condition of Certification **BIO-12** (acquisition of desert tortoise compensation lands) in the areas depicted in **Appendix B** of the RSA, staff believes that the Project's contribution to connectivity impacts in the region would be fully mitigated. Condition of Certification **BIO-12** specifies that compensation habitat acquisitions occur within the Colorado Desert Recovery Unit in areas that have potential to contribute to desert tortoise habitat connectivity and build linkages between desert tortoise designated critical habitat, known populations of desert tortoise, and/or other preserve land.

Colorado Recovery Unit (CBD Testimony, Page 5)

CBD states that the RSA generally fails to recognize that based on the current desert tortoise recovery plan, the project is located in the E*astern* Colorado Recovery Unit. Instead, the analysis uses a *draft* revision of the desert tortoise recovery plan's scheme which "lumped" two currently distinct recovery units - the Eastern Colorado and the Northern Colorado recovery units - into a single unit –

the Colorado Recovery Unit. CBD cites Murphy et al. 2007 indicating that these data indicate that the two recovery units in the current recovery plan are genetically unique and fully justifiable. CBD comments that the conditions of certification do not require that mitigation lands be in the Eastern Colorado Recovery Unit, but instead include the much larger and genetically different Northern Colorado Recovery Unit, which CBD asserts undermines the efficacy of the proposed mitigation and fails to fully mitigate the impacts to the unique genetic type of desert tortoise found in the Eastern Colorado Recovery Unit.

> **Staff Response**: In subsections C.2.4.1 and C.2.4.2, staff thoroughly discussed the existing condition of the local and regional desert tortoise and including the status of the Northern and Eastern Colorado Recovery Units. This subsection was developed in close coordination with staff at the USFWS, who reviewed and approved use of the 2008 draft Desert Tortoise Recovery Plan in the RSA (pages C.2-44-45) and the language describing the recovery units and the status of desert tortoise at the Project site. Subsection C.2.4.2 and C.2.11 addresses project impacts to gene flow and connectivity of these two recovery units. In the cumulative impact section, Subsection C.2.11, the RSA provides a detailed analysis of the cumulative effect of the Project combined with other likely foreseeable projects and effects to populations of desert tortoise within the entire NECO planning area, an area that is roughly equivalent to the boundaries of the Northern and Eastern Colorado Desert Recovery Unit.
>
> The draft 2008 revised USFWS recovery plan does indeed combine the Colorado Desert recovery units based on new genetic information available to the Desert Tortoise Recovery Office (DTRO). In the 2008 draft plan, studies by Murphy et al. 2007 were considered together with more recent genetic analyses, thus the reconfiguration of the revised recovery units is the resultant interpretation of those data. The evaluation conducted by the DTRO does not solely rely upon one research paper but instead upon several resources -- CBD has chosen to only consider Murphy et al. 2007. Because desert tortoise genetics are characterized by isolation by distance, tortoises at one end of a recovery unit may look slightly different genetically than tortoises at the other end of the recovery unit because of a gradation across the range. Recovery units should not be broken up solely based on recent genetics analyses because other factors (e.g., genetic inference limitations due to sample design, habitat characteristics and topography, behavior) are also at play. In developing the draft 2008 recovery plan the DTRO considered all best available information and concluded that the Colorado Desert recovery units have minimal genetic differentiation and a gradient of environmental variation across the ecoregion.
>
> Condition of Certification **BIO-12** is specific about where desert tortoise compensation lands may be acquired within the Colorado Recovery Unit,

and with the criteria in **BIO-12** such acquisition would not occur in areas distant from the Project site. According to the **BIO-12** criteria, lands within the Chuckwalla DWMA, which is close to the project site, is the first priority for acquisition. The lands must also have potential to contribute to desert tortoise habitat connectivity and build linkages between desert tortoise designated critical habitat, known populations of desert tortoise, and/or other preserve lands. Staff, BLM, USFWS and CDFG all agree these conditions will fully mitigate for Project impacts to desert tortoise, and will help maintain and preserve genetic connectivity for desert tortoise populations within the Colorado Recovery Unit.

Canid Predation (CBD Testimony, Page 6).

CBD notes that canid predation affects resident, control and translocated desert tortoises, stating that while minimization measures are proposed for reducing some predators on the project site, the new and best available science needs to be incorporated into the conditions of certification for this (and other projects). The conditions of certification require that payment be made to support the USFWS Regional Raven Management Program (Bio 13(2)). CBD suggests that the Energy Commission or CDFG set up and implement a similar program to address the regional canid management in support of reducing predation of desert tortoises (and other rare animals) and that payment in support of that program also be required as a condition of certification."

Staff Response: CBD does not indicate what new and best science is available on this topic that would alter the conditions of certification that help minimize risk of canid predation. Staff agrees that research and management efforts to address the issue of canid predation on desert tortoise would be a worthwhile effort and might contribute to the recovery of the species, but believes that development of a regional canid management program is beyond the scope of appropriate mitigation for the Palen Project.

Sand Dune Community/MFTL (CBD Testimony Page 6)

CDB believes that entire habitat for MFTL needs to be mitigated at a 3:1 mitigation ratio including habitat that is affected by indirect impacts. CBD also found it confusing and unclear how **BIO-20** in the RSA relates to the information provided in the Data Requests of July 9, 2010, and if "high quality MFTL habitat" equates to "Zone 2 MFTL habitat" or how that relates to the occupancy of the lizards identified during surveys in those areas or the areas identified in the RSA as "stabilized and partially stabilized sand dunes", "non-dune Mojave fringe-toed lizard habitat".

Staff Response: As summarized in **Biological Resources Table 8**a, (RSA page C.2-148), only those portions of the Mojave fringe toed lizard habitat consisting of stabilized or partially stabilized sand dune would be mitigated at a 3:1 ratio. This mitigation ratio is based on guidance in the

NECO plan. The NECO plan does not provide recommendations for mitigation for direct or indirect impacts to MFTL habitat, so staff developed an approach of 1:1 mitigation for direct impacts to MFTL habitat and 0.5:1 for indirect impacts. Staff recommended the lesser mitigation ratio for indirect impacts because this impact would not be irreversible as it would be on the plant site where all natural habitat would be graded.

Pages 13 – 18 of Biological Resources Appendix C (*Geomorphic Assessment of Sand Transport Impacts*) provides a detailed description of the various sand transport zones present on and near the Project site, and their suitability for MFTL; Figure 8 from this document also offers a graphical depiction of the densities of MFTL in relation to the zones. In general, Zone II, the area of greater sand transport, supported higher densities of MFTL than Zone III, and Zone IV did not support any. However, staff did not rely on the location of the sand transport zones to determine assess the aerial extent of direct or indirect effects to MFTL habitat, or make distinctions between high or low quality habitat for MFTL, but instead used the mapping provided by the Applicant (Figure 20, Solar Millennium 2010m) as to what constituted occupied MFTL habitat. As described on page C.2-46 of the RSA, MFTL habitat was defined by the presence of fine, wind blown sand. In **Biological Resources Table 8a**, staff referred to this as "sand fields". Direct impacts to all occupied habitat, regardless of zone, required mitigation at a 1:1 ratio except for the 285 acres of stabilized or partially stabilized sand dune, which was mitigated at 3:1

Bird Collisions (CBD Testimony page 6)

CBD asserts that the RSA dismisses recognized avian attractants such as evaporation ponds and agricultural fields as not occurring in the vicinity of the project (RSA at C.2-11) but notes that the proposed project will have 8 acres of ponds (RSA at C.2-119) and is directly adjacent to agricultural fields (RSA at Appendix C, Figure 5 through 8). CBD cites the McCrary study, suggesting that the much larger Palen project will have much higher mortality, and says the RSA fails to quantitatively evaluate the impact to birds based on the McCrary results. CBD notes that other data are available on injury and mortality associated with reflective surfaces and powerlines which could have been used to evaluate impacts to birds, stating that avian point count data were not folded into an analysis of the potential impacts to birds from attraction onto the site by the proposed evaporation ponds.

Staff Response. Staff does not agree that the Palen Project's 8 acres of netted evaporation ponds and a nearby date orchard make it comparable to the site in the McCrary study, which was adjacent to bird-attracting alfalfa fields and 130 acres of open ponds. Furthermore, CBD has not indicated how additional pre-construction point count data on birds would be useful in analyzing impacts or developing mitigation measures. The

missing piece of information, which is not supplied by the McCrary study or any others, is what the anticipated mortality from collisions might be for a solar trough project, where the solar arrays are surrounded by barren, leveled terrain (in contrast to the McCrary study, where heliostats were within a vegetated, ungraded landscape that supported habitat that would attract birds). Staff does not agree with CBD's assertion that bird collision data from powerlines or other reflective surfaces (e.g., windows) could be extrapolated to solar troughs to provide a quantitative assessment of likely bird collisions. Pre-construction bird surveys would not provide useful data on post-construction bird use of the site, after it is graded and developed, or information as to how many birds might be attracted to netted evaporation ponds surrounded by solar arrays. This issue of bird collisions with solar arrays is, as staff has described in the RSA, a topic where there is little information and much uncertainty.

Staff believes that Condition of Certification **BIO-16** provides a conservative and protective approach to addressing the uncertainty associated with the potential threat of bird collisions with the Project's solar arrays, and provides an adaptive management approach for addressing impacts if they occur.

Burrowing Owl (CBD Testimony Page 7).

CBD says the RSA failed to evaluate the potential impacts to burrowing owls in the context of the regional population, including data are available on burrowing owls in eastern Riverside County from the California Burrowing Owl Survey – 2006-2007. CBD cites declines in Imperial Valley, and states that because burrowing owls are in decline mitigation of only 78 acres for 4 owls is too low, especially in the Colorado Desert, as it is outdated agency guidance. CBD thinks additional mitigation acreage should be required, and suggests a calculation using the mean foraging territory size times the number of owls = 2,391 acres (or that it may be that in this area of the Colorado Desert 4,000+ acres is necessary to support 4 burrowing owls). CBD also recommended that language be included that mitigation lands that are acquired for burrowing owl be native habitats on undisturbed lands, not cultivated lands, which are subject to the whims of land use changes.

Staff Response: Staff provided an analysis of the Project's contributions to cumulative loss of regional burrowing owl habitat on page C.2-188, and determined that these impacts would be cumulatively considerable. To offset this Project impact and the loss of burrowing owl foraging habitat, staff worked with CDFG and applied the standard mitigation guidance consistently recommended by CDFG. Staff agrees that the CDFG guidance for burrowing owl mitigation is in need of revision, and agrees that the revised guidance should reflect the sorts of declines described by CBD in the recent Imperial County survey data. CDFG is currently updating their guidance, but it is not yet available. Staff also believes that

the acquisition of approximately 5,000 acres of desert tortoise mitigation lands described in **BIO-12** will provide substantial benefits to burrowing owls because there is considerable overlap in the habitat requirements of these two species.

Staff does not agree that additional language is needed in **BIO-18** specifically requiring that the acquired lands be native undisturbed lands rather than cultivated lands because fallow cultivated lands sometimes provide good habitat for burrowing owls. As described in **BIO-12**, which is incorporated by reference into **BIO-18**, compensatory mitigation lands are acquired in fee title or in easement with a requirement that the lands be managed for the long-term benefit of the species; no land use changes would be allowed on such mitigation lands that did not benefit burrowing owls.

Insects (CBD Testimony Page 7).

CBD states that sand dune habitats are notorious for supporting endemic insects, typically narrow habitat specialists, and that the RSA fails to address insects on the proposed project site. CBD asserts that the RSA brushes off this important issue by characterizing the impact to the sand dune community without actually requiring insect surveys. CBD states that without surveys no evaluation of impacts to rare insects can be made.

Staff Response: Surveys for insects and other invertebrates are not standard or routinely conducted except when state or federal listed species are known to occur in the Project vicinity. No listed insect species are known to occur near the Project site, and CDB has not identified which special-status insect species have prompted their concerns on this Project. While no insect surveys were conducted, staff does not agree that the RSA fails to address impacts to sand dune biota, including insects. Subsection C.2.4.1 discusses the unique biota adapted to sand dunes, including possibly unique and rare insect species. Staff's analysis of impacts to sand dunes was based on the assumption that sand dunes are unique and threatened habitat types that support unique and threatened species, whether or not those species had been formally petitioned for threatened or endangered status.

Based on staff's analysis and recommendations, the Applicant has reconfigured the project so that habitat for dune-endemic species is largely avoided and the impacts significantly reduced. Furthermore, mitigation for dunes required under Condition of Certification **BIO-20** would benefit all dune species, including insects dependent on dunes, by preserving remaining habitat in the Chuckwalla Valley dune system that could otherwise be developed in the future. Indirect impacts to adjacent dunes (and dune insects) from fugitive dust minimized through the dust control measures in **AQ-SC3**, **AQ-SC7**, and **SOIL&WATER-1**. Condition

of Certification **BIO-14**, #5b, contains guidelines for the safe use of herbicides to avoid drift and unintended harm to plants and wildlife in adjacent habitats.

Special Status Plants (CBD Testimony Page 7).

CBD states that late-season botanical surveys should have been done prior to the assessment of impacts from the proposed project; failure to conduct sufficient surveys prior to construction of the project effectively eliminates the most important function of surveys using the information from the surveys to avoid and minimize harm caused by the project and to reduce the need for mitigation. CBD comments that often efforts to mitigate harm are far less effective than preventing the harm in the first place

Staff Response: CBD's suggestion that the surveys will *not* be conducted "prior to construction of the project" is incorrect; **BIO-19 Section B** (fall survey requirements) is very clear about the requirement to conduct these surveys in fall of 2010 (RSA, pp C.2:289-291). Condition of Certification **BIO-19** requires the final botanical report no less than 30 days prior to the start of construction. Staff fully analyzed the significance of impacts for all of the special-status plants known to occur in similar habitats within 50 miles or more of the Project site; the 7-page analysis is contained in the RSA, pages C.2-129-136. Staff then devised a 20-page, highly-detailed, and peer-reviewed condition of certification (RSA, pp C.2-286-306) that includes thresholds for significance based on status, rarity, and threat codes (see **Section C of BIO-19**, pp C.2- 291-294).

Staff agrees that "*often efforts to mitigate harm* [off-site] *are far less effective than preventing the harm in the first place.*" Consequently, **BIO-19 (Section C)** makes 100 percent on-site avoidance *mandatory* along the Project linears and around the perimeter of the solar facility. Additionally, **BIO-19 (Section D)** requires that all significant unavoidable impacts must be minimized through preservation or restoration, consistent with CEQA guidelines for acceptable mitigation. **BIO-19 Section D** (pp C.2- 295-304) includes 9 pages of highly detailed specifications and performance standards for off-site mitigation for any unavoidable impacts. The results of the late season surveys conducted *this fall and prior to the start of construction* will be subject to the requirements for both on-site avoidance and off-site mitigation, including monitoring and reporting requirements (Verifications, pp C.2:304-306), in **BIO-19**.

The detailed analysis of indirect impacts to plants, including climate change, is provided in three pages of the RSA (pp. C.2- 136-139). Indirect impacts to plants occurring in close proximity to the project are minimized through three pages of mitigation measures in **Section A of BIO-19** (pp. C.2-286-289), and through the strict weed management measures specified in the fall 2009 data requests that are reflected in the Applicant's

draft Weed Management Plan and will be finalized as specified in **BIO-14** (RSA, pp. C.2- 278-281). Indirect effects from non-native plants and soil disturbance are also minimized through the soil salvaging and revegetation requirements for temporarily disturbed soils contained in **BIO-8**. Staff also considered the indirect effects to rare plants from changes in hydrology and sediment transport and included requirements in **BIO-21,** measures 5, 6 and 7, for re-grading disturbed soils to restore the original drainage patterns, providing culverts or Arizona crossings where drainages are interrupted by permanent roads, and protecting the integrity of the washes (RSA, pp. C.2-310-311). Indirect impacts to dune-dependent rare plants located north and northeast of the Project are avoided under the reconfigured alternatives.

Habitat Loss and Compensatory Mitigation (CBD Testimony Page 9).
CBD notes that mitigation in **BIO-12** (Desert Tortoise Compensatory Mitigation) is proposed as the mitigation for impacts to many other rare animals. CBD states that the RSA should have specific criteria for each rare resource, as was done for state jurisdictional water, where at least 608 acres of waters must be acquired. Even with rare species occurring on the mitigation lands, CBD states that the Energy Commission must still recognize that the proposed project is a net loss of occupied habitat and possibly individuals of these species.

Staff Response: Staff believes it is entirely appropriate to assume that land acquisitions for desert tortoise at the Project site would simultaneously benefit other animals found in the same habitat types. Desert kit fox, badger, and desert tortoise all utilize Sonoran creosote scrub habitats and it is common for these species to co-exist. The acquisition of habitat for desert tortoise would support habitat for kit fox, badger and other special-status species found on the Project site since these species utilize similar creosote scrub habitats.

Mitigation for impacts to state waters must include the specific acreages targets described in **BIO-21** to satisfy CDFG Lake and Streambed Alteration codes, although it is very likely that the desert tortoise land acquisitions will also simultaneously satisfy the requirements for ephemeral stream mitigation. Acquisition of desert dry wash woodland and other state waters specified in **BIO-21** would also benefit a number of special status bird species, including loggerhead shrike and LeConte's thrasher. **BIO-12**, acquisition of habitat for desert tortoise, would also protect foraging habitat for golden eagles that is in close proximity to mountainous nesting habitat.

Cryptobiotic Soils (CBD Testimony Page 9).
CDB states that cryptobiotic soils are an essential component in arid ecosystems to prevent desertification and perform a myriad of ecological functions including soil stability, porosity, and water retention. They are easily disturbed and slow to

regenerate. CBD commented on the Staff Assessment requesting an evaluation of where the cryptobiotics were on the proposed project site and an analysis of the impacts of the project on these important soils, but states that the RSA failed to do so. CBD asserts that the disturbance of these types of soil crusts will affect the nearby ecological functions including increased amount of PM-10 emissions from the proposed project site, alteration in hydrology, and water retention among many other impacts.

> **Staff Response.** Staff agrees with CBD that cryptobiotic soil crusts confer essential ecological benefits, but their statement that staff failed to analyze impacts to cryptobiotic soil crusts is incorrect; please refer to pages C.2-139-140 and 208-209 of the RSA. Subsection C.2.4.2 discusses the benefits of soil crusts for weed control as well as their function as a carbon sink, protection of air quality and soil resources through their ability to control erosion. This subsection also describes the direct and indirect impacts of the Project on cryptobiotic soil crusts, noting that windblown sand and dust exacerbates the erodibility of the soil and accelerates the loss of nutrients.
>
> Staff did not request additional surveys specifically for distribution of soil crusts, nor are such surveys standard or routinely required components of biological surveys. However, staff observed soil crusts in the Project area during site visits, and analyzed the plot data collected in Chuckwalla Valley for the NECO vegetation mapping project (Evans and Hartman 2007) which indicates that cryptobiotic soil crusts are present in similar habitats throughout the valley. Staff's analysis was sufficient for staff to conclude that the cumulative loss of soil crusts and their carbon sequestration benefits *are* potentially significant.
>
> To minimize the Project's contribution to this cumulative effect, staff included measures for salvaging and replacing the soil crusts for all temporarily disturbed soils in **BIO-27 (E)** (Please note these measures were subsequently moved to **BIO-8).** The temporal loss of natural weed control during the re-establishment phase is minimized through the requirement to manage weeds along all the project linears and other temporarily disturbed soils (see **BIO-14**). Impacts from fugitive dust during construction and operation will be minimized through conditions of certification **AQ-SC3**, **AQ-SC7**, and **SOIL&WATER-1.** The requirement to compensate for the loss of Mojave fringe-toed lizard habitat (**BIO-20**) within Chuckwalla Valley and desert washes (**BIO-21**) and desert tortoise habitat (**BIO-12**) within the Colorado Desert region of California will minimize future impacts to soil crusts by preventing future development of acquired private lands that could otherwise be developed. These conditions also require management plans be developed for acquired lands, and such plans would likely include restoration of degraded portions of the acquired habitat. Regulations promulgated by BLM at 43 CFR

3809.550 et seq. require a detailed reclamation plan for decommissioning (**BIO-22**). For the reclamation plan to meet the standards in §3809.420, it must include plans for topsoil handling and revegetation (RSA, pp C.2-141-142).

Staff concluded that compliance with these mitigation measures would reduce the Project's contribution to the cumulative loss of soil crusts and carbon sequestration benefits to a level that is less than cumulatively considerable.

Fire Threats (CDB Testimony p. 9)

CBD states that fire in desert ecosystems is well documented to cause catastrophic landscape scale changes and impacts to the local species. CBD states that while the RSA mentions the impacts of fire via the proliferation of non-native weeds (RSA at pg. C.2-18 through 19, and many other places), CBD asserts that it fails to adequately analyze the impacts of this issue for this proposed project that routinely relies on superheated liquids, and that it fails to adequately analyze the impact that a fire could have on the natural lands adjacent to the project site if it escaped from the site or address the mitigation of this impact. Instead it defers it to the Worker Environmental Awareness Program (WEAP) and only requires "a discussion of fire prevention measures to be implemented by workers during project activities" (RSA at pg. C.2-258). A fire prevention and protection plan needs to be required to preclude the escape of fire onto the adjacent landscape (avoidance), lay out clear guidelines for protocols if the fire does spread to adjacent wildlands (minimization) and a revegetation plan if fire does occur on adjacent lands originating from the project site (mitigation) or caused by any activities associated with construction or operation of the site even if the fire originates off of the project site.

Staff Response. Staff shares CBD's concern about the impacts of fire on desert ecosystems and discussed this in many areas of the RSA. Staff addressed these impacts in the context of the tendency of fire to proliferate weeds *as well as* its direct and indirect impacts to wildlife, special-status plants and native plant ecosystems. Staff considered the altered fire regimes that result from the conversion to weed-dominated habitats after a fire, and the cumulative effects of increased fire danger. (pp C.2-18-19; 43; 72; 103; 127; 136-137; 170; 176; 178; 180; 184; 187-188; 193-194; 201; 203; 206). Staff concluded that these indirect effects were cumulatively considerable, and recommended mitigation to reduce these impacts to less than significant levels.

Staff's background research included consultation with the Energy Commission risk assessment staff, Dr. Greenberg, who indicated that no fires have occurred around any of the solar facilities in California, to date. Nevertheless, staff concluded that the increase in roads and vehicle traffic (vehicles are common vectors for roadside fires), the documented

increased risk associated with transmission lines, and the potential for project-related soil disturbance to increase weeds (which in turn increase flammability) warranted the addition of fire prevention and education measures. The fire prevention and education measures in the mitigation measures described below are based on staff's research on the primary causes of wildland fires and the ways in which transmission lines increase fire risk. The mitigation measures that address fire prevention measures include:

- **BIO-6** (Worker Environmental Awareness Program, measure #4, page C.2-258).
- **BIO-14** (Weed Management Plan, page C.2-280), #5d, prohibiting use of mowers and off-site equipment during periods of high fire risk and prohibiting disking, which increases weeds (flammability).
- **BIO-8** (Avoidance and Minimization Measures, pp C.2:261-265), #3 for prohibiting off-road traffic, #5 for reducing the risk of bird collisions and electrocutions, which are a primary cause of transmission line-associated fires (aside from trees in wooded or forested areas), #15 for prohibiting firearms and use of vehicles or equipment off-road traffic (also common causes of fire in wildlands), and #18 for controlling unauthorized and OHV use of the Project access roads.
- **BIO-14** and **BIO-27** (Revegetation of Temporarily Disturbed Areas, now incorporated into **BIO-8** and **BIO-14,** minimize the Project's contribution to the spread of weeds, which increase flammability of the vegetation and, in some cases, and increase the frequency and intensity of wildfires. The revegetation measures include a requirement to install vertical mulching at the head of all temporary access roads to prevent OHV use of those roads; OHV use would also be expected to increase the risk of fire from vehicle exhaust systems contact with dried and flammable weeds.

With respect to CBD's request that a revegetation plan be required if fire occurs on adjacent lands originating from the Project, staff believes that BLM policy already addresses this concern. Staff researched BLM policy on fire investigation and their authority to assign financial responsibility for fire-fighting costs and restoration to its permitees. The Palm Springs BLM Field Office indicated that BLM could seek reimbursement for all bureau suppression costs along with costs associated with burned area stabilization, restoration, revegetation, monitoring, administration of the investigation, and fire trespass resolution if the fire was the result of negligence.

This testimony responds to the Applicant's Opening Testimony.

I. Reconfigured Alternatives and Minor Project Modifications

Staff agrees with the statements made by the Applicant on page 3 of their Opening Testimony, and concludes that the analysis of impacts to biological resources in the Revised Staff Assessment (RSA) thoroughly addressed both Reconfigured Alternative 2 and Reconfigured Alternative 3. Staff has crafted the conditions of certification so that Project impacts to biological resources would be reduced to less than significant levels with adoption of either reconfigured alternative.

Staff also carefully reviewed the Applicant's description of minor modifications to the Project as provided on pages 3 – 6 of the Opening Testimony to make sure that they are consistent with the analysis and conclusions in the RSA. As described in the summary of staff's analysis below, staff's analysis of impacts to biological resources in the RSA accommodates these minor modifications.

1. **Box Culvert for Wildlife Movement.** Staff's assessment of this box culvert had already been analyzed in the RSA, and was incorporated into Condition of Certification **BIO-8**, #10. Staff has added the additional detail provided in the Opening Testimony to this condition of certification in Section II below.

2. **Secondary Access Road**. Staff analyzed a slightly different alignment in the RSA than the one depicted in the Figures 1 and 2 of the Applicant's Opening Testimony. The Applicant's proposed alignment is 4,066 ft (0.77 mi) west of the one shown in Biological Resources Figure 25 of the RSA. The direct impacts of construction of the secondary access road on the Applicant's proposed alignment would be the same as that described on pages C.2-77 – 78 of the RSA because both staff- and Applicant-proposed alignments are entirely within Sonoron creosote scrub in similarly disturbed habitat in the narrow strip between the southern Project boundary and the I-10 freeway embankment. It is located outside of the Critical Habitat Unit for desert tortoise. A total of 0.2 acres of creosote scrub would be impacted along the 180-foot long road, based on a total 50-foot wide work area and a 24-foot wide graveled roadbed. No sand dunes or desert dry wash woodland would be directly affected. The alignment comes in close proximity (<20 ft) to some minor, hydrologically-impaired, unvegetated ephemeral washes that were cut off from their watershed by the construction of I-10. No rare plants or other sensitive resources were documented in this area during the Project surveys. Staff has concluded that implementation of the avoidance and minimization measures and Best Management Practices included in Condition of

Certification **BIO-21** (Mitigation for Impacts to State Waters) would provide sufficient protection for the minor relict channels. Impacts to Sonoran creosote scrub would be minimized to a less than significant level through habitat acquisition at a 1:1 ratio according to the terms of **BIO-12**.

3. **Changes to Height of Control Building, Dimensions of Water Storage Tank.** These minor changes do not affect staff's analysis or conclusion of impacts to biological resources as described in the RSA because they are already within the area considered to be completely impacted by the Project. The proposed minor changes in the height of the Control Building and water tank are well within the range analyzed by staff in the RSA.

4. **Change in Location of the Evaporation Ponds for Unit 1**. The shift in location of the evaporation ponds as described in the Applicant's Opening Testimony would not change staff's analysis in the RSA of the impacts of these ponds. With implementation of Condition of Certification **BIO-26** (Evaporation Pond Netting and Monitoring) impacts to biological resources from the Project evaporation ponds would be reduced to less than significant levels, regardless of the location of those ponds within the Project footprint

II. Conditions of Certification

Staff accepts most of the Applicant's proposed changes to conditions of certification described in their Opening Testimony because the suggested revisions reflect agreements achieved at staff workshops held in August and September, 2010. As discussed in previous workshops, **BIO-27** was deleted because staff agreed the Applicant should not be required to conduct full habitat restoration on temporarily disturbed lands (linears) that would be already be mitigated in full through habitat acquisition under the terms of **BIO-12, BIO-20** and **BIO-21**. The additions to conditions of certification **BIO-8** and **BIO-14** were docketed on September 30, 2010 under the title "Staff Consideration of Request to Delete **BIO-27**" (Docket TN58683). Staff agreed to delete **BIO-27** on the condition that: 1) Avoidance and minimization measures described in **BIO-27** were incorporated into **BIO-8** (General Avoidance and Minimization Measures), and 2) Weed management measures described in **BIO-27** were incorporated into **BIO-14** (Weed Management Plan). These changes were made in the Applicant's Opening Testimony, and staff agrees to them.

However, staff does not agree with all of the Applicant's proposed changes for conditions of certification **BIO-20**, **BIO-23**, and **BIO-24**. In addition staff has added some new language in Conditions of Certification **BIO-8**, BIO-20, **BIO-23**, and **BIO-24**.

Staff has also made changes in **BIO-29** (Project Phasing) so that Tables **BIO-29 Table 1, BIO-29 Table 2,** and **BIO-29 Table 3** replace **Biological Resources Tables 22, 23,** and **24** in the RSA. Staff agrees with the Applicant's proposed text changes to **BIO-29**, but has modified some of the figures in those tables to be consistent with the analysis in the RSA.

New text introduced by staff is shown below in bold, blue and underline. The Applicant's edits are shown in dark red and underline. Original text that the Applicant deleted, and which staff agrees to delete, is shown in red strikethrough. New text introduced by the Applicant that is unacceptable to staff is shown in blue strikethrough. The original text of the condition is shown in black.

In summary, staff accepts all of the Applicant's changes to conditions of certification as shown in their Opening Testimony except as described below.

BIO-8 AVOIDANCE AND MINMIZATION MEASURES

Staff has added some new language in Condition of Certification **BIO-8**, #10 (below), based on additional detail on the box culvert provided in the Applicant's Opening Testimony.

BIO-8 #10 Install Box Culvert. To provide for connectivity for desert tortoise and other wildlife, the Project owner shall install a box culvert suitable for passage by desert tortoise and other wildlife under the Project Site Access Road. **The box culvert shall be a concrete structure no less than 4 feet high and 6 feet wide with 3:1 side slopes and shall maintain a minimum of 18 inches of native material on the floor of the culvert at all times to facilitate tortoise movement**.

BIO-20 SAND DUNES/MOJAVE FRINGE-TOED LIZARD MITIGATION

A remaining area of substantial disagreement between staff and the Applicant is Condition of Certification **BIO-20** (Sand Dune/Mojave Fringe-toed Lizard Compensation). The Applicant has indicated in their Opening Testimony that they believe they can make design modifications to the northern and eastern wind fence of Phase 2 that would allow sand to move through the site. The Applicant asserts that this would eliminate any indirect impacts related to the blocking of the sand transport corridor.

Staff objects to the sudden introduction of a new Project feature (i.e., a wind fence that differs dramatically from that described in the original project description and from that analyzed in the RSA) and objects even more to revising the condition of certification and mitigation requirements based on this new feature. Staff's modeling of indirect impacts of the Project to sand transport, as discussed in **Biological Resources Appendix C** (*Geomorphic Assessment of Sand Transport Impacts*), used the wind fence as the point of measurement from

which sand transport would be obstructed, but that does not mean it is the only object on the Project site that would interfere with sand transport. Staff has not analyzed the wind/sand obstructions of the desert tortoise exclusion fencing, the solar arrays, power blocks, drainage ditches or any other components of the Project independent of the wind fence that are likely to interfere with sand transport, so cannot provide a quantitative assessment of how much these elements would interfere with wind transport with a fence that ended five feet above the ground. Even desert tortoise fencing without the wind fence could present an obstruction to sand transport; as discussed on page 20 of **Biological Resources Appendix C** 90 percent of sand transport occurs within 30 cm (11 inches) of the ground surface. Given that the entire site would be enclosed by desert tortoise fencing no less than 18 inches high, with a 1 X 2 inch mesh, we could expect that the tortoise fencing would by itself pose a barrier to sand transport.

Staff has provided ample evidence (RSA pages C.2-105 to C.2-108 and **Biological Resources Appendix C** [Exhibit 301], Barrows et al. 2009 [Exhibit 306], Turner et al. 1984 [Exhibit 305]) supporting the conclusion that the Project would result in significant indirect impacts to downwind Mojave fringe-toed lizard habitat. Staff is appreciative of the Applicant's reconfiguration of the Project to avoid direct and indirect impacts to sand dune habitat, and acknowledges that these impacts have been significantly reduced as a result of the reconfigurations. However, even with the reconfigured footprints the Project would still intrude slightly into a portion of the sand transport corridor, and staff has concluded based on the evidence cited above that significant indirect impacts to downwind habitat would result. Only with implementation of staff's proposed mitigation (acquisition of habitat at a 0.5:1 ratio for areas indirectly impacted) can staff conclude that these indirect impacts would be reduced to less than significant levels.

Other than the changes relating to the wind fence in the condition and in the verification (shown in strikeout below), staff finds the other revisions to **BIO-20** suggested by the Applicant to be acceptable.

SAND DUNE/MOJAVE FRINGE-TOED LIZARD MITIGATION

BIO-20 To mitigate for habitat loss and direct impacts to Mojave fringe-toed lizards the Project owner shall provide compensatory mitigation, which may include compensation lands purchased in fee or in easement in whole or in part, at the following ratios:

- 3:1 mitigation for direct impacts to stabilized and partially stabilized sand dunes (~~285 acres~~ per **BIO-29 – Table 2** or final acreage impacted by the Project footprint);

- 1:1 mitigation for direct impacts non-dune Mojave fringe-toed lizard habitat (~~1,496 acres~~ per **BIO-29 – Table 2** or final acreage impacted by the Project footprint); and
- ~~If the Project owner includes fencing along the northern and eastern boundaries of Phase 2 that includes features that block the wind from ground level to a height of 5 feet, the Project owner shall provide~~ 0.5:1 mitigation for indirect impacts to stabilized and partially stabilized sand dunes (~~1,629 acres~~ per **BIO-29 – Table 2** or final acreage impacted by the Project footprint).

If compensation lands are acquired, the Project owner shall provide funding for the acquisition in fee title or in easement, initial habitat improvements, and long-term maintenance and management of the compensation lands. In addition, the compensation lands must include ~~a minimum of 855~~ **at a minimum, the number of** acres of stabilized and partially stabilized sand dune habitat **shown in BIO-29 Table 2**.

1. Criteria for Compensation Lands: The compensation lands selected for acquisition shall:
   a. Provide suitable habitat for Mojave fringe-toed lizards, and, aside from the minimum amount of stabilized and partially stabilized sand dunes, may include stabilized and partially stabilized desert dunes, sand drifts over playas, or Sonoran creosote bush scrub;
   b. Be within the Palen or Chuckwalla valleys with potential to contribute to Mojave fringe-toed lizard habitat connectivity and build linkages between known populations of Mojave fringe-toed lizards and preserve lands with suitable habitat;
   c. Be prioritized near larger blocks of lands that are either already protected or planned for protection, or which could feasibly be protected long-term by a public resource agency or a non-governmental organization dedicated to habitat preservation;
   d. Provide quality habitat for Mojave fringe-toed lizard that has the capacity to regenerate naturally when disturbances are removed;
   e. Not have a history of intensive recreational use or other disturbance that might make habitat recovery and restoration infeasible;
   f. Not be characterized by high densities of invasive species, either on or immediately adjacent to the parcels under consideration, that might jeopardize habitat recovery and restoration;
   g. Not contain hazardous wastes that cannot be removed to the extent the site is suitable for habitat;

h. ~~Not be subject to property constraints (i.e. mineral leases, cultural resources)~~ Have water and mineral rights included as part of the acquisition, unless the CPM, in consultation with CDFG, BLM and USFWS, agrees in writing to the acceptability of the land; and

i. Be on land for which long-term management is feasible.

2. Security for Implementation of Mitigation: The Project owner shall provide financial assurances to the CPM to guarantee that an adequate level of funding is available to implement the acquisitions and enhancement of Mojave fringe-toed lizard habitat as described in this condition. These funds shall be used solely for implementation of the measures associated with the Project. Financial assurance can be provided to the CPM according to the measures outlined in **BIO-12**, and within the time period specified for this assurance (see the verification section at the end of this condition). The final amount due will be determined by an updated appraisal and a PAR analysis conducted as described in **BIO-12**, but current estimates are included in **Biological Resources Tables 22** and **23** located at the beginning of the Conditions of Certification subsection.

3. Preparation of Management Plan: The Project owner shall submit to the CPM, BLM, and CDFG a draft Management Plan that reflects site-specific enhancement measures for the Mojave fringe-toed lizard habitat on the acquired compensation lands. The objective of the Management Plan shall be to enhance the value of the compensation lands for Mojave fringe-toed lizards, and may include enhancement actions such as weed control, fencing to exclude livestock, erosion control, or protection of sand sources or sand transport corridors.

Verification: ~~No later than 30 days prior to beginning Project ground-disturbing activities, the Project owner shall submit to the CPM for review and approval plans detailing fencing that allows sand movement through the northern and eastern boundaries of Phase 2.~~

No later than 30 days prior to beginning Project ground-disturbing activities, the Project owner shall provide written verification of an approved form of Security in accordance with this condition of certification. Actual Security shall be provided no later than 7 days prior to the beginning of Project ground-disturbing activities for each Project phase as described in **BIO-29**. The Project owner, or an approved third party, shall complete and provide written verification of the proposed compensation lands acquisition within 18 months of the start of Project ground-disturbing activities for each Project phase.

No less than 90 days prior to acquisition of the property, the Project owner shall submit a formal acquisition proposal to the CPM, CDFG, and USFWS describing the parcels intended for purchase.

The Project owner, or an approved third party, shall provide the CPM, BLM, and CDFG, with a management plan for the compensation lands and associated funds within 180 days of the land or easement purchase, as determined by the date on the title. The CPM shall review and approve the management plan, in consultation with BLM and CDFG.

Within 90 days after completion of Project construction, the Project owner shall provide to the CPM and CDFG an analysis with the final accounting of the amount (detailed by habitat type) of Mojave fringe-toed lizard habitat disturbed during Project construction.

The Project owner shall provide written verification to the CPM, and CDFG that the compensation lands or conservation easements have been acquired and recorded in favor of the approved recipient no later than 18 months from the start of ground-disturbing activities.

BIO-23 GROUNDWATER DEPENDENT VEGETATION MONITORING AND BIO-24 REMEDIAL ACTION

Staff accepted some but not all of the Applicant's suggested language in conditions of certification **BIO-23** and **BIO-24** (Groundwater-Dependent Vegetation Monitoring and Remedial Action). The Applicant disagreed with staff's assumption that pumping of the deep aquifer may cause downward flow of the shallow aquifer in the eastern portion of the project, becoming a source of deep aquifer recharge. The applicant's hydrogeologist noted that there was some recharge occurring to the north of the pumped well. If this were to occur, it could lower the shallow water table below the effective rooting depth of the groundwater-dependent ecosystems.

The Applicant believes that such vegetation (phreatophytes) is supported by a perched shallow aquifer that is not hydraulically connected to the deeper aquifer from which it will draw water. Therefore, the Applicant proposed modifications to the condition that would allow it to prove through geological investigation that the lower aquifer is not hydraulically connected to the groundwater that supports the phreatophytes.

Staff accepts the Applicant's proposal to conduct additional pre-construction testing, with some modifications. Staff disagrees with the Applicant's assumption that if groundwater was measured at 180 feet deep at the Project site that it could not be related to groundwater that is being used by the phreatophytes located approximately two miles up-gradient of the Project site. The Applicant has not provided evidence that the shallow groundwater used by the phreatophytes is unrelated to the deeper groundwater proposed for Project water supply needs.

Further, the Applicant's hydrogeologist noted that there was some recharge occurring to the north of the pumped well. Staff also notes that the Applicant has offered no evidence to show that the extent, thickness, continuity, and permeability of the aquitard is sufficient to preclude vertical or horizontal flow of groundwater. Staff is concerned about evidence in Chuckwalla Valley of historic impacts from groundwater pumping, and documented evidence of pumping impacts to similar communities in similar settings throughout California.

Staff accepts—in concept—the Applicant's proposal to conduct pre-construction soil and aquifer testing to determine whether additional long-term monitoring, as described in **BIO-23,** was still warranted (see **BIO-23**, #15 a-d). However, staff added a requirement to refine the modeling of the predicted groundwater drawdown and zone of influence after two years of data collection (following commencement of groundwater production) from the Project wells and piezometers (see **SOIL&WATER-4**, **SOIL&WATER-6**). Staff also added a threshold or trigger for additional off-site monitoring if the refined modeling indicates the drawdown or zone of influence would be greater than predicted in the Applicant's Groundwater Investigation.

Staff finds the other revisions to **BIO-23 & -24** suggested by the Applicant to be acceptable. Staff also made some revisions to the original language based on consultation with Todd Keeler-Wolf, the Senior Vegetation Ecologist with the California Department of Fish and Game, and Kit Custis, Senior Engineering Geologist (various electronic communications with Carolyn Chainey-Davis between October 4, 2010 and October 20, 2010).

GROUNDWATER-DEPENDENT VEGETATION MONITORING

BIO-23 The Project owner shall prepare a Groundwater-Dependent Vegetation Monitoring Plan for monitoring the Project effects of groundwater pumping on groundwater dependent vegetation. The monitoring shall encompass the area depicted in *Figure Soil and Water-3 (Project Only Revised Operational Water Supply End of 30 Years)* within the 0.1-foot drawdown polygon of the Model Predicted Drawdown (Galati & Blek 2010i). The vegetation and groundwater data collected as part of the Plan shall be used to determine if remedial action is required, as described in **BIO-24.**

The Project owner may forgo development of a Groundwater Dependent Vegetation Monitoring Plan, or may cease implementation of such a plan, by providing evidence to the CPM that the **source of water for the GDEs is a shallow perched water-bearing zone rather than the regional groundwater system and that the shallow perched water-bearing zone is unrelated and not influenced by the regional groundwater system that the Project owner proposes**

to use for water supply~~ source of water for the GDEs is regional groundwater rather than a shallow water-bearing zone unrelated to the regional water table~~ as described under Condition 15a – 15d.

The Project owner shall develop and implement a Groundwater-Dependent Vegetation Monitoring Plan (Plan) that meets the performance standards described below and includes the following components:

1. Monitoring Objectives and Performance Standards. The objectives of the Plan shall be to monitor the Project effects of groundwater pumping on vegetation and groundwater-dependent ecosystems (GDEs) and, in conjunction with the remedial action described in **BIO-24**, to ensure that the Project groundwater pumping has a less than significant effect on biological resources. Monitoring shall be conducted at a level of detail adequate for detecting adverse effects, as reflected in vegetation attributes and groundwater levels in the shallow (alluvial) aquifer. The baseline for groundwater levels shall be the lowest baseline water level as measured at the Project site prior to the start of groundwater pumping.

2. Location of Monitoring Plots. The monitoring plots shall be established within the area depicted in *Figure Soil and Water -3 (Project Only Revised Operational Water Supply End of 30 Years)* within the Model Predicted Drawdown showing the 0.1-foot drawdown polygon (Galati & Blek 2010i). **The majority of the plots shall be in the area north and east of the Project site, where groundwater-dependent ecosystems (GDEs) and the intersection of the ground surface and shallow groundwater are located, in the topographic lows in the valley.**~~Monitoring shall focus in particular on impacts within the areas most likely to experience groundwater drawdown, therefore the majority of the plots shall be established within the predicted 1-foot drawdown area depicted in *Soil and Water Figure 2 (Project Only Revised Construction Water Supply)* (Galati & Blek 2010i)~~

3. Monitoring Plots and Controls. Because of the variation in vegetation types and depth to groundwater within the predicted groundwater drawdown zone, the study design shall treat the monitoring plot with a corresponding control plot as a pair (versus comparing the mean of all treatment plots to the mean of all control plots). The “control” plots shall consist of the data collected at the same plot during the baseline (pre-disturbance) monitoring for a pre-disturbance vs. post-disturbance comparison. Appropriate statistical methods shall be used to analyze the differences

between the control and monitoring plots (for example, a one-tailed paired-sample statistical test (Manly 2008)[1]).

4. Off-Site Reference Plots: Off-site monitoring plots shall be established as reference sites to distinguish changes in plant vigor seen at the site from the effects of a region-wide drought. The off-site reference plots can be located within Chuckwalla Valley but shall be within areas that would not be affected hydrologically by groundwater pumping for the Project or other projects or agricultural operations. Off-site monitoring reference plots shall be located in the same **general hydrologic and geologic setting** (i.e., **playa margins** ~~dry playa and adjacent sandy plains~~), in the same climatic region (Sonoran Desert region of California), and contain the same natural communities or vegetation alliances as those to which they are being compared. Impacts from pests and diseases, if present, must also be considered and excluded or adjusted for as part of the analysis. **Data on climate and surface runoff in the study area shall be collected to identify "drought" conditions and correlate groundwater changes and weather changes.**

5. Sample Size and Design The number of monitoring sites shall be established using appropriate statistical methods (for example, by a "priori power analysis" (Elzinga et al. 1998)) and shall be sufficient to achieve adequate (90%) statistical power. Following collection of the baseline data a statistical analysis shall be conducted to refine the power analysis and evaluate the adequacy of the sampling design. If the analysis of baseline data indicates that the sampling design is insufficient to achieve adequate statistical power, the design shall be modified (for example, by adding additional monitoring sites).

6. Water Table Monitoring. The Project owner shall install piezometers at each of the dominant vegetation community types within or near the monitoring plots. The number, location, depth and monitoring frequency of the piezometers shall be sufficient to establish the effect of Project groundwater pumping on the shallow aquifer water levels. At a minimum, each piezometer shall be monitored twice per year, in early spring (March) and post-monsoon (September). The piezometers shall be designed to monitor the maximum expected fluctuation in the water table and to last the duration of the Project. **Data collected from the Project wells and piezometers for SOIL &WATER-4 (Groundwater Level Monitoring, Mitigation, and Reporting) and S&W-6 (groundwater monitoring for the evaporation ponds and land treatment unit) shall be used to refine the modeling of the predicted groundwater drawdown**

[1] Manly, B. 2008. Statistics for Environmental Science and Management (2nd ed). CRC Press/Chapman and Hall. 292 pages.

and zone of influence after two years of data collection following the start of groundwater production. The Project owner shall submit to the CPM, for review and approval, a report on the results of the refined modeling. The report shall include all calculations and assumptions made in development of report data and interpretations, and all well monitoring data and piezometer data collected and used in the calculations. If the results indicate that the drawdown and zone of influence is greater than the effect predicted in the GRI, and the GDE are found to be drawing groundwater that is hydraulically connected to the regional groundwater system, then the project owner will submit a revised monitoring plan for GDE areas outside of the original monitoring area.

7. Soil Monitoring. Soil salinity and pH shall be monitored annually at every monitoring plot. The Plan shall describe the monitoring devices and techniques used to collect and interpret this data, relative to ecosystem function. One soil core sample per community type shall be collected as part of the baseline data to establish the approximate rooting depth of the phreatophytes, and thereafter shall be repeated every five years. The coring method must provide a continuous core that will provide visual examination of roots and root nodules, soil profile, and soil moisture.

8. Baseline and Long-term Data Collection. At a minimum, baseline data shall be collected at all monitoring sites prior to the start of pumping; however, vegetation data collected from sites farther from the nearest wells will allow for the collection of multiple years of "pre-disturbance" data. Although the Project proposes to begin construction (and pumping) by December 2010, it appears that the effects of pumping would not reach the areas supporting the GDEs or phreatophytic plants for several years (see C.9 **Soil and Water Resources**). Because the proposed well in the northeast portion of the Project (Soil & Water Figure 1, Galati & Blek 2010i) is located in very close proximity to known phreatophytes, this well shall not be used within the first 3 years of the Project in order to allow an adequate period for baseline data collection in the area northeast of the Project. Subject to approval by the CPM, if groundwater pumping ceases or is replaced by other water sources, groundwater and vegetation monitoring shall continue for a period of 5 years or until refined modeling indicates that the groundwater levels have returned to baseline levels and the decline in plant vigor has been restored to pre-disturbance conditions.

9. Target Vegetation Population. The monitoring sites shall include GDEs and other vegetation potentially affected by the drawdown **that occur within the zone of influence. The following phreatophytes have been documented to occur around Palen**

Lake:~~, including thephreatophytes documented to occur in the Palen Lake area such as:~~ honey mesquite (*Prosopis glandulosa*); iodine bush (*Allenrolfea occidentalis*), bush seep-weed (*Suaeda moquinii*), jackass clover (*Wislizenia refracta*), four-wing saltbush (*Atriplex canescens*), allscale (*A. polycarpa*), spinescale (*A. spinifera*), **a potentially new taxon of saltbush (*Atriplex* sp. nov. Andre),** ~~and any other sink scrubs and playa margin communities detected during the vegetation mapping described in this condition. Monitoring sites shall also include microphyll woodlands with~~ **ironwood (*Olneya tesota*),** palo verde (*Cercidium microphyllum*), cat's claw (*Acacia greggii*), and smoke tree (*Psorothamnus spinosus*). ~~Sampling shall also include examples of non-phreatophytes that occur within the affected area (creosote bush (*Larrea tridentata*) and white bursage (*Ambrosia dumosa*) alliances/associations).~~ The final number of each community type sample needed shall be based on the *priori* power test conducted after the first year of baseline data collection.

10. Fine-Scale Vegetation Mapping. Within the monitoring sites vegetation shall be mapped to the alliance level, consistent with classification protocol in the *Manual of California, 2nd edition* (Sawyer et al. 2009) but any important associations shall also be mapped. Mapping shall be done using minimum 1 meter resolution color orthophotos or higher resolution infrared imagery. The mapping shall also be used to determine the acreages of GDEs and establish the amount of security to be deposited in the event that adverse effects are detected during the monitoring.Boundaries of the permanent plots and any off-site reference sites shall be recorded using GPS technology and depicted on the geo-referenced aerials. GIS shapefiles and metadata shall be submitted along with the draft Plan and any subsequent revisions to the Plan (i.e., following the collection of baseline data and subsequent power analysis).

11. Guidelines for the Monitoring Plan. The Groundwater-Dependent Vegetation Monitoring Plan (Plan) shall be prepared ~~consistent~~ with guidance **from** ~~for designing vegetation monitoring plans and conducting statistical analysis such as those found in~~ *Measuring and Monitoring Plant Populations* (Elzinga et al. 1998) ~~and Statistics for Environmental Science and Management (Manly 2008).~~ The Plan shall provide a detailed description of each of the following components:

    a. Sampling Design. The sampling design shall include a description of: a) the populations (vegetation types) sampled; b) number, size, and shape of the sampling units; c) layout of the sampling units; d) methods for permanently marking plots in the field; e) monitoring schedule/frequency; f) vegetation and other

attributes sampled; and g) sampling objectives (target/threshold, change/trend-based) for each attribute.

b. Habitat Function and Values. The Plan shall describe the hydrologic, geologic/geomorphic, geochemical, biological and ecological characteristics of the GDEs, and shall also describe whether species are obligate or facultative; root growth and water acquisition characteristics; morphological adaptations to the desert environment; reproduction and germination characteristics; general and micro-habitat preferences; obligate or facultative halophytes and phreatophytes; role in the morphology of dunes; and importance to wildlife, etc.

c. Field techniques for measuring vegetation. This will include the vegetation (or other) attributes selected based on a demonstrated knowledge of the biology and morphology of the species, and include a discussion of the limitations involved in each measurement. Examples of appropriate field techniques for measuring drought response include: percent dieback; live crown density; **crown height and width,** percent cover of live (versus dead or residual) vegetation, percent cover/frequency of associated species; percent composition of native versus non-native species; and percent cover based on wetland status codes (OBL, FACW, FAC, FACU, UPL[2]) and status as phreatophytes or halophytes. Photo monitoring shall not be considered an acceptable monitoring method but may be useful to conduct periodically (e.g., every 3 to 5 years).

d. Data Management. Including how the data will be recorded in the field (e.g., using a GPS data dictionary), processed and stored.

e. Training of personnel. Describe minimum standards for training and monitoring personnel.

f. Statistical analysis. Describe statistical methods used to analyze the monitoring data (incorporating the minimum standards for statistical power and error rate described above).

12. Peer Review of the Plan. The draft Plan shall undergo a peer review by recognized experts, which shall include one or more scientists with expertise in: the preparation of monitoring plans for plant populations; the physiological responses of desert phreatophytes to drought stress; assessing the effects of groundwater withdrawal on vegetation in the desert region; and biostatistics. The Project owner shall provide the resumes of suggested peer reviewers to the CPM for review and approval.

[2] OBL= Obligate Wetland; FACW= Facultative Wetland; FAC= Facultative; FACU= Facultative Upland UPL= Obligate Upland. *In;* U.S. Fish and Wildlife Service. 1993. **1993 supplement to list of plant species that occur in wetlands: Northwest (Region 9).** Supplement to U.S. Fish & Wildlife Service Biological Report 88 (24.9). Online: http://plants.usda.gov/wetinfo.html

13. Annual Monitoring Report. Annual Monitoring Reports shall be submitted to the CPM and BLM and shall include, at a minimum: a) names and contact information for the responsible parties and monitoring personnel; b) summaries of the results of the monitoring as required in **Soil&Water-4 and Soil&Water-6~~5~~**; c) piezometer monitoring results**,** and a comparison of predicted versus actual water table declines; d) summary of the results of vegetation, groundwater, and soil monitoring data compared to the baseline data for each plot (pre- versus post-disturbance comparison); e) description of sampling and monitoring techniques used for each attribute; f) description of the data management and statistical analysis; g) photos; h) conclusions and recommendations for remedial action, if the monitoring data indicates that the threshold described below has been met.

    The first Annual Monitoring Report shall include an appropriate statistical analysis using the first year baseline monitoring data to assess whether the sampling design was adequate to provide statistically meaningful data, as described above. If warranted, the first year Annual Monitoring Report shall include recommendations for revisions to the Plan based on this analysis.

14. Threshold for Remedial Action: The Project owner shall implement remedial action, as described in Condition of Certification **BIO-24,** if the monitoring described in **BIO-23** detects a decline in plant vigor of 20 percent or more compared to the same plots pre-disturbance AND also detects a decline in the alluvial (shallow) aquifer confirmed by two consecutive annual water monitoring events in any amount greater than the lowest baseline water level as measured prior to groundwater pumping. If regional drought, off-site pumping or other activities unrelated to the Project are also contributing to the decline in water table, the Project owner shall only be responsible for the portion of the effect that can be statistically demonstrated to be the result of Project pumping. To determine whether declines in plant vigor ~~and aquifers are is~~ are related to Project pumping as opposed to regionwide drought or offsite pumping conditions the Project owner shall install a network background monitoring piezometers and incorporate these dat~~r~~a in the ~~this analysis in the~~ assessment of Project-related effects on GDEs.

15. To understand the source of the water for the GDEs, the Project owner shall prepare a groundwater investigation work plan for submittal to the CPM that will outline steps to determine if the source of water for the GDEs is regional groundwater and not a shallow water-bearing zone unrelated to the regional water table.

The groundwater investigation will be comprised of the following components:

a. A continuous soil coring program at five locations to be identified based on field mapping of GDEs in the area shown on the Figure *Soil and Water-3 (Project Only Revised Operational Water Supply End of 30 Years)* within the 0.1-foot drawdown polygon of the Model Predicted Drawdown (Galati & Blek 2010i). One of the five borings will be drilled adjacent to a GDE containing mesquite, and the other four located to provide an assessment of the range of plant communities within GDEs in the area of interest (i.e., to assess the variability of GDE plant type water requirements and root zone depth).

b. The soil cores shall extend a minimum of 20 feet below the **deepest** root zones of the GDEs investigated to demonstrate separation between the shallow and regional water zones. At a minimum the soil cores shall show that 20 feet of unsaturated conditions are present below the **deepest** root zones of the plant communities investigated. The soil cores will be logged by a professional geologist in the State of California, and the coring program will be overseen by a qualified biologist with experienced in the plant communities identified within each GDE.

c. A sampling plan for selective analysis of soil moisture content and saturation will also be conducted for each soil core advanced adjacent to a GDE. The number and frequency of soil samples shall be established to confirm field observations of soil moisture content in the shallow water-bearing zone, through the root zone and in the deeper sediments below the root zone above the regional water table. Soil samples shall be analyzed for moisture content after ASTM Method D2216.

d. Depending on the results of the soil coring program, piezometers may be installed as monitoring points for the regional water table and to monitoring changes in the shallow water-bearing zone from Project pumping. In the report of results from the soil coring program, a water-level monitoring program shall be proposed if it is shown that the regional water table is **in direct hydraulic connection to** the source of water to the GDE's. If the field data clearly shows **an unsaturated zone** ~~separation~~ of 20 feet or more **below the deepest root zones of the GDEs,** then piezometers will not be installed.

If the results of the **pre-construction** field observations and soil sampling demonstrate 20 feet or more of ~~separation~~ **unsaturated sediments** between the ~~shallow water-bearing sediments~~**deepest root zones of the GDEs** and the regional water table, there will be no requirements to implement any of the underlying conditions as provided for in BIO-23 and BIO-24, as sufficient evidence will have been provided to demonstrate that the groundwater is not the source for the GDE's.

If the refined modeling of the predicted groundwater drawdown and zone of influence after two years of data collection (following the start of groundwater production), as described in Subsection 6 of this condition and in SOIL&WATER-4 and SOIL&WATER-6, indicates the drawdown or zone of influence would be greater than predicted in the Project owner's Groundwater Resources Investigation (GRI), and the GDE are found to be drawing groundwater that is hydraulically connected to the regional groundwater system, then the project owner will submit a revised monitoring plan for GDE areas outside of the original monitoring area .

Verification: ~~No more than 45 days following the docketing of the Energy Commission Final Decision~~ At least 30 days prior to operation of project pumping wells, the Project owner shall submit to the CPM and BLM for review and approval a draft Groundwater-Dependent Vegetation Monitoring Plan (Plan). ~~and the resumes of proposed peer reviewers~~ The final plan ~~draft, which~~ shall incorporate recommendations from the peer review and shall be submitted to the CPM and BLM no less than 15 days prior to the start of groundwater pumping.

No less than 15 days prior to the start of groundwater pumping the Project owner shall submit as-built drawings indicating the location and depth of piezometers, and shall provide evidence that the piezometers are operational.

Baseline groundwater and groundwater-dependent vegetation monitoring shall begin 15 days prior to construction ~~no later than March 1st following docketing of the Energy Commission Final Decision~~ and shall occur every year during the same one to two week time period in early spring (March) and post-monsoon (September).

The First Annual Monitoring Report shall be provided to the CPM and BLM no later than January 31st following the first year of data collection, and shall include an assessment of whether the sampling design would provide statistically adequate monitoring data and whether modifications to the monitoring design would be needed. If the first Annual Monitoring Report recommends a revised sampling design, the Project owner shall submit the revised Plan to the CPM and BLM no later than March 1st.

Thereafter the Project owner shall submit a Groundwater-Dependent Vegetation Annual Monitoring Report to the CPM and BLM no later than January 31st of each year for the duration of Project operation.

If the project owner elects to prepare a **geologic and** groundwater investigation **(as described in Subsection 15 a-d of this condition)** to determine if the **source of water for the GDEs is a shallow perched water-bearing zone rather than the regional groundwater system, and that the shallow perched water-bearing zone is unrelated and not influenced by the regional groundwater system that the Project owner proposes to use for water supply**~~source of the water for the GDEs is regional groundwater, and not a shallow water bearing zone~~, the project owner shall submit the resumes of at least two independent, qualified peer reviewers 45 days prior to submittal of the report **to the CPM and BLM for review and approval. The Project owner must submit the results of their investigation, subject to review and approval by the CPM, prior to the start of construction or Project groundwater use.**

If the refined modeling conducted according subsection 6 of this condition indicates that the drawdown and zone of influence is greater than the effect predicted in the GRI, and the GDE are found to be drawing groundwater that is hydraulically connected to the regional groundwater system, then the Project owner shall submit a revised monitoring plan for GDE areas outside of the original monitoring area. The Revised Monitoring Plan shall be submitted no later than January 31st in the third year following the start of groundwater pumping and well monitoring.

REMEDIAL ACTION AND COMPENSATION FOR ADVERSE EFFECTS TO GROUNDWATER-DEPENDENT BIOLOGICAL RESOURCES

BIO-24 If monitoring detects Project-related adverse impacts to groundwater dependent ecosystems (GDEs), as described in **BIO-23** and the impacts are shown to be the result of a decline in the regional groundwater table due to Project pumping, the Project owner shall determine which well(s) are the source of the adverse impacts and shall implement remedial measures as outlined below. If regional drought, off-site pumping or other activities unrelated to the Project are also contributing to the decline in water table, the Project owner shall only be responsible for the portion of the effect that can be demonstrated to be the result of Project pumping. The remedial measures shall be implemented ~~cease pumping at those well(s). In addition, the Project owner shall prepare and implement a detailed Remedial Action Plan~~ with the objective of restoring the groundwater levels to the baseline described in **BIO-23**, and shall compensate for impacts to GDEs with off-site habitat acquisition or restoration. The Project owner shall do all of the following:

1. Modification and/or Cessation of Pumping: The Project owner shall provide to the CPM evidence based on groundwater monitoring and modeling indicating which wells are likely to be causing adverse impacts to GDEs. The Project owner shall initially modify operation of ~~cease operation of~~ those wells to reduce the offsite drawdown in the areas of the GDEs.

   Remedial Action Plan: The objective of remedial action shall be restoration of the spring groundwater table in the alluvial (shallow) aquifer to baseline levels, as described in **BIO-23**. The Remedial Action Plan shall include one or more of the following measures: 1) Begin rotational operation of the site water supply wells reducing pumping in wells that are the most proximal to the GDEs, 2) reducing the pumping rate in the wells that have been identified as the cause of the drawdown in the area of the GDEs, 3) focus pumping on wells on the southern portion of the project site away from the GDEs 4) cease operation of the well(s) that are the cause of the drawdown. Groundwater water level monitoring shall increase to a frequency necessary to document change and recovery in the drawdown from the changes in the pumping program. ~~1) relocate the Project pumping well to another location where the groundwater-dependent vegetation is no longer within the area of groundwater drawdown, or 2) reduce Project water usage through water conservation methods or new technologies to a level that would restore groundwater levels in the shallow aquifer to the pre-impact levels.~~

   The Remedial Action Plan shall include a water level monitoring program of sufficient frequency to document changes in operation of the water supply wells, and demonstrate that the water table has been restored to baseline levels. ~~provide evidence that the proposed measures would restore the spring groundwater table in the alluvial (shallow) aquifer to baseline levels and would help restore healthy ecological functioning in the affected plant communities.~~

   ~~If installation of a new, relocated well is proposed as remedial action, the Project owner shall identify the proposed location of the new well in relation to phreatophytic communities and shall provide evidence through groundwater modeling that groundwater dependent communities do not occur within the 0.1-foot cone of groundwater drawdown around the well.~~ The Project owner shall use the following guidelines for determining if an ecosystem (or species) is phreatophytic (Brown et al 2007; LeMaite et al 1999; Froend & Loomes 2004):

   a. It is not known or documented to depend on groundwater, based on scientific literature or expert opinion (local knowledge

can be useful in making a determination as some species' dependence varies by setting);

b. The species are not known to have roots extending over a meter in depth;

c. The community does not occur in an area where the water table is known to be 'near' the surface (relative to the documented rooting depths of the species);

d. The herbaceous or shrub vegetation is not still green and/or does not have a high leaf area late in the dry season (compared to other dry areas in the same watershed that do not have access to groundwater).

2. Compensate for Loss of Ecosystem Function. If the decline in the water table in the alluvial (shallow) aquifer is accompanied by a corresponding decline in plant vigor greater than 20 percent (as described in BIO-23), the Project owner shall compensate for the loss of habitat functions and values in the affected groundwater-dependent ecosystems. The amount of compensation shall be at a 3:1 ratio based on area of affected area, using mapping as described in **BIO-23**. The Project owner shall acquire, in fee or in easement, a parcel or parcels of land that include an amount of groundwater-dependent vegetation that is of the same habitat-type as the community affected (e.g., mesquite woodland, alkali sink scrubs, or microphyll woodland) and of an equal or greater habitat quality. The compensation lands shall be located within the watersheds encompassing the Chuckwalla or Palen valleys. As an alternative to habitat compensation, the Project owner may submit a plan that achieves restoration of lost habitat function and value at another location ~~offsite and~~ within the Chuckwalla Groundwater Basin that contains the same habitats as those affected.

   a. Review and Approval of Compensation Lands Prior to Acquisition or re**s**toration. The Project owner shall submit a formal acquisition proposal to the CPM describing the parcel(s) intended for purchase. This acquisition proposal shall discuss the suitability of the proposed parcel(s) as compensation lands in relation to the criteria listed above. Approval from the CPM shall be required for acquisition of all compensatory mitigation parcels.

   b. Preparation of Management Plan: The Project owner shall submit to the CPM and CDFG a draft Management Plan that reflects site-specific enhancement measures for the acquired compensation lands. The objective of the Management Plan shall be to maintain the functions and values of the acquired GDE plant communities and may include enhancement actions

such as weed control, fencing to exclude livestock, or erosion control.

c. Delegation of Acquisition. The responsibility for acquisition of compensation lands may be delegated to NFWF or another third party other than NFWF, such as a non-governmental organization supportive of desert habitat conservation, by written agreement of the Energy Commission. Such delegation shall be subject to approval by the CPM prior to land acquisition, enhancement or management activities.

Verification: No more than 30 days following submission of the Groundwater Dependent Vegetation Annual Monitoring Report ~~No more than 30 days following submission of the Groundwater-Dependent Vegetation Annual Monitoring Report,~~ the Project owner shall submit to the CPM for review and approval a draft Remedial Action Plan if that report indicates that the threshold for remedial action as described in **BIO-23** has been met. At the same time the Project owner shall submit written evidence that the Project wells responsible for impacts to groundwater levels and GDEs have modified their operation or ~~under~~ ceased operation.

A final Remedial Action Plan shall be submitted to the CPM within 30 days of receipt of the CPM's comments on the draft plan. No later than 6 months following approval of the final Remedial Action Plan, the Project owner shall provide to the CPM written documentation of the effectiveness of the completed remedial action.

No more than 30 days following submission of the Groundwater-Dependent Vegetation Annual Monitoring Report**,** the Project owner shall provide to the **CPM** a final accounting of the amount of GDE habitat affected by Project groundwater pumping.

No more than 6 months following submission of the Groundwater-Dependent Vegetation Annual Monitoring Report the Project owner shall submit a formal acquisition or restoration proposal to the CPM, describing the mitigation parcels intended for purchase or restoration. The acquisition/restoration proposal shall describe how the proposed parcels meet the acquisition or restoration criteria described in this condition.

No fewer than 90 days prior to **compensatory** acquisition or restoration ~~of compensatory mitigation lands~~, the Project owner shall submit to the CPM and obtain CPM approval of any agreements to delegate land acquisition to an approved third party, or to manage compensation lands; such agreement shall be executed and implemented no more than months following approval of the acquisition proposal.

The Project owner shall provide written verification to the CPM that the compensation lands or conservation easements have been acquired and recorded in favor of the approved recipient no later than 18 months from

submission of the Groundwater-Dependent Vegetation Annual Monitoring Report.

PROJECT CONSTRUCTION PHASING PLAN

Tables **BIO-29 Table 1, BIO-29 Table 2,** and **BIO-29 Table 3,** below, replace **Biological Resources Tables 22, 23,** and **24** in the Revised Staff Assessment (RSA). Staff agrees with the Applicant's proposed text changes to **BIO-29**, but has modified the tables.

The Applicant included new values for indirect impacts to Mojave fringe-toed lizard habitat and the sand transport corridor in their Opening Testimony, but has not communicated the methods behind this recalculation or demonstrated the absence of indirect impacts to this resource during Phase 1 of both the alternatives. Therefore, staff has reverted to their most recently calculated numbers (from the RSA), and has adjusted the values in the tables below. Staff recalculated the Security based on the compensatory acreages in **BIO-29 Table 2** using the July 23, 2010 version of the REAT table (REAT 2010) and edited **BIO-29 Table 3** based on these calculations.

BIO-29 The Project Owner shall provide compensatory mitigation for the total Project Disturbance Area and may provide such mitigation in two phases for Units 1 and 2 as described in Figures BIO-5 and BIO-6 in the July 19, 2010 Response to Data Request (AECOM 2010u). For purposes of this condition, the Project Disturbance Area means all lands disturbed in the construction and operation of the Palen Project or its phases, including all linears and ancillary facilities, as well as undeveloped areas inside the Project's boundaries that would no longer provide viable long-term habitat.

The disturbance area for each project Phase and resource type is provided in **BIO-29** Table 1 ~~the tables~~ below. Mitigation is shown in **BIO-29** Table 2, **and mitigation security is shown in BIO-29 Table 3,** below**.** This table shall be refined prior to the start of each construction phase with the disturbance area adjusted to reflect the final Project footprint for each phase. Prior to initiating each phase of construction the Project owner shall submit the actual construction schedule, a figure depicting the locations of proposed construction and amount of acres to be disturbed. Mitigation acres are calculated based on the compensation requirements for each resource type as described in the above conditions of certification – **BIO-12** (Desert Tortoise), **BIO-20** (Mojave Fringe-toed Lizard), **BIO-18** (Western Burrowing Owl), and **BIO-22** (State Waters). Compensatory mitigation for each phase shall be implemented according to the timing required by each condition.

BIO-29 Table 1. Area of Habitat Type Disturbed by Construction Phase (acres)[1]

Habitat Type	Reconfigured Alternative 2 Disturbance Area		Reconfigured Alternative 3 Disturbance Area	
	Phase 1	Phase 2	Phase 1	Phase 2
MFTL Habitat				
Stabilized & Partially Stabilized Dunes	44	112	59	128
Non-Dunes	637	711	509	845
Indirect Impacts[2]	~~0~~ **117**	~~135~~ **27**	~~0~~ **280**	~~115~~ **-186**
TOTAL	~~681~~ **798**	~~957~~ **850**	~~568~~ **848**	~~1089~~ **787**
DT Habitat				
DT Habitat - inside critical habitat[3]	225	0	225	0
DT Habitat - outside critical habitat	2115	1855	1969	1933
TOTAL[4]	**2340**	**1855**	**2194**	**1933**
WBO Habitat				
Impacts to 4 WBO	4 WBO	0	4 WBO	0
TOTAL	4 WBO	**0**	4 WBO	**0**
Jurisdictional Waters (Direct Impact)				
Dry Desert Wash Woodland	202	6	193	5
Unvegetated Ephemeral Dry Wash	99	81	95	73
Subtotal	***301***	***87***	***287***	***78***
Jurisdictional Waters (Indirect Impact)				
Dry Desert Wash Woodland	0	0	0	0
Unvegetated Ephemeral Dry Wash	17	2	15	2
Subtotal	***17***	***2***	***15***	***2***
TOTAL WATERS	**317**	**89**	**303**	**80**

1 – Sources: Reconfigured Alternatives 2 and 3 - Solar Millennium 2010l.
~~2 – Indirect Impacts if the CPM does not approve fencing that allows sand transport thorugh the site.~~ **Some indirect impacts in Alternative 3 within Phase 1 become direct impact in Phase 2. The security in Phase 3 is reduced to credit that portion of the security already provided to cover the indirect impacts in Phase 2.**
3 – Impacts to desert tortoise critical habitat are assumed to be wholly within the Phase 1 Project Disturbance Area.
4 – Raven Acres subject to the one-time USFWS Regional Raven Management Program fee are equivalent to the total DT Habitat impact acreages.

BIO 29 Table 2. Mitigation by Habitat Type Disturbed by Construction Phase (acres)[1]

Habitat Type	Mitigation Ratio	Reconfigured Alternative 2 Disturbance Area		Reconfigured Alternative 3 Disturbance Area	
		Phase 1	Phase 2	Phase 1	Phase 2
MFTL Habitat					
Stabilized & Partially Stabilized Dunes	3:1	~~0~~ **132**	336	178	385
Non-Dunes	1:1	637	711	509	845
Indirect Impacts[2]	0.5:1	~~0~~ **59**	~~68~~ **14**	~~0~~ **140**	~~58~~ **-93**
TOTAL		~~***637***~~ ***828***	~~***1114***~~ ***1061***	~~***687***~~ ***827***	~~***1288***~~ ***1137***
DT Habitat					
DT Habitat - inside critical habitat[3]	5:1	1127	0	1126	0
DT Habitat - outside critical habitat	1:1	2115	1855	1969	1933
TOTAL		**3242**	**1855**	**3095**	**1933**
WBO Habitat					
Impacts to 4 WBO	19.5 acre/WBO	78	0	78	0
TOTAL		78	**0**	78	**0**
Jurisdictional Waters (Direct Impact)					
Vegetated (Dry Desert Wash Woodland)	3:1	605	18	578	15
Unvegetated Ephemeral Dry Wash	1:1	99	81	95	73
Subtotal		***704***	***99***	***673***	***88***
Jurisdictional Waters (Indirect Impact)					
Vegetated (Dry Desert Wash Woodland)	1.5:1	0	0	0	0
Unvegetated Ephemeral Dry Wash	0.5:1	8	1	8	1
Subtotal		***8***	***1***	***8***	***1***
TOTAL WATERS		**712**	**100**	**680**	**89**

1 – Sources: Reconfigured Alternatives 2 and 3 - Solar Millennium 2010l.
2 – Mitigation for Indirect Impacts if the CPM does not approve fencing that allows sand transport thorugh the site.
3 – Impacts to desert tortoise critical habitat are assumed to be wholly within the Phase 1 Project Disturbance Area.

BIO-29 Table 3. Mitigation Securities by Construction Phase (acres)[1]

Habitat Type	Reconfigured Alternative 2 Security		Reconfigured Alternative 3 Security	
	Phase 1	Phase 2	Phase 1	Phase 2
MFTL Habitat	~~$1,968,197~~ **$2,481,714**	~~$3,439,948~~ **$3,239,487**	~~$2,115,886~~ **$2,478,739**	~~$3,976,935~~ **$3,401,144**
DT Habitat	~~$10,005,202~~ **$10,024,571**	~~$5,735,255~~ **$5,895,824**	~~$9,550,072~~ **$9,569,173**	~~$5,968,772~~ **$5,985,642**
Raven Fee Impacts[2]	$340,410	$194,775	$324,975	$202,965
WBO Habitat	$250,089	$0	$250,089	~~$282,522~~
Jurisdicational Waters	~~$2,191,999~~ **$2,254,165**	~~$310,565~~ **$322,117**	~~$2,096,486~~ **$2,113,340**	~~$282,522~~ **$282,820**
Total	~~***$14,755,897***~~ ***$15,350,949***	~~***$9,680,543***~~ ***$9,652,203***	~~***$14,337,507***~~ ***$14,736,316***	~~***$10,713,716***~~ ***$9,872,571***

1– Securities (aside from Raven fees) based on REAT Biological Resources Mitigation/Compensation Cost Estimate Calculation Table - July 23, 2010 (REAT 2010), **adjusted to reflect a 160-acre parcel size estimate. Security does not include NFWF fees.** Security amounts may change based on final Project footprint. The final amount shall be determined by an updated appraisal conducted as described in **BIO-12.**
2 – Based on U.S. Fish and Wildlife Service Cost Allocation Methodology for Implementation of the Regional Raven Management Plan, dated July 9, 2010 (USFWS 2010b). Fee calculated at $105/acre for direct project impacts.

Verification: The Project owner shall not disturb any area outside of the area that has been approved for that phase of construction and for the previously approved phases of construction.

No less than 30 days prior to the start of desert tortoise clearance surveys for each phase, the Project owner shall submit a description of the proposed construction activities for that phase to CDFG, USFWS and BLM for review and to the CPM for review and approval. The description for each phase shall include the proposed construction schedule, a figure depicting the locations of proposed construction, and amount of acres of each habitat type to be disturbed.

No less than 30 days prior to beginning Project ground-disturbing activities for each phase, the Project owner shall provide the form of Security in accordance with this condition of certification in the amounts described in **BIO-29 Table 3** ~~(below).~~ No later than 7 days prior to beginning Project ground-disturbing activities for each phase, the Project owner shall provide written verification of the actual Security. The Project owner, or an approved third party, shall complete and provide written verification of the proposed compensation lands acquisition within 18 months of the start of Project ground-disturbing activities for each phase.

Docket Number: 09-AFC-7 Date: 10/22/10

Project Name: Palen Solar Power Project

UPDATED STAFF EXHIBIT LIST

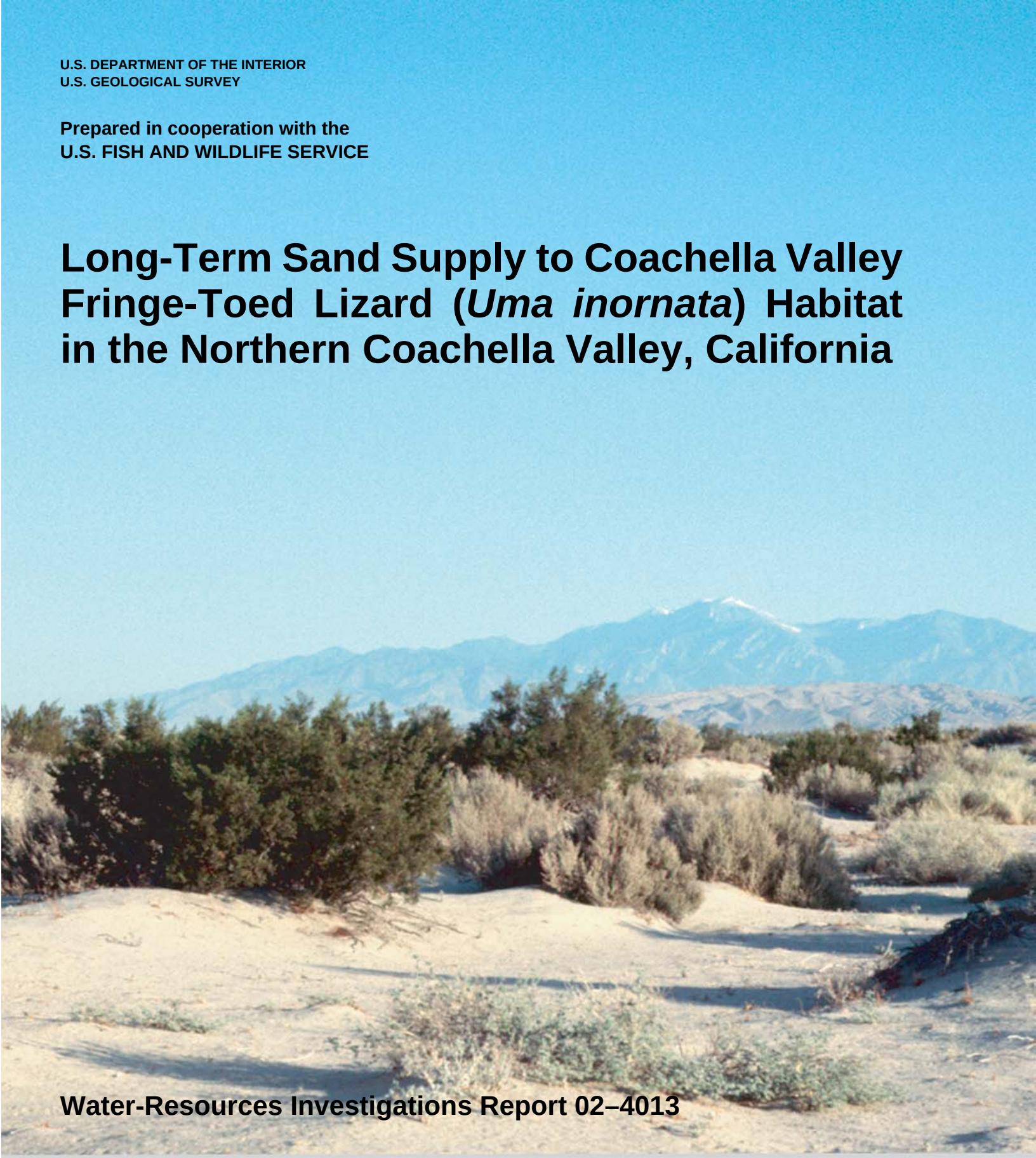
Exhibit	Witness	Brief Description	Stipulation	Offered	Admitted	Refused	CEC Use Only
300	Various	Revised Staff Assessment, Part I					
301	Various	Revised Staff Assessment, Part II					
302	Various	Energy Commission Staff's Rebuttal Testimony, filed October 11, 2010					
303		Energy Commission Staff's Rebuttal Testimony, filed October 22, 2010					
304		Griffiths et al 2002 report - Long-term sand supply to Coachella Valley fringe-toed lizard (*Uma inornata*) habitat in the northern Coachella Valley, California: U.S. Geological Survey Water-Resources Investigations Report.					
305		Turner et al 1984 report - Effects of reduction in windblown sand on the abundance of the fringe-toed lizard (*Uma inornata*) in the Coachella Valley, California. Copeia 1984.					
306		Barrows et al 2009 report - Effects of an invasive plant on a desert sand dune landscape. Biological Invasions 11:673.					
307		REAT Biological Resource Compensation/Mitigation Cost Estimate Breakdown for use with the REAT-N EWE Mitigation Account, dated July 23,					

		2010					
308		**Weaver, D.C. 1981. Aeolian sand transport and deposit characteristics at ten sites in Coachella Valley, California. Part II. In: The effect of blowsand reduction on the abundance of the fringe-toed lizard (*Uma inornata*) in the Coachella Valley, California. A report submitted to U.S. Army Corps of Engineers, Los Angeles District.**					
309		**Barrows, C.W. 1996 An ecological model for the protection of a dune ecosystem. Conserv. Biol. 10(3).**					
310		**Helix – Palen exhibit, Groundwater Drawdown and Vegetation Communities**					
311		**Figure 5.17-2 – Site Topography Map, Solar Millennium AFC August 2009, Water Resources Section**					
312		**Groundwater-dependent Ecosystems, Test Wells, and Proposed New Wells**					
313		**PWA Microsoft PowerPoint presentation**					
314		**Black and Veatch, LTPP Solar PV Performance and Cost Estimates**					
315		**Solar Millennium Responses to January 14, 2010 Workshop Queries on Ground Water.**					
316		**Wind Barriers offer Short Term Solution to Fugitive Dust. California Agriculture, Volume 52, Number 4, pages 14 – 18.**					

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
U.S. FISH AND WILDLIFE SERVICE

Long-Term Sand Supply to Coachella Valley Fringe-Toed Lizard (*Uma inornata*) Habitat in the Northern Coachella Valley, California



Water-Resources Investigations Report 02–4013

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COVER PHOTOGRAPH

June 21, 1978. View of Mount San Gorgonio from the Bermuda Dunes, Coachella Valley (photograph by Phil Medica, used with permission).

Long-term Sand Supply to Coachella Valley Fringe-toed Lizard Habitat in the Northern Coachella Valley, California

By Peter G. Griffiths, Robert H. Webb, Nicholas Lancaster, Charles A. Kaehler, and Scott C. Lundstrom

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U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 02-4013

Prepared in cooperation with the

U.S. Fish and Wildlife Service

Tucson, Arizona
2002

U.S. DEPARTMENT OF THE INTERIOR

GALE A. NORTON, *Secretary*

U.S. GEOLOGICAL SURVEY

Charles G. Groat, *Director*

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For additional information write to:

Regional Research Hydrologist
U.S. Geological Survey
345 Middlefield Road
Menlo Park, CA 94025
http://water.usgs.gov/nrp

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Building 810
Box 25286, Federal Center
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CONVERSION FACTORS AND DATUMS

CONVERSION FACTORS

Multiply	By	To obtain
inch (in)	25.41	millimeter
foot (ft)	0.3048	meter
yard (yd)	0.9144	meter
mile (mi)	1.609	kilometer
miles per hour (mi/hr)	1.609	kilometer per hour
knots	1.852	kilometer per hour
acre	0.4047	hectare
square foot (ft^2)	0.09290	square meter
square mile (mi^2)	2.590	square kilometer
cubic foot (ft^3)	0.02832	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
pound, avoirdupois (lb)	0.4536	kilogram
ton, short (2,000 lb)	0.9072	megagram
ton per year (ton/yr)	0.9072	megagram per year
ton per year (ton/yr)	0.9072	metric ton per year
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter

VERTICAL DATUM

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

HORIZONTAL DATUM

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83), unless otherwise noted.

Long-Term Sand Supply to Coachella Valley Fringe-Toed Lizard (*Uma inornata*) Habitat in the Northern Coachella Valley, California

By Peter G. Griffiths, Robert H. Webb, Nicholas Lancaster, Charles A. Kaehler, and Scott C. Lundstrom

ABSTRACT

The Coachella Valley fringe-toed lizard (*Uma inornata*) is a federally listed threatened species that inhabits active sand dunes in the vicinity of Palm Springs, California. The Whitewater Floodplain and Willow Hole Reserves provide some of the primary remaining habitat for this species. The sediment-delivery system that creates these active sand dunes consists of fluvial depositional areas fed episodically by ephemeral streams. Finer fluvial sediments (typically sand size and finer) are mobilized in a largely unidirectional wind field associated with strong westerly winds through San Gorgonio Pass. The fluvial depositional areas are primarily associated with floodplains of the Whitewater – San Gorgonio Rivers and Mission Creek – Morongo Wash; other small drainages also contribute fluvial sediment to the eolian system. The eolian dunes are transitory as a result of unidirectional sand movement from the depositional areas, which are recharged with fine-grained sediment only during episodic floods that typically occur during El Niño years. Eolian sand moves primarily from west to east through the study area; the period of maximum eolian activity is April through June. Wind speed varies diurnally, with maximum velocities typically occurring during the afternoon.

Development of alluvial fans, alteration of stream channels by channelization, in-stream gravel mining, and construction of infiltration galleries were thought to reduce the amount of fluvial sediment reaching the depositional areas upwind of *Uma* habitat. Also, the presence of roadways, railroads, and housing developments was thought to disrupt or redirect eolian sand movement. Most of the sediment yield to the fluvial system is generated in higher elevation areas with little or no development, and sediment yield is affected primarily by climatic fluctuations and rural land use, particularly livestock grazing and wildfire. Channelization benefits sediment delivery to the depositional plains upwind of the reserves by minimizing in-channel sediment storage on the alluvial fans.

The post-development annual sediment yield to the Whitewater and Mission Creek – Morongo Wash depositional areas are 3.5 and 1.5 million ft^3/yr, respectively, covering each depositional area to a depth of 0.2 to 0.4 in. Given existing sand-transport rates, this material could be depleted by eolian processes in 8 to 16 months, a rate consistent with the presence of persistent sand dunes. However, these depletion times are likely minimum estimates, as some eolian sand is seen to persist in the immediate vicinity of depositional areas for longer time periods. Transport rates may be reduced by the presence of vegetation and other windbreaks.

Because they are perpendicular to prevailing winds, the infiltration galleries on Whitewater River trap fluvial and eolian sediment, reducing sediment availability. Also, the presence of the railroad and Interstate 10 redirect eolian sand movement to the southeast along their corridors,

potentially eliminating the Whitewater depositional area as a sand source for the Willow Hole Reserve. Using directional wind data, we discuss the potential for eolian sand transport from the Mission Creek – Morongo Wash depositional area to Willow Hole.

INTRODUCTION

The Coachella Valley fringe-toed lizard (*Uma inornata*) is a federally listed threatened species that inhabits active sand dunes and their margins in the vicinity of Palm Springs, California (fig. 1). As part of the Habitat Conservation Plan for this species (Nature Conservancy, 1985), a series of reserves has been established to benefit this species and other species that are restricted to active dunes and their margins. Two of these reserves, the Whitewater Floodplain and Willow Hole – Edom Hill Reserves, are in the northern Coachella Valley between the towns of Palm Springs, Thousand Palms, and Desert Hot Springs (fig. 1).

The U.S. Fish and Wildlife Service is concerned that flood-control and water-management structures on Whitewater River and other smaller desert washes are reducing the sand supply to these reserves, potentially stabilizing the dunes and thereby degrading *Uma* habitat. Development of alluvial fans, alteration of stream channels by channelization, in-stream gravel mining, and construction of infiltration galleries were thought to reduce the amount of fluvial sediment reaching the depositional areas upwind of *Uma* habitat. Also, the presence of roadways, railroads, and housing developments was thought to disrupt or redirect eolian sand movement. Most of the sediment yield to the fluvial system is generated in higher elevation areas with little or no development, and sediment yield is affected primarily by climatic fluctuations and rural land use, particularly livestock grazing and wildfire. Channelization benefits sediment delivery to the depositional plains upwind of the reserves by minimizing in-channel sediment storage on the alluvial fans.

Previous studies of sediment supply to *Uma* habitat have generally been non-quantitative and, to a lesser extent, divergent in their conclusions as to the long-term sand budget in the northern Coachella Valley and how it might change given modifications to the major watercourses that provide sand to the eolian system. This study addresses specific questions of fluvial supply of fine-grained sediments to fetch areas upwind of two reserves in the northern Coachella Valley and eolian transport of these sediments to the reserves.

Purpose and Scope

The objective of this project is to describe the sand-delivery system and to quantify the sand budget for Coachella Valley fringe-toed lizard (*Uma inornata*) habitat in the northern Coachella Valley. This project will focus on the Whitewater Floodplain Reserve and the western half of the Willow Hole – Edom Hill Reserve – referred to in this study as the Willow Hole Reserve – and their sand sources, both before and after major development in the Coachella Valley. In particular, this study addresses the interrelations between fluvial and eolian processes that create the unique sand-delivery system to *Uma* habitat in the northern Coachella Valley and attempts to quantify sand transport rates.

In addition, this report addresses major questions asked of the U.S. Geological Survey by the U.S. Fish and Wildlife Service. These questions are:

- For both reserves, is the sand supply sufficient to maintain *Uma* habitat in the Willow Hole and Whitewater Floodplain Reserves?
- How would channelization of Mission and Morongo Creeks and urban development on their adjacent floodplains affect sand supply to both reserves?
- Do the infiltration galleries and associated retention dikes along the Whitewater River affect sand supply to the Whitewater Floodplain Reserve, and by how much? Could the design of the recharge ponds be modified to increase the sand supply to the reserve?
- How much of the floodplain of the washes supplying sand upwind of the reserves has to be preserved to ensure a perpetual sand supply? What areas are essential to preserve to maintain an adequate sand supply and sand-transport corridor for these two reserves?

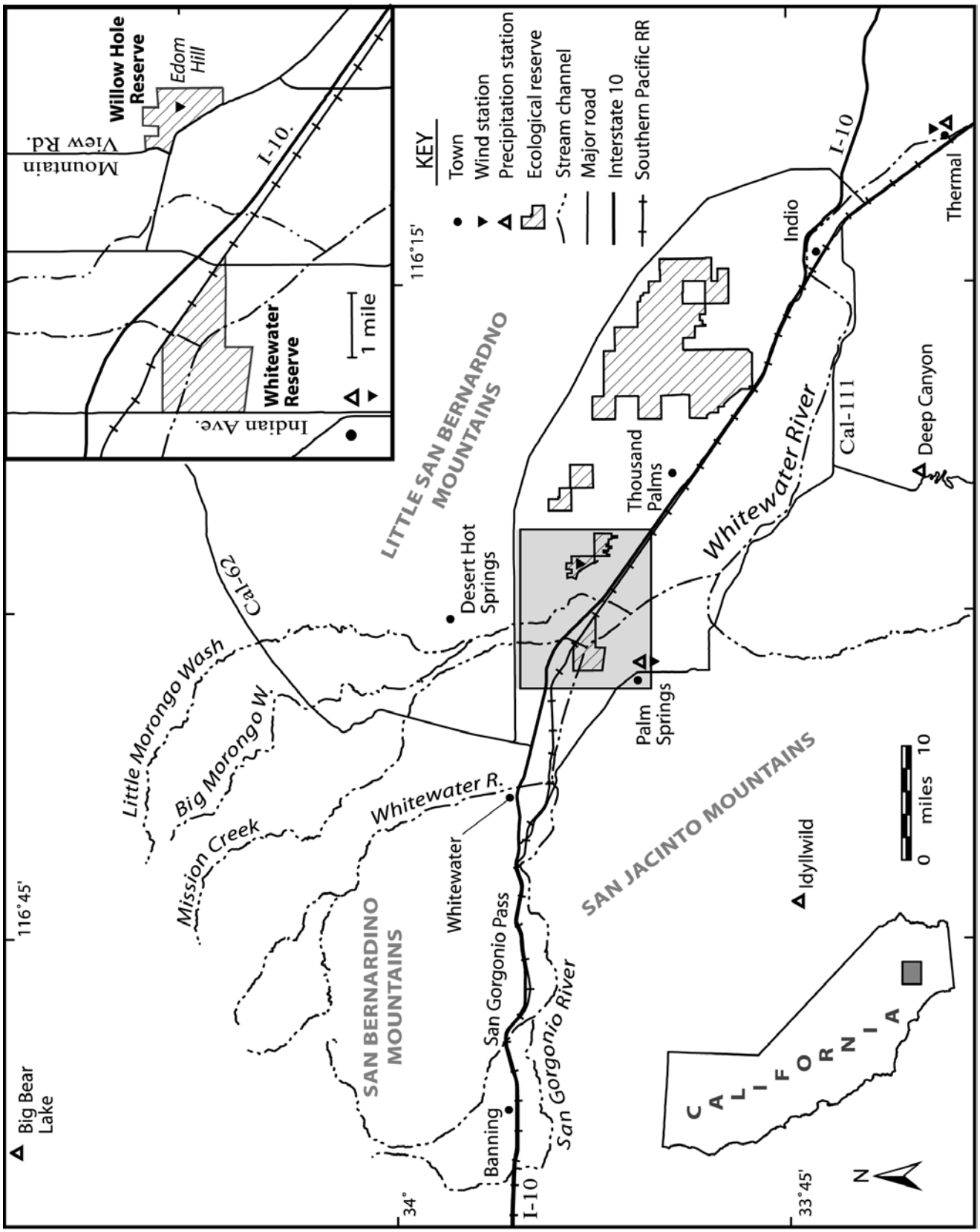

Figure 1. Map of the northern Coachella Valley. Inset shows details of the area including the Whitewater River and Willow Hole Reserves.

Acknowledgments

The authors thank Jessica Young of the U.S. Geological Survey for her contributions to the geographical information system (GIS) analysis of the drainages contributing sand to the Coachella Valley. Mimi Murov of the U.S. Geological Survey helped considerably with the field work on this project. Daniel Farris of the Coachella Valley Water District supplied key wind and dredging data. Kurt Cupp of the Desert Research Institute collected and scanned the air photographs and Ed Corbett of the Desert Research Institute helped with image and wind-data analysis. We thank R.R. Shroba and J.C. Matti of the U.S. Geological Survey for helpful discussions during Quaternary geologic mapping of the area. Mark Fisher of the Boyd Deep Canyon Desert Research Center provided precipitation data for his facility. Van Williams, also of the U.S. Geological Survey, provided invaluable GIS support for the geologic mapping. The manuscript was critically reviewed by Fisher, Allan Muth, and Cameron Barrows, collectively known as the Science Advisory Committee of the Coachella Valley Multiple Species Habitat Conservation Plan; Bill Havert of the Coachella Valley Mountain Conservancy; and Pete Sorensen and Ken Corey of the U.S. Fish and Wildlife Service.

BACKGROUND

Habitat Requirements of Uma inornata

The Coachella Valley fringe-toed lizard (*Uma inornata*) is a sand-dwelling species that is narrowly endemic on active dunes and their stabilized margins in the northern Coachella Valley. One of its closest relatives is the Mojave fringe-toed lizard (*Uma scoparia*), which is a species of special concern in California (Trepanier and Murphy, 2001). *Uma scoparia* is endemic to eolian sand habitats in the Mojave Desert in California and western Arizona, particularly within eolian systems associated with the Mojave and Amargosa Rivers (Hollingsworth and Beaman, 1999). The remaining habitat for *Uma scoparia* is substantially larger than that of *Uma inornata*, and *Uma scoparia* is not a federally listed threatened species.

Uma inornata was once relatively common in the Coachella Valley, and its original range was about 324 mi^2. By 1976, the eolian habitat available to this species had decreased by 27 percent to 236 mi^2, and the most-suitable habitat was estimated to be only 120 mi^2 (England and Nelson, 1976). The 1985 Habitat Conservation Plan (Nature Conservancy, 1985) created the Willow Hole – Edom Hill Reserve of 3.8 mi^2 (2.2 mi^2 of suitable habitat) and the Whitewater Floodplain Reserve of 1.9 mi^2, all of which is considered suitable habitat. A larger Coachella Valley Reserve (also known as the Thousand Palms Reserve) was also created east of the study area.

The numbers of *Uma inornata* began decreasing because of habitat destruction for a variety of human uses, including agriculture, development of subdivisions, and construction of railroads and highways. The active sand dunes that are required for *Uma* appear to have decreased in area, in part owing to road construction, the erection of windbreaks using non-native *Tamarix* trees, and modifications to stream channels; the operation of power-generating windmills upwind may possibly have contributed to the decline (Turner and others, 1984). Because its habitat, which was never very large, was reduced by at least two thirds, *Uma inornata* was listed as a threatened species by the U.S. Fish and Wildlife Service in 1980. The habitat conservation plan developed to protect this lizard (Nature Conservancy, 1985) is often cited as a model for species preservation under the Endangered Species Act (Barrows, 1996).

Uma inornata habitat consists of active or minimally stabilized dunes of late Holocene age or active eolian surfaces on dunes of greater antiquity. The lizards may use active, relatively large barchanoid dunes, or their habitat may consist of relatively large coppice mounds around mesquite (*Prosopis glandulosa*), creosote bush (*Larrea tridentata*), or other shrubs. *Uma* requires loose sand to create burrows, and the range in b-axis diameter of sand must fall between 0.1 and 1.0 mm with a mean of about 0.2 to 0.4 mm, as reported by Turner and others (1984), or 0.180 to 0.355 mm as reported by Barrows (1997). Turner and others (1984) conclude that *Uma inornata* may be very sensitive to minor variations in eolian sand size. Therefore, small alterations of sand supply may have significant effects on this species.

These lizards prefer the leeward side of dunes and hummocks and seldom use the windward (or more stabilized) side. However, Turner and others (1984)

found positive correlations with the amount of surface crusting on the windward sides of dunes, indicating that some stabilization of dunes may be a desirable attribute of *Uma* habitat; they note that *Uma* may use the windward sides at night. Barrows (1997) found that sand compaction, as defined by a standardized penetration depth, was consistently the most important determinant of appropriate habitat for *Uma*; this species requires the deep, loose sand that generally occurs only in active sand dunes as protection from predators and summer heat.

Uma require some proximity to vegetation for their food supply, which suggests that the dune systems they occupy must be relatively small or have a thin cover of loose sand over more stable substrates anchored by vegetation. Barrows (1997) found that *Uma* preferred the presence of such native plant species as *Dicoria canescens* and *Atriplex canescens* as well as the non-native *Salsola tragus*. *Dicoria* is an important food source, particularly in late summer (Barrows, 1997). Another factor noted by Barrows (1996) is ground-water overdraft, which may be killing mature *Prosopis* and thereby facilitating degradation of coppice mounds that provide dune anchorage as well as negatively affecting food supplies.

The Fluvial System in the Coachella Valley

The fluvial system in the Coachella Valley consists of stream channels that are ephemeral downslope from the mountain front and that pass through large, coalescing alluvial fans called bajadas. These ephemeral streams, also known as washes, deliver sediment in flash floods that occur infrequently. These floods occur during large winter storms that drop most of their precipitation in the mountains west and north of the Coachella Valley (larger drainages), or during intense summer thunderstorms (smaller drainages). The last large flood on the Whitewater River was in 1938, and most floods that occur at a frequency of every 2 years or more often are relatively small and transport only small amounts of fine-grained sediments in comparison with the larger events.

Streamflow is the most common sediment-transport process that occurs in the washes entering the Coachella Valley. Streamflow typically has a sediment concentration of less than 40 percent by weight (Pierson and Costa, 1987). In addition to streamflow, “hyperconcentrated flow” and debris flows occur in the Coachella Valley and particularly in the surrounding mountainous terrain (Sharp and Nobles, 1953). Hyperconcentrated flow, as originally defined by Beverage and Culbertson (1964) and modified by Pierson and Costa (1987), contains 40 to 70 percent sediment by weight. Debris flows are slurries of clay- to boulder-sized sediment with volumetric water concentration ranges from about 10 to 30 percent (Pierson and Costa, 1987; Major and Pierson, 1992) and are an important sediment-transport process in a variety of geomorphic settings throughout the world (Costa, 1984).

A variety of classifications has been proposed for distinguishing streamflow, “hyperconcentrated flows,” and debris flows, with the most recent work focused on rheological properties (Pierson and Costa, 1987) and the interactions of fluid and solid forces (Iverson, 1997). Hyperconcentrated-flow deposits are differentiated from those of streamflow and debris flow by sedimentological criteria based on differences in particle-size distribution, sedimentary structures such as slight laminar bedding, and an overall coarse-sand, upward-coarsening texture commonly containing erratic cobbles and boulders (Pierson and Costa, 1987). In this study, hyperconcentrated flow is grouped with streamflow in calculating sediment transport in the Coachella Valley, and the sediment contribution of debris flows is not calculated owing to lack of information on their occurrence.

Fluvial sediment is mostly generated in the headwaters areas of drainage basins within the mountains that surround the western and northern parts of the Coachella Valley. During infrequent floods, sediment is entrained from hillslopes and channels in the headwaters and is transported downstream into channels that pass through the bajadas. Some sediment is stored within channels in small terraces; during larger floods, sediment is stored on the bajada surface as floodplain deposits. Sediment transported through the bajada in the channelized washes is deposited over broad, low-angle depositional plains, referred to in this report as depositional areas. The largest of these areas is the Whitewater depositional area, most of which historically was west of Indian Avenue and south of Interstate 10 (fig. 1).

The particle-size distribution of sediments transported by these ephemeral streams varies depending on the transport process. Debris flows, which occur infrequently, transport particles ranging from clay to boulders; abundant debris-flow deposits

appear along the channel of Whitewater River upstream from Interstate 10 and on alluvial fans emanating from the San Jacinto Mountains. No historical debris flows have been reported, however. Most sediment transported by streamflow ranges in size from sand to small gravel, with a relatively small (<10 percent) component of silt and clay. This range in particle size reflects the sizes of particles generated from weathering of granitic terranes in the San Bernadino and San Jacinto Mountains.

At various times, flood-control and water-management projects that were proposed to solve regional problems were thought to reduce the sand supply issuing from major tributaries, particularly the Whitewater River. One flood-control project proposed but not implemented by the U.S. Army Corps of Engineers could have reduced the sand supply by half (Turner and others, 1984).

Water-spreading structures and earthen dikes are used to infiltrate low flows from the Whitewater River into the regional aquifer. A total of 19 infiltration galleries, also known as percolation ponds, are formed from these dikes. The initial diversion dikes into the infiltration galleries are designed to breach during floods; this has occurred several times since construction, particularly during floods in early 1977 and again in 1979 at the site of the spillway between the ponds (Daniel Farris and Patti Schwartz, Coachella Valley Water District, oral commun., 2002). The intake channel to the galleries is designed to trap much of the sand transported downstream in the Whitewater River, potentially making it available to downstream transport to the Whitewater River depositional area.

Flow in the lower Whitewater River is occasionally artificial. Water imported from the Colorado River is released into the channel of the Whitewater River about one mile upslope (north) of the Interstate 10 bridge at Whitewater (fig. 1). These aqueduct releases typically range from less than 100 to 500 ft^3/s, and the releases are redirected from the main channel into the infiltration galleries. This flow too is episodic and aseasonal, depending on negotiations between the local water district and the Metropolitan Water District of Los Angeles. This sediment-free water quickly entrains fine-grained sediments of the size range required for *Uma* habitat and moves at least some of the sediment out of the fetch area that supplies sand to the Whitewater Floodplain Reserve. In addition, because of their steep windward sides, the dikes impounding the infiltration galleries trap fluvial sand moving down the corridor of the Whitewater River and prevent eolian sand from escaping.

The Eolian System in the Coachella Valley

The sand dunes of the northern Coachella Valley have been described in several previous studies (Russell, 1932; Sharp, 1964, 1980; Beheiry, 1967; Lancaster and others, 1993; Lancaster, 1997). Abundant evidence of significant prehistoric eolian activity is preserved in ventifacts (sandblasted rocks), fossil dunes, and altered vegetation form and distribution (Proctor, 1968; Sharp and Saunders, 1978). The dune forms that have been previously described in the northern Coachella Valley range from knob dunes (now called nebkha or coppice dunes; Lancaster, 1995) – small and ephemeral mounds up to 6 ft high and 35 ft long and anchored by perennial vegetation – to barchan dunes up to 35 ft high and 100 ft long (Beheiry, 1967). Parabolic dunes occur in the Coachella Valley Reserve to the east. Sand veneers on surfaces that are not eolian in origin (also called sand sheets) are relatively common, particularly following pulses of fluvial sediment input, but mesquite-anchored coppice dunes are the only relatively permanent dune forms in the northern Coachella Valley.

The actual rates of dune movement and sand transport are determined by the supply of sediment for transport and its availability. Sand availability is limited by vegetation cover and soil moisture, the influence of which is indicated by the dune-mobility index (Lancaster and Helm, 2000). A climatic index of dune mobility developed to predict the mobility of sand dunes (Lancaster, 1988) has been used to understand dune mobility in a variety of environments, including the Kalahari Desert (Bullard and others, 1997), the Great Plains of the USA and Canada (Muhs and Maat, 1993; Wolfe and Nickling, 1997), and southern Washington State (Stetler and Gaylord, 1996). The index is based on the two factors of wind strength and the ratio of precipitation to potential evapotranspiration as a surrogate for vegetation cover. It has been shown to accurately reflect eolian sand transport measured at long-term monitoring sites in the southwestern United States (Lancaster and Helm, 2000). One major assumption is that dune movement and eolian activity are determined by sediment availability as determined by vegetation cover. Lancaster and others (1993) and

Lancaster (1997) used the dune mobility index to show that dunes in the Coachella Valley migrated on a temporal pattern that was predicted by the index.

As previously discussed, the sand supply for the eolian system comes from ephemeral washes, most of which have headwaters in either the San Bernardino or Little San Bernardino Mountains. Wasklewicz and Meek (1995) used geochemical analyses to attempt to quantify the sources of sands for the *Uma* reserves. These sources are predominantly the major watercourses, particularly the Whitewater River for the Whitewater Floodplain Reserve and Mission Creek and Morongo Wash for the Willow Hole Reserve. Floods down these watercourses occur infrequently, leading to episodic addition of fine-grained fluvial sediments to the channels and alluvial fans upwind of the reserves.

Westerly winds through San Gorgonio Pass (fig. 1), which shift to northwesterly winds with distance into the Coachella Valley, provide the dominant force for moving fine-grained fluvial sediments deposited by major watercourses on the valley floor into eolian deposits that become *Uma* habitat (Lancaster and others, 1993). Winds can shift to other directions during occasional thunderstorms, but these events are sporadic and very localized. Wind energy is not a limiting factor to wind transport in this region (Lancaster, 1997). Because of the episodic nature of fluvial sediment input into the system and the high energy of the wind regime, depletion of upwind sand sources as well as ephemeral eolian landforms are expected. With increasing time after fluvial deposition, wind can erode fine sediments from both the channel margins and the downwind habitat, thereby depleting the source for eolian sand as well as *Uma* habitat.

Accumulation of eolian deposits requires: (1) a source of available sediment, (2) sufficient wind energy to transport that sediment, and (3) conditions that promote accumulation in the depositional zone. A key principle in the understanding of eolian sand deposits is the recognition that they occur as part of recognizable sediment transport systems in which sand is moved from source areas (*e.g.*, distal fluvial deposits) and transported along distinct transport corridors to depositional sinks (Lancaster, 1995).

The dynamics of eolian sediment transport systems on any time scale are determined by the relations between the supply, availability, and mobility of sediment of a size suitable for transport by wind (Kocurek and Lancaster, 1999). In turn, sediment supply, availability, and mobility are determined in large part by regional and local climate and vegetation cover. Sediment supply is the presence of suitable sediment that serves as a source of material for the eolian transport system. It may be affected by variations in flood magnitude and frequency, fluvial sediment-transport rates, and rates of bedrock weathering at sediment source areas. Climatic changes impact sediment availability (the susceptibility of a sediment surface to entrainment of material by wind) and mobility (transport rates) via vegetation cover, soil moisture, and changes in the magnitude and frequency of winds capable of transporting sediment.

Rates of eolian transport and deposition are affected by a number of factors. Wind fetch, or the length of unobstructed area exposed parallel to the wind, is the primary factor. Because the natural surfaces along the floor of the arid northern Coachella Valley are mostly flat with sparse perennial vegetation, fetch is generally not a restriction unless anthropogenic obstacles are present. Other factors influencing eolian transport include wind speed and duration, availability and size fractions of sand in channel bottoms, the presence and dimensions of natural or artificial windbreaks, and the density and size of natural vegetation in channels and among sand dunes. Lancaster and others (1993) add the factor of channel entrenchment and (or) change, which decreases eolian entrainment of particles and transport out of channels. Some of these factors – particularly wind speed, availability of appropriately sized sediment, channel stability, and natural vegetation – are affected by regional climatic variability on a decadal or longer time scale. Other factors – particularly wind fetch – are directly affected by development and modification of river channels and the landscape.

Eolian processes transport a relatively narrow range of sand sizes. In the mid-1960s, Beheiry (1967) found that the median diameter (D_{50}) of eolian sand at sixteen sites in the Coachella Valley ranged from 0.09 to 0.44 mm with an average of 0.28 mm. The particle-size distributions he measured had a bimodal component, suggesting that several sand sources were being mixed in transport. The range of eolian sand preferred by *Uma inornata* is 0.180 to 0.355 mm (Barrows, 1997), indicating that these lizards have a more narrow habitat preference than what is available throughout the eolian dune fields.

Accumulation of sand is the product of spatial changes in transport rates and temporal changes in sediment concentration such that:

$$\frac{dh}{dt} = -\left(\frac{dq_s}{dx} + \frac{dC}{dt}\right) \quad (1)$$

where

- h is the elevation of the deposition surface,
- t is time,
- q_s is the spatially averaged bulk volume sediment-transport rate,
- x is the distance along the transport pathway, and
- C is the concentration of sediment in transport.

In this model, the transport rate (q_s) consists of two components, a first owing to bedform migration (bedform transport, q_b) and a second that is through-going (q_t) as a result of saltation or bedload transport. The sediment concentration (C) is a measure of the total amount of sediment in transport, and can be approximated by the average height of the dunes or other eolian bedforms (Havholm and Kocurek, 1994).

Although sediment-transport rates over sandy surfaces are almost always at the capacity of the wind to transport sediment (sediment saturated), those over other desert surfaces such as bedrock, alluvial fans, or playas are frequently below transport capacity, or undersaturated or metasaturated (Wilson, 1971) because the sediment supply is limited. Thus actual sand transport rates (q_a) may be less than potential rates (q_p) in proportion to the ratio q_a/q_p, which ranges between zero for completely undersaturated flows to 1 for fully saturated conditions. The wind is potentially erosional until its transport capacity is reached, regardless of whether the wind is accelerating, steady, or decelerating. Deposition occurs wherever there are local decreases in transport capacity (*e.g.*, deceleration in the lee of obstacles or change in surface roughness). The wind may still be transporting sand, as deposition only occurs until the transport rate is in equilibrium with changed conditions.

Following principles of sediment-mass conservation, if transport rates decrease in the direction of flow, deposition will occur. If, however, sediment-transport rates increase, then sediment will be eroded. If there is no spatial change in transport rates, then net sediment bypassing will occur (Havholm and Kocurek, 1994). The change in transport capacity in both time and space, defined as the ratio between the potential transport rate upwind and downwind of the area of concern, determine the domains of erosion, bypass, and accumulation of sand. These concepts can be used to assess the nature of changes that may occur through time. For example, assuming that the basic wind regime characteristics of an area do not vary with time, changes in sediment availability from source zones and thus the saturation level of the input will determine the behavior of the system.

Sand depletion is considered an on-going problem in the northwestern part of the Coachella Valley because wind velocities and therefore sand-transport rates are highest in this area and the watercourses that supply sediment have been subjected to considerable modification. Lancaster and others (1993) concluded that the northern Coachella Valley has been strongly affected by changes in sand supply and transport rates through the 20th century. They note that eolian transport rates were relatively high between 1948 and 1974, which is generally regarded as a period of prolonged drought, and lower thereafter, a period that is relatively wet but with highly variable conditions. Lancaster (1997) concluded that variations in precipitation and perennial vegetation on dunes control the eolian systems in the California Deserts. Although the extreme flood events needed to supply large amounts of fine-grained fluvial sediments to alluvial fans are extremely episodic, higher frequency variations in annual precipitation and particularly prolonged periods of climatic shifts – to either wetter or drier conditions – may strongly affect the stability of *Uma* habitat. In addition, development increased dramatically after the mid-1970s and human effects on trapping sand through windbreaks and altering the sand supply cannot be ignored.

METHODS

Quaternary Geologic Mapping

Geologic units of Quaternary age (last 2 million years) were mapped for the Desert Hot Springs and Seven Palms Valley quadrangles (scale 1:24,000) as part of ongoing studies under the Southern California Areal Mapping Project (SCAMP) of the U.S. Geological Survey (Lundstrom and others, 2001; and unpublished mapping of Lundstrom, R. Shroba and J. Matti). The geology of the study area previously was mapped at a scale of 1:250,000 as compiled by Rodgers

(1966), but he had little differentiation of Quaternary surficial geologic units. Similarly, Proctor (1968) provided a map of the Desert Hot Springs area at a scale of 1:62,500 and differentiated Pleistocene units from Holocene but provided no subdivisions within these eras.

Our mapping improves upon that of Proctor and Rodgers by using a larger scale map base as well as differentiating the ages of geomorphic surfaces within the Pleistocene and Holocene eras and by distinguishing the deposits by the geomorphic processes that resulted in their deposition. Mapping was based mostly on National Aerial Photography Project (NAPP) false-color infrared imagery (nominal scale of 1:40,000) from August 18, 1989, supplemented by National Historical Aerial Photography (NHAP) black-and-white imagery (scale of 1:80,000) from 1984. For the Indio Hills mapping, we used natural color aerial photography (scale of 1:24,000) flown on April 9, 1999. The descriptions of mapping units appears in Appendix 1; readers are referred to Birkeland (1974), McFadden (1982), and Cooke and others (1993) for more information on the use of soils geomorphology for age discrimination of geomorphic surfaces.

Climatic and Hydrologic Data

We analyzed existing precipitation and hydrologic data concerning the Coachella Valley and its watercourses to evaluate the hypothesis that climatic change affects *Uma* habitat in three ways: (1) by altering flood frequency, and thereby affecting sediment supply; (2) by increasing landscape roughness by increasing the amount and size of perennial native vegetation; and (3) by increasing the perennial vegetation in the vicinity of dunes, leading to increased stabilization. Monthly precipitation data were obtained from the Western Region Climatic Center in Reno, Nevada (www.wrcc.edu), and the University of California Philip L. Boyd Deep Canyon Desert Research Center (Mark Fisher, written commun., 2001). Discussions of standardization techniques for monthly and seasonal precipitation appear in Hereford and Webb (1992).

Streamflow gaging data from the U.S. Geological Survey were obtained from the California District of the Water Resources Division; gaging data availability for the northern Coachella Valley appears in Appendix 2. Streamflow data is relatively sparse in this region, and most records are only 10-20 years in length. In addition, many of the stations on major watercourses have been moved, in some cases repeatedly. The Southern Oscillation Index (SOI), the most commonly used indicator of El Niño conditions in the equatorial Pacific Ocean, is regularly updated on various web sites; for more information on this index, see Webb and Betancourt (1992) and Cayan and Webb (1992).

Delineation of Drainage and Depositional Areas

Drainage areas of principal washes that contribute sediment to depositional areas upwind of the Coachella Valley reserves were hand drawn on 7.5-minute topographic maps and digitized (fig. 2). Drainage areas were calculated within a GIS and are given in table 1. Topographic information associated with the drainage areas was obtained from U.S. Geological Survey 30-m digital-elevation models.

Predevelopment, or historic, depositional areas were identified as late Holocene surfaces on the Quaternary geologic map. Active channels and current, or modern, depositional areas were determined by a combination of digitization of SPOT imagery provided by C.W. Barrows (written commun., 2001) and field evaluation. The Mission Creek – Morongo Wash depositional area in particular was determined as the entire area between the west splay of Mission Creek and the east splay of Morongo Creek north of Interstate 10 and south of the Banning (San Andreas) Fault (figs. 1 and 2). In March 2001, after a small flow on Mission Creek, sediment appeared to be recently deposited throughout this area, indicating reasonably active deposition even during modest floods. Because of these observations, we could not quantitatively evaluate whether some parts of the Mission Creek – Morongo Wash depositional area were more active than other parts. In both the predevelopment and modern eras, the boundaries of the Willow Hole depositional areas are difficult to map at a landscape scale and we chose not to formally delineate them.

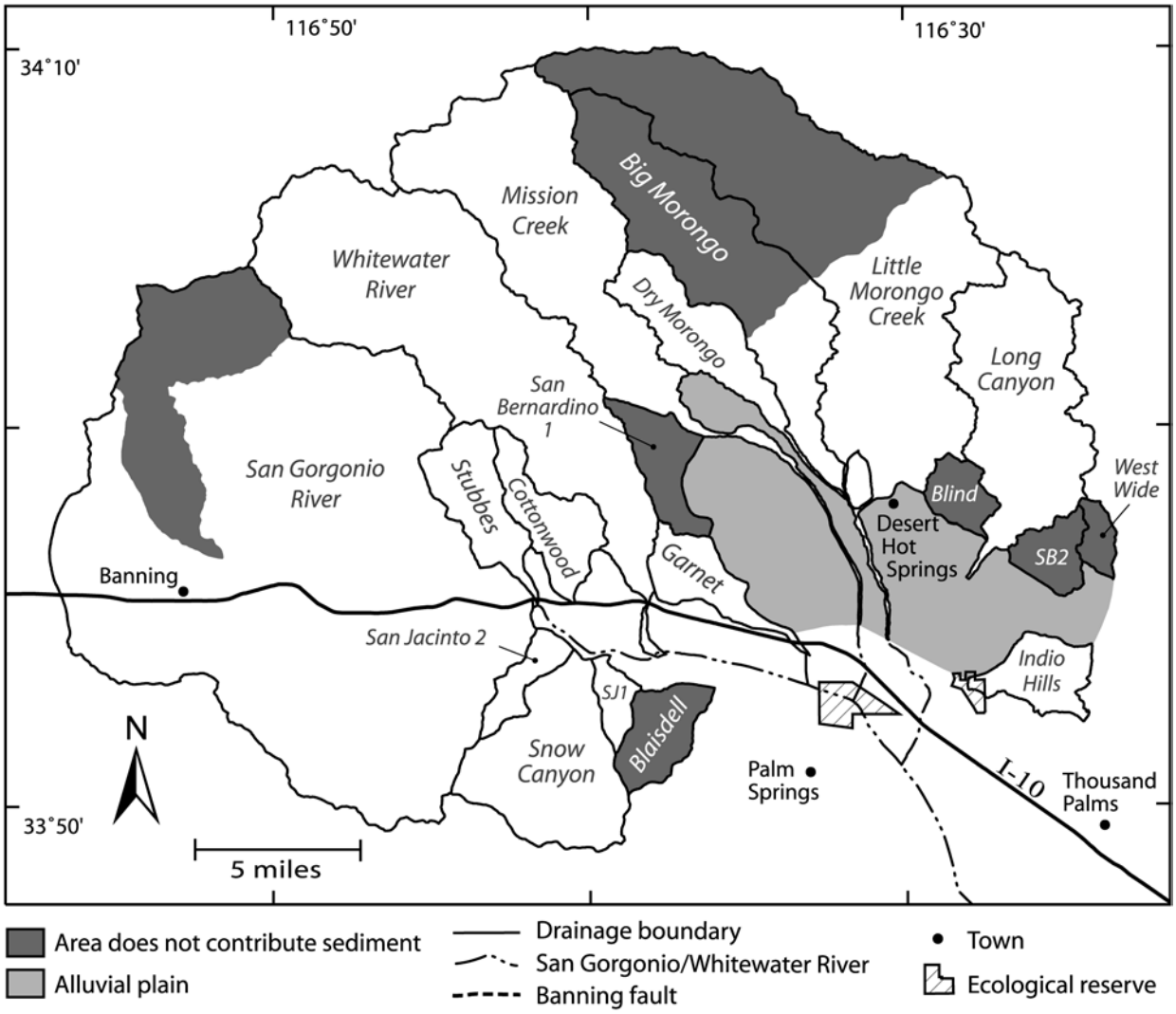

Figure 2. A. Drainage areas for principle watersheds contributing fluvial sediment to the northern Coachella Valley.

Fluvial Sediment Yield

Fluvial sediment yield (sediment moved by rivers) was analyzed using indirect techniques because little sediment-transport data has been collected in the study area (Appendix 2). We rejected standard approaches such as the Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1978; Peterson and Swan, 1979), the CREAMS and WEPP models of the Agricultural Research Service (Knisel, 1980; Gilley and others, 1988), and the procedure outlined by the PSIAC (Pacific Southwest Inter-Agency Committee, 1968). The USLE was developed strictly for low-slope agricultural land and is not appropriate for the steep terrain of drainages entering the Coachella Valley. Likewise, the CREAMs and WEPP models were developed for relatively low-slope agricultural and rangeland and require considerable watershed data for proper application. The PSIAC method involves rating a watershed on the basis of nine factors related to erosion (surface geology, soil, climate, runoff, topography, land use, upland erosion, and channel erosion/sediment transport) to produce an estimate of sediment yield. This method can be applied to large areas using pre-calculated PSIAC sediment-yield ratings mapped by the Soil Conservation Service (Soil Conservation Service, 1975). It generally produces high sediment-yield estimates in arid regions of high relief (Webb and others, 2000).

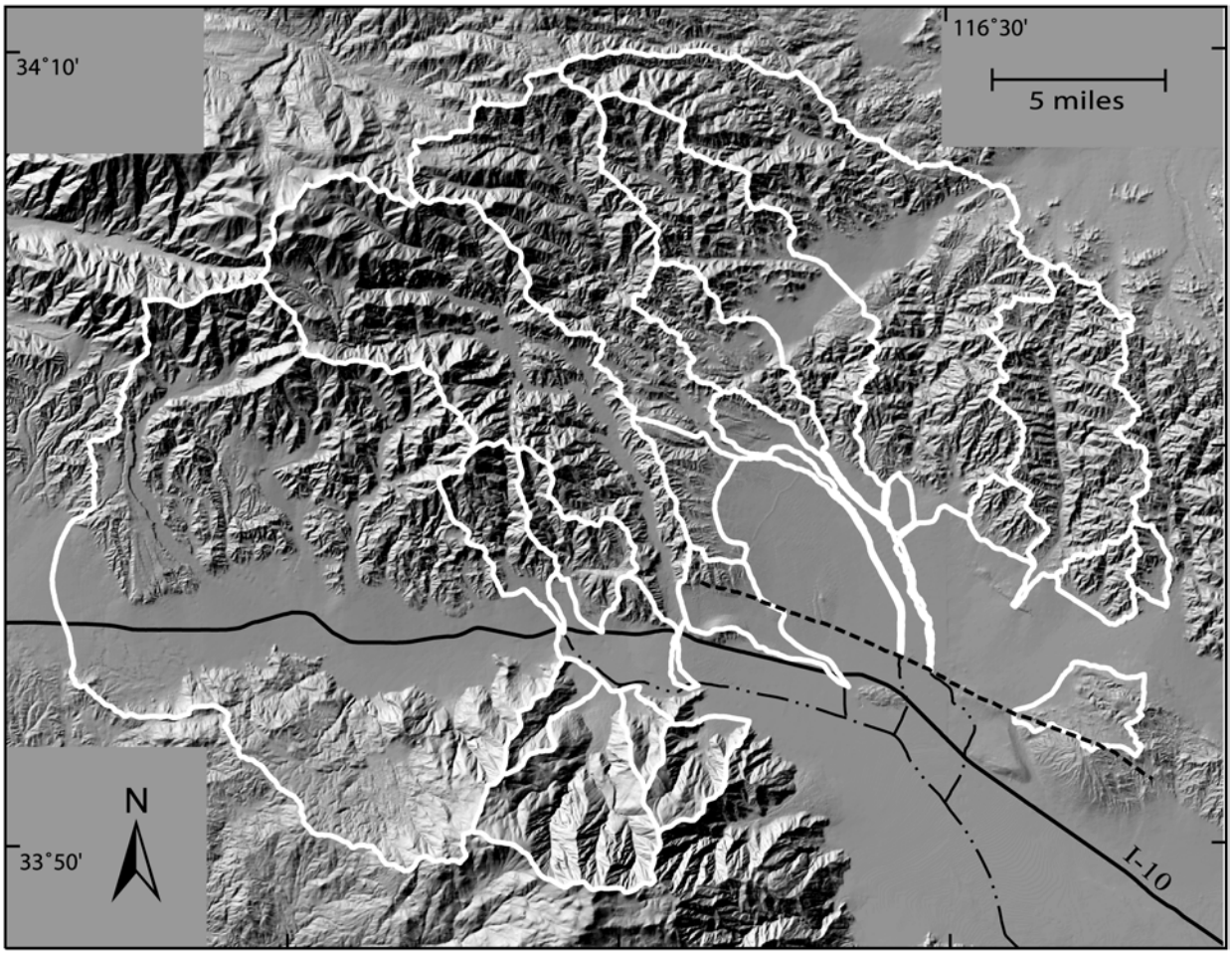

Figure 2. *Continued.*

B. The shaded relief map is based on a 30-m digital-elevation model of the northern Coachella Valley and the San Bernardino, Little San Bernardino, and San Jacinto Mountains. White lines indicate drainage boundaries.

The Power-Function Approach

The power-function method of estimating fluvial sediment yield is purely empirical and uses power functions fit to empirical data (*e.g.*, Renard, 1972). Some approaches include more-intensive statistical modeling (*e.g.*, Flaxman, 1972) and deterministic sediment-yield models that are data intensive (*e.g.*, Gilley and others, 1988). In places like the Coachella Valley, where little sediment data have been collected (Appendix 2), the best technique is to apply an empirical function from a similar region. For example, from the Colorado Plateau, one estimator based on regional data is of the form:

$$Q_s = 493 \cdot A^{1.04} \qquad (2)$$

where

Q_s is sediment yield in short tons per year (t/yr), and

A is drainage area (mi^2).

In relations of this type, sediment yield typically is a function of drainage area to a power close to 1.0, a nearly linear relation.

In the Coachella Valley, we elected to use the Renard (1972) equation, which, converted from units of volume to weight by assuming a sediment density of 0.0375 tons per cubic foot (t/ft^3), is

$$Q_s = 895 \cdot A^{0.88}, \qquad (3)$$

Table 1. Sediment source areas for the northern Coachella Valley.

Tributary	Area (mi^2)	Mean elevation (ft)	Depositional area[1]
San Gorgonio River[2]	153.5	3612	San Gorgonio/Whitewater
Little Morongo Creek[3]	67.7	3725	Mission/Morongo
Whitewater River	59.6	5540	San Gorgonio/Whitewater
Mission Creek	38.4	5488	Mission/Morongo
Big Morongo Creek[3]	31.0	3988	Mission/Morongo
Long Canyon	26.3	3100	Willow Hole
Snow Canyon	19.3	5231	San Gorgonio/Whitewater
Dry Morongo Creek	10.7	3126	Mission/Morongo
Stubbes Canyon	8.4	3500	San Gorgonio/Whitewater
Cottonwood Canyon	7.5	2889	San Gorgonio/Whitewater
Garnet Wash	6.0	1407	San Gorgonio/Whitewater
Blaisdell Canyon[2]	6.0	3101	San Gorgonio/Whitewater
“Indio Hills”[4]	5.9	1132	Willow Hole
“San Bernardino 1”[4]	5.8	2493	n.a.
“San Bernardino 2”[4]	3.8	1748	n.a.
Blind Canyon	3.4	1835	Mission/Morongo
“San Jacinto 2”[4]	3.4	2825	San Gorgonio/Whitewater
“San Jacinto 1”[4]	2.4	2552	San Gorgonio/Whitewater
West Wide Canyon	1.9	2059	n.a.

[1]na, not applicable; sediment does not reach deposition zones.
[2]Upper San Gorgonio River and Blaisdell Canyon do not supply sediment in the modern setting.
[3]Sediment from Upper Little Morongo and Upper Big Morongo Creeks does not reach deposition zones.
[4]Tributary has no official name.

where

Q_s is sediment yield in short tons per year (t/yr), and

A is drainage area (mi^2).

Sediment yield (and therefore the sediment contribution) is estimated from the contributing drainage area alone. Other factors, such as variation in slope angle within the drainage area as well as elevational gradients in precipitation, are very important to sediment yield but are not considered in this approach because of lack of data. The Renard equation is based on watershed data collected in the southwestern United States and has been successfully applied to other arid landscapes of high relief in the southwest (Webb and others, 2000).

The Flood-Frequency, Rating-Curve Technique

We developed a flood-frequency, rating-curve technique to estimate streamflow sediment yield based loosely on the work of Strand (1975) and Strand and Pemberton (1982). This technique requires numerous assumptions, one of the most important of which is that the decadal streamflow sediment yield in a tributary can be estimated by summing the sediment delivered by several floods of recurrence intervals described by regional flood-frequency relations (table 6; Thomas and others, 1997). Accordingly, we assumed that sediment yield can be calculated using:

$$Q_s = \Sigma[(m/n) \cdot \Theta(Q_n)] / m, \qquad (4)$$

where

$\Theta(Q_n)$ is the sediment yield of a nth year flood,

m is the rarest flood return period (years) in the summation, and

n are the more frequent flood return periods (years) ranging irregularly from 2 to m.

We assumed that sediment yield could be calculated from an expected value for the number of floods to occur in a decade. This expected value

contains five 2-yr floods, two 5-yr floods, and one 10-yr flood which are thought to deliver most of the sediment in an arid region such as the Coachella Valley. We assume that the annual flood does not contribute significant sediment. Considering the intermittent-flow regime of these tributaries, which probably have flow less than one percent of the time, this is likely not an egregious assumption. Also, regional flood-frequency relations do not produce annual floods, so we have no means of determining the effect of neglecting the smallest events on ungaged tributaries, and we chose not to include the influence of long recurrence-interval floods in the analysis. The regional-regression equations reported by Thomas and others (1997) for the 2-year, 5-year, and 10-year floods in Region 10 (the Southern Great Basin Region, which includes the Coachella Valley) are listed in table 2.

In order to calculate sediment yield for an n-year flood, we derived two relations based on daily sediment data collected on the Whitewater River near Whitewater, California (10256000). Sediment-concentration data was collected daily from October 1, 1970, to September 30, 1972, with daily streamflow discharge ranging from 0.2 to 126 ft^3/s (Appendix 2). The first relation was a sediment rating curve for that gaging station. Owing to evidence of channel change in the sediment data, data collected prior to December 21, 1971, was not used to calculate the rating curve. In addition, data for very low discharges (< 1.8 ft^3/s) was clearly non-linear with a high degree of scatter and was also not used in the calculation of the rating curve relation. The rating curve relation took the form of:

$$Q_d = Q_a \cdot 10^b, \qquad (5)$$

where

Q_d is sediment yield in short tons per year (t/yr),

Q is daily discharge in ft^3/s, and

a, b are coefficients determined using linear regression.

We next calculated the relation between total event sediment yield and peak daily discharge for each of the 50 largest floods recorded at the Whitewater stream gage. The streamflow record is much longer than the sediment record, extending from October 1, 1948, to September 30, 1979 (Appendix 2). The 50 largest floods range between 59 and 4,970 ft^3/s, with 26 floods (52 percent) peaking at 126 ft^3/s (the maximum flood in the sediment record). Total sediment yield for each flood event was calculated as the sum of all daily sediment yields for the duration of the flood. We then calculated the regression relation between peak discharge and total event sediment yield for each flood, resulting in an equation of the form:

Table 2. Regression equations for streamflow flood-frequency in Region 10 (Thomas and others, 1997).

Recurrence interval	Flood-frquency relation[1]
2-year flood	$Q_p = 12A^{0.58}$
5-year flood	$Q_p = 85A^{0.59}$
10-year flood	$Q_p = 200A^{0.62}$

[1] Q_p = peak discharge for flood (ft^3/s); A = drainage area (mi^2).

$$Q(Q_p) = Q_p^{\,a} \cdot 10^b, \qquad (6)$$

where

$Q(Q_p)$ is the total sediment yield for the flood in tons,

Q_p is peak daily flood discharge in ft^3/s, and

a, b are coefficients determined empirically using regression techniques.

We used this final relation of peak discharge to total flood sediment yield to in the calculation of expected annual sediment yield from each tributary as expressed in (4).

Non-Contributing Drainage Areas

In estimating fluvial sediment yield, it became apparent that some drainage areas, although having the potential to produce sediment, do not deliver sediment to the main depositional areas on a regular basis. In the case of upper Little Morongo and upper Big Morongo Washes this is a factor of topography: sediment from these basins is mostly trapped in the low-gradient Morongo Valley and does not reach Coachella Valley (fig. 2). Other drainage areas – San Bernardino 1, Blind Canyon, and San Bernardino 2 – are too small to generate streamflow sufficient to move sediment across the alluvial fans. This is evident from the absence of significant channels or areas of Late Holocene sediment at the mouths of these tributaries. In the modern era, man-made impediments prevent the delivery of sediment from both the upper San Gorgonio

River, which feeds into a gravel pit near the town of Banning, and Blaisdell Canyon, which is cut off from the Whitewater depositional area by California Highway 111 (figs. 1 and 2). Similarly, flood control projects at the mountain front of the Little San Bernardino Mountains eliminate West Wide Canyon as a sediment source, although whether it was ever a significant source of sediment is unknown. These tributaries and sub-tributaries were deemed non-contributing and were not included in sediment-yield estimates.

Particle-Size Distributions

To evaluate the fraction of streamflow sediment yield that is of the appropriate particle size for use by *Uma*, we collected samples of streamflow sediment from most of the prominent stream channels in the study area (fig. 3). Most of these channels consisted of left and right overbank areas, which are typically inundated during most floods, as well as the center of the channel. In most cases, we collected samples from the left and right overbank areas as well as the center of the channel. For sediment particle sizes, we use the standard unit ϕ, defined as

$$\phi = \log^2 (D), \qquad (7)$$

where D is the diameter, in millimeters, of the intermediate axis, also known as the b-axis (Folk, 1974). After sieving and analysis, the samples were composited into one sample for each channel cross section sampled.

The samples were oven dried and sieved following standard techniques (Kellerhals and Bray, 1971; Folk, 1974) using brass sieves at 1 ϕ intervals and a rotational shaker. Particles retained on each screen were weighed and the percent of the subsample in each ϕ class determined and combined to yield a channel-averaged particle-size distribution.

Historical Wind Energy and Direction

The primary source of wind data used for this report was the weather station at Palm Springs International Airport; additional data were obtained for Thermal, California and Edom Hill (fig. 1). Neither the Palm Springs nor the Thermal stations are truly representative of wind on the two reserves – Palm Springs is south of the study area and is slightly south of the main wind jet from San Gorgonio Pass, and Thermal is 25 miles southeast of Edom Hill and about 25 miles east southeast of Palm Springs International Airport – but these are the only available records of suitable length. Wind data collected at Palm Springs and Thermal from 1992 to May 2001 were analyzed. These data are available from the Western Region Climate Center. The Edom Hill data are of limited extent, with only the data collected in 2001 sufficiently complete (90 percent). Data from Edom Hill were collected by SeaWest on the western slopes of Edom Hill just east of Varner Road. These data are very well situated for directional analysis with regard to the Mission Creek – Morongo Wash depositional area, but are not applicable to any other depositional area.

Before 1998, observations at Palm Springs were made only 18 hours a day (6 am-12 am) and data availability averages about 67 percent. Starting in February 1998, observations were made on a 24-hr basis and data availability increases to about 95 percent. One result of this change in instrumentation is that the magnitude of the sand drift potential changes significantly after February 1998 and is reduced by a factor of 3.6, apparently because the new system appears to provide generally lower hourly average wind speeds. The other impact of this change is that there are differences in recorded wind directions, so that the vector direction of the sand-transport potential changes by approximately 30°. Because of these uncertainties, we have concentrated our analysis on the more recent continuously recorded data that began in 1998.

Wind directions at Palm Springs International Airport and Edom Hill were summarized by calculating the percentage of observations that fall within each of the sixteen standard compass directions, such as “west” or “west southwest.” This results a division of the compass into sixteen intervals, or sectors, of 22.5° each. Frequency values were calculated for all winds measured as well as for only sand-transporting winds. Sand-transporting winds are defined as those winds that exceed the minimum velocity necessary to transport sand at a given location. This threshold velocity varies between Palm Springs and Willow Hole owing to differences in the height at which winds are measured.

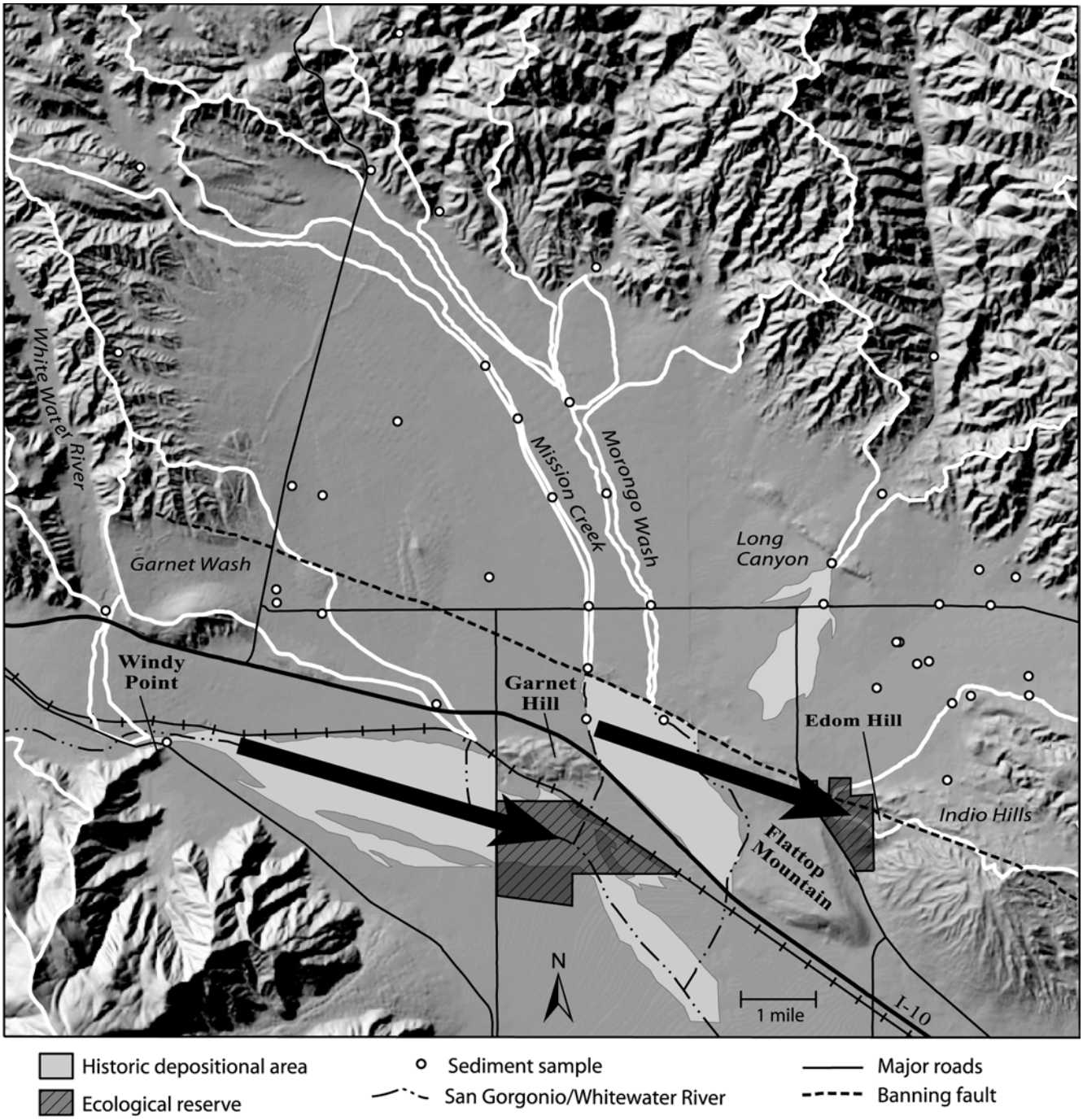

Figure 3. Shaded relief map of the northern Coachella Valley showing general paths of eolian transport from areas of fluvial deposition to the Whitewater Floodplain and Willow Hole Reserves and locations of sampled fluvial sediment. White lines indicate drainage boundaries.

Because the Edom Hill wind data were collected at the approximate center of the Willow Hole Reserve, wind-direction frequency derived from these data for a given compass sector can also be used as a measure of the percent frequency of time – expressed as a probability – that winds crossing that sector in the neighborhood of the Reserve are headed directly toward the center of the Reserve. For example, if winds at Edom Hill come from the North sector 7.3 percent of the time, then, conversely, winds across the Northern sector will be headed directly toward Edom Hill 7.3 percent of the time. We applied this principle to the Mission Creek – Morongo Wash depositional area for sand-transporting winds, presenting the frequency with which sand-transporting winds are headed directly towards the center of Willow for each sector that crosses the depositional area. For increased resolution over the depositional area, we recalculated frequencies for smaller 10° sectors, which resulted in seven sectors between 235° and 305° crossing the Mission – Morongo depositional area. These frequencies reflect the probability that a sand-transporting wind can deliver sand to the Reserve from each sector in the Mission Creek – Morongo Wash depositional area and give one measure of the relative value of different parts of the Mission Creek – Morongo Wash depositional area as it relates to sand transport to Willow Hole. Slight differences in summed percentages result from the differences between defining 22.5° and 10° sectors and the accuracy with which the original wind data were collected.

Sand-Transport Potential

Sand-transport potential is a measure of how much sand can be transported by the wind, assuming that: (1) there is a supply of sand for transport by wind and (2) this sand is available for transport. That is, the surface is not protected by vegetation, the sand is dry, and the surface is not crusted (Kocurek and Lancaster, 1999).

A commonly-used method for analyzing wind data was developed by Fryberger (1979). This method assigns a weighting to the measured wind speed based on how much it exceeds a threshold velocity for transport to estimate a potential sand transport rate (q). Thus:

$$q = V^2 (V - V_t) \cdot t, \qquad (8)$$

where

- q is the sand transport potential in arbitrary velocity units (VU),
- V is the wind speed,
- V_t is the threshold wind speed for sand transport at the height of the wind recorder, and
- t is the percentage of the time the wind blows from a given direction.

Values of q are calculated for each wind speed class and summed to estimate a sand drift potential (DP) in vector units for all winds above threshold at a given location. In addition, a vector sum (resultant drift potential, or RDP) and direction is calculated for sand transport potential.

Fryberger (1979) presented a classification scheme in which the DP of a location could be grouped into low-, intermediate-, and high-energy environments based on values of the drift potential (DP). For a station where wind speed is measured in knots (1 nautical mile/hour), low-energy environments have a DP <200, intermediate-energy environments have 200<DP<400, and high-energy environments have DP>400.

The Dune Mobility Index

Whether or not eolian dunes are expected to be mobile or stable under specific wind regime and climatic conditions can be calculated as a function of wind conditions and climate. The dune mobility index (M) is calculated as:

$$M = W / (P/PE), \qquad (9)$$

where

- W is the percentage of the time that the wind is above the threshold for sand transport,
- P is the annual precipitation (mm),
- PE is the threshold wind speed at the height of the wind recorder, and
- t is the annual potential evapotranspiration (mm) calculated using the Thornthwaite method (Thornthwaite and Mather, 1957).

Threshold values of the mobility index are: M<50, dunes are inactive (stabilized by vegetation); 50<M<100, only crests of dunes are active;

100<M<200, dunes are active but lower slopes are vegetated; and >200, dunes are fully active (Lancaster and Helm, 2000).

Historical Changes in Eolian Deposits

Following Lancaster and others (1993), we analyzed aerial photography taken in various years to evaluate changes in the spatial extent of eolian deposits (table 3). Aerial photography was analyzed in a geographical information system (GIS) by georeferencing the aerial photography to 7.5' topographic maps. Using these techniques, we have revisited the findings of Lancaster and others (1993) and also qualitatively assessed the areas of active sand in the vicinity of the two reserves and extended the temporal coverage of these eolian systems.

A CONCEPTUAL MODEL OF THE SAND-DELIVERY SYSTEM IN THE NORTHERN COACHELLA VALLEY

This section provides a qualitative description of the sand-delivery system that ultimately produces the eolian habitats in the northern Coachella Valley. Basic geomorphic terms and the elements of the delivery system are defined for clarity and for use in later sections. The sections that follow will provide quantitative estimates of fluvial and eolian transport that logically follow from this conceptual model.

Sand-size particles that eventually become eolian sand in the northern Coachella Valley are generated in the headwaters and steep areas of the San Jacinto, San Bernardino, and Little San Bernardino Mountains. Most sediment is produced on steep slopes at higher elevations in these mountains, where precipitation is more than five times greater than precipitation on the valley floor (table 4). Floods are of higher magnitude below 7,500 ft elevation (Thomas and others, 1997), primarily because most precipitation at higher elevations falls as snow in winter or gentle rainfall in other seasons. Development has not affected sediment sources significantly because most of the areas where sediment is produced is currently under federal or state management. The alluvial fans that coalesce to form the Desert Hot Springs bajada produce insignificant amounts of sediment from most of their surfaces because of the low precipitation, the sandy substrate that readily absorbs rainfall, and the low slope angle of the fan surface.

Sediment is transported from headwaters to depositional areas in Coachella Valley in episodic streamflow floods that are not necessarily even annual in recurrence. Channels through the alluvial fans in the northern Coachella Valley are mostly sediment conduits with little change in storage. Some of these channels, particularly Mission Creek and Morongo Wash, were naturally channelized because the south branch of the Banning (San Andreas) Fault crosses both washes (figs. 2b and 3). Vertical fault offsets prehistorically created nickpoints that migrated upstream on both Mission Creek and Morongo Wash, creating entrenched channels known as arroyos.

Table 3. Aerial photography of the Whitewater and Willow Hole Reserves used to analyze historical changes in eolian deposits.

Photo year	Series title	Date of photograph	Number of photographs	Type of photograph[1]	Photo scale	Coverage of Whitewater?	Coverage of Willow Hole?	Comments
1996	USGS Orthophotos	June	4	Digital	1:12,000	Yes	Yes	1m pixels
1989	USGS NAPP	7/25, 8/16	9	CIR	1:40,000	Yes	Yes	
1984	USGS NHAP	8/24	4	CIR	1:58,000	Yes	Yes	
1979	Oblique	11/15	1	B&W	n.a.[2]	Yes	Yes	one oblique
1977	7	2/4	1	B&W	1:40,000	Partial	Partial	single photo
1972	472	8/17	9	B&W	1:40,000	Yes	Yes	
1965	Universe Special	unknown	2	B&W	1:24,000	No	Yes	
1959	AXM-6W & 10W	June	9	B&W	1:20,000	Yes	Yes	
1953	AXM-1K, 3K, 9K, &10K	8/19, 9/19, 10/24	22	B&W	1:20,000	Yes	Yes	
1939	C6060	12/7	4	B&W	1:18,000	No	Yes	

[1]Digital, orthophotographs derived from aerial photography; CIR, color infrared; B&W, black-and-white aerial photography.
[2]A scale is not applicable because the photograph is oblique.

Table 4. Mean and range in annual precipitation at selected long-term stations in or near the Coachella Valley, California.

		ANNUAL PRECIPITATION[1]		
Location	**Elevation (ft)**	**Annual**	**Minimum**	**Maximum**
Idyllwild Fire Department	5,400	26.09	10.60	56.87
Big Bear Lake	6,760	22.44	6.99	55.76
Deep Canyon	800	5.78	1.37	18.82
Palm Springs	420	5.00	0.76	13.72

[1]Data are from Western Region Climate Center (period of record through 2000), except for University of California Philip L. Boyd Deep Canyon Research Center (M. Fisher, Deep Canyon Preserve, written commun., 2001).

Downstream from the confluence of the San Gorgonio and Whitewater Rivers, and particularly downstream (east) from Windy Point, the Whitewater River channel broadens into what historically was a depositional plain more than a mile in width. This flat depositional plain historically had several channel splays with low banks and may have originated from prehistoric debris-flow deposition. The combined floodwaters of the San Gorgonio and Whitewater Rivers debouch onto the depositional plain, depositing fluvial sediments in a low-energy environment (fig. 3). Because little non-anthropogenic topography is present on these floodplains, fluvial sediments can be assumed to be deposited evenly over the area instead of in discrete packets of relatively thick floodplain deposits as occurs on more entrenched rivers.

Sediment is entrained from the Whitewater depositional area by the unidirectional wind field and is moved across eolian plains downwind from the depositional areas (fig. 3). Much of this eolian transport is unimpeded across the Whitewater Floodplain Reserve, but flow on the north and south sides of the depositional area and the Reserve is influenced by local obstructions. Interruptions in a continuous fetch by buildings, windbreaks, or small or large dikes will create local windbreaks that store eolian sand. Because of this, the windbreaks, as well as raised roadbeds of both the railroad and Interstate 10, interrupt the flow of sand from the Whitewater flood plain, likely storing much of that sand along the windbreaks and embankments and diverting some of it towards the southeast. Other artificial features, such as excavations on the south side of Garnet Hill and recharge and flood-control levees, create sand-storage sites on their lee (downwind) sides even if sand does not overtop the surface.

The Mission Creek – Morongo Wash depositional area is bounded on the north by the vertical offset of the south branch of the San Andreas Fault, which creates a natural channelization of these water courses upstream (fig. 3). Downstream from the fault, and upstream from the embankments and dikes associated with Interstate 10, floodwaters spread over a broad floodplain with little significant topography other than local bar-and-swale features. This depositional area is bounded on the west by the westerly splay of Mission Creek and on the east by the main splay of Morongo Creek at the footslope of Flattop Mountain (fig. 3). Dikes associated with the raised roadbed of Interstate 10 enhance deposition on this floodplain because floodwaters are forced to pass under the freeway at relatively constricted culverts.

Eolian sand is entrained from the Mission Creek – Morongo Wash depositional area in the same manner as from the Whitewater depositional area. The prevailing wind direction is westerly and impinges directly upon Flattop Mountain and a low pass just north of this hill. Flattop Mountain has a gentle slope on its west side, possibly shaped by wind erosion, and this slope allows sand transport over the hill and into the Willow Hole Reserve and to another deposit locally known as Stebbins Dune. During very intense windstorms, and presumably when fluvial sediment is not limiting, some eolian sediment is swept over the Willow Hole Reserve area and is transported onto the hillslopes of the Indio Hills drainage to the north of Edom Hill. Certainly urbanization and the introduction of windbreaks – particularly *Tamarix* trees – has reduced the amount of eolian sand transported by an unknown amount. However, many windbreaks were in place by 1925, and aerial photography since then indicates that a substantial amount of sand has still been transported over Flattop Mountain and into Willow Hole.

Historically, Long Canyon deposited sediment across a two-mile long area stretching south from the mouth of the canyon across the Hot Springs bajada (fig. 3). With the Willow Hole Reserve positioned slightly east of south from this depositional area, only a small fraction of available sand likely would have been transported directly to the Reserve in the prevailing winds. Predominantly westerly winds transport most eolian sand either along the northern edge of the Indio

Hills or into the Indio Hills drainage north of Edom Hill. That the Indio Hills drainage acts as a trap for eolian sand from fluvial deposits to the west is evidenced by the deposits of eolian sand several yards thick that blanket the hillslopes of this area. Much of this sand was likely deposited during the Pleistocene, but sand may still be transported from the Mission – Morongo area during very intense windstorms, as well as from the Long Canyon area. Trapped in a fluvial source area, this eolian sand is recycled into the system as fluvial sediment, entrained and transported out of the Indio Hills drainage during intense summer thunderstorms. Historically, this sediment was deposited locally within the Willow Hole Reserve, where it was available for local redistribution by eolian processes. However, recent storms have entrenched the channel through Willow Hole with the result that much of the fluvial sediment is now deposited just outside the southern boundary of the Reserve where the channels are less entrenched. This material has the potential to be carried back into the Reserve by eolian processes only if sufficient southerly winds occur along the topographic low between Flattop Mountain and the western end of the Indio Hills (fig. 3).

FLUVIAL SEDIMENT TRANSPORT

Quaternary Geologic Units

The Desert Hot Springs bajada is comprised of a mosaic of geomorphic surfaces of Pleistocene and Holocene age (fig. 4). This mosaic is useful for evaluating the potential sediment contributions from the Desert Hot Springs bajada to the depositional areas of Whitewater River and Mission Creek – Morongo Wash. A total of 15 mapping units were identified on this bajada (table 3); descriptions of these units are given in Appendix 1.

Active channels and depositional areas (**Qayy**) comprise 22.3 percent of the mapped bajada area (table 5), and much of this area defines the Whitewater, Mission Creek – Morongo Wash, and Long Canyon depositional areas. These areas are considered to be the most significant to the sand-delivery system of the northern Coachella Valley. Most of the bajada (50.1 percent) is mapped as young fan alluvium of both Holocene and latest Pleistocene age (**Qay**). Units of early Holocene to Pleistocene age comprise 18.1 percent of the alluvial fans. These units, combined with **Qay**, likely produce little fluvial or eolian sediment that reaches the depositional areas for reasons of low precipitation, high infiltration rates, and low slope angles. Reflecting the ephemeral nature of eolian deposits in this part of the Coachella Valley, only 6.1 percent of the area was mapped as eolian sand (**Qe**) or sand dunes (**Qd**). Most of these units are in the southeast corner of the mapped area in the Willow Hole Reserve (fig. 4). Despite this, **Qayy** and **Qay** units on the south edge of the mapping area (fig. 4) historically have had significant ephemeral dune migration across their surfaces.

Table 5. Quaternary geologic units of the Desert Hot Springs and Seven Palms Canyon 7.5′ quadrangles, California.

RANKED BY AGE			RANKED BY SURFACE AREA		
Quaternary unit	Area (mi2)	Coverage (percent)	Quaternary unit	Area (mi2)	Coverage (percent)
Afd	1.0	1.0	Qay	48.3	50.1
Qd	0.5	0.5	**Qayy**	**21.5**	**22.3**
Qe	5.4	5.6	Qe	5.4	5.6
Qayy	**21.5**	**22.3**	Qai	4.8	5.0
Qayi	**2.4**	**2.5**	Qayo	4.1	4.2
Qay	48.3	50.1	Qao	3.1	3.3
Qayo	4.1	4.2	**Qayi**	**2.4**	**2.5**
Qfy	0.7	0.7	Qtps	2.0	2.1
Qaiy	0.7	0.7	Qtpc	1.1	1.2
Qai	4.8	5.0	Afd	1.0	1.0
Qao	3.1	3.3	Qaiy	0.7	0.7
Qau	0.7	0.7	Qfy	0.7	0.7
Qcf	0.2	0.2	Qau	0.7	0.7
Qtpc	1.1	1.2	Qd	0.5	0.5
Qtps	2.0	2.1	Qcf	0.2	0.2

Fluvial Sediment Yield and Delivery

Flood-Frequency, Rating-Curve Relation

The sediment rating curve calculated for the Whitewater River near Whitewater took the form:

$$Q_d = Q^{2.72} \cdot 10^{-1.21}, \qquad (10)$$

where

Q_d is the daily sediment yield (t/day), and

Q is the daily flood discharge (ft^3/s).

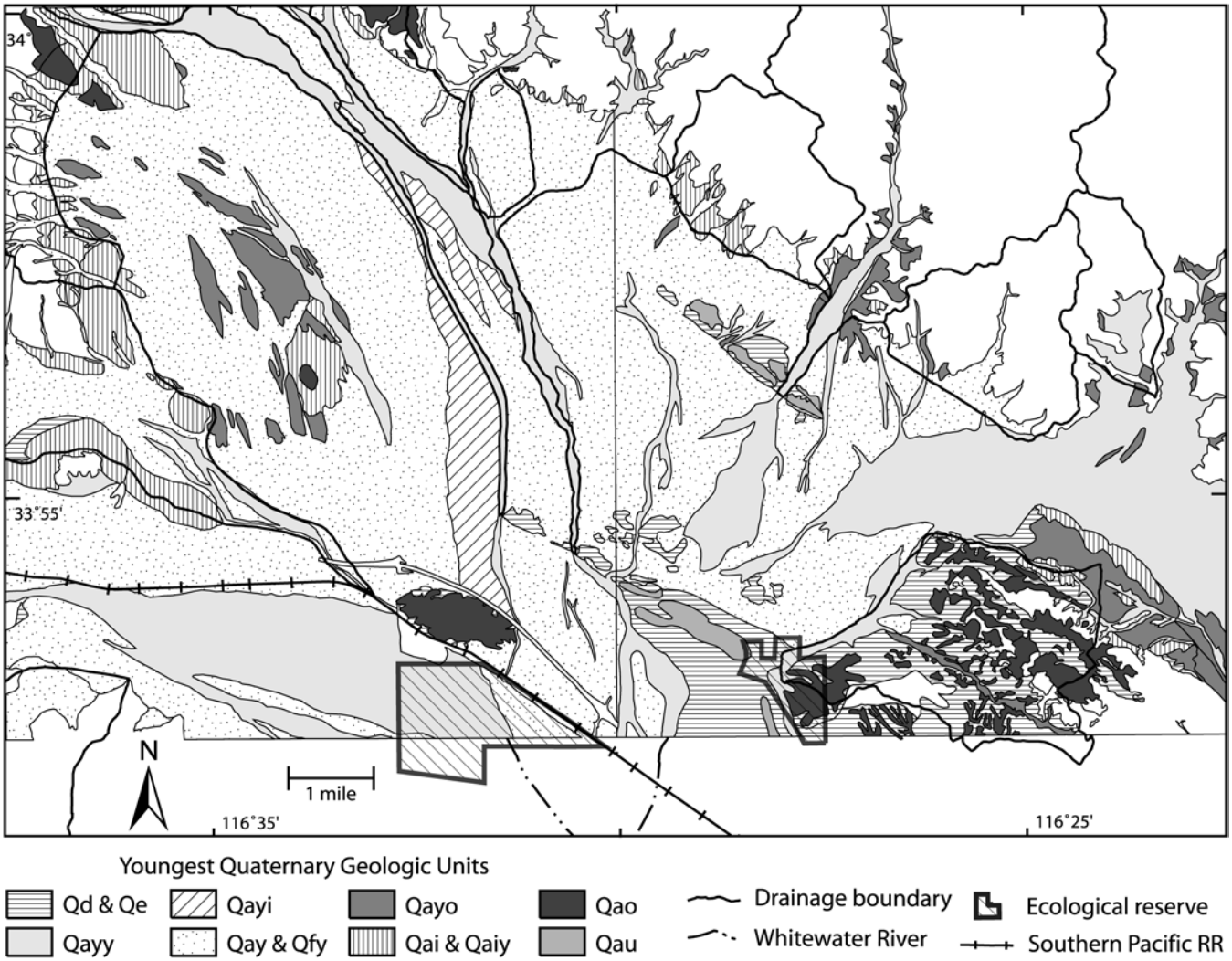

Figure 4. The eleven most recent Quaternary geomorphic surfaces and deposits in the Desert Hot Springs and Seven Palms Valley 7.5′ Quadrangle Maps in the northern Coachella Valley, California (Lundstrom and others, 2001). See Appendix 1 for a description of map units.

R^2 is 0.90 for this rating curve, indicating a high degree of relation between streamflow discharge and sediment yield (fig. 5). Using this relation to calculate total event yield for the 50 largest floods on the Whitewater River, we derived the relation between event sediment yield [$\Theta(Q_p)$] in tons/yr and peak discharge (Q_p) in ft^3/s as:

$$\Theta(Qp) = Q_p^{2.751} \cdot 10^{-1.092}. \qquad (11)$$

R^2 for this relation is 0.91. Equation (11) was used in combination with flood frequency relations (table 2) to estimate annual sediment yields for drainages contributing sediment to the northern Coachella Valley.

Sediment-Yield Estimates

Sediment-yield estimates calculated using the flood-frequency/rating-curve technique (equation (11)) were in reasonably close agreement with those calculated using the Renard (1972) relation (equation (3)), being of the same order of magnitude and consistently twice the quantity (table 6). Estimates from both techniques are given in the tables to provide minimum and maximum estimates of sediment yield. For simplicity, the following discussion and analysis will only use the estimates based on Renard (1972).

Sediment yield to the Whitewater depositional area in the modern era is slightly less than in the predevelopment period owing to the absence of the

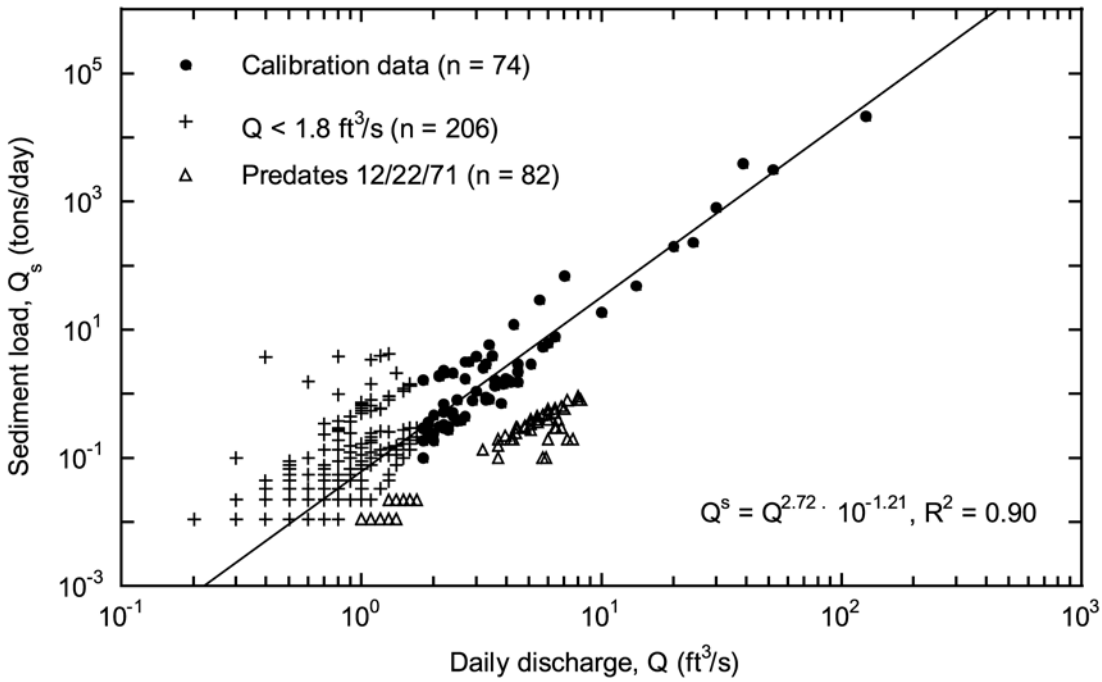

Figure 5. Sediment-rating curve for the Whitewater River near Whitewater, California (station number 10256000). Daily sediment samples were collected between October 1, 1970, and September 30, 1972

upper San Gorgonio River and Blaisdell Canyon as sources of sediment. The in-stream mining operation on the upper San Gorgonio River appears to reduce sediment yields in the entire San Gorgonio basin by 14 percent (table 6). Reflecting differences in drainage area, the volume of sediment delivered to the Whitewater depositional area at 3.5 million ft^3/yr is roughly double that delivered to the Mission Creek – Morongo Wash depositional area at 1.5 million ft^3/yr. Long Canyon delivers 0.42 million ft^3/yr and the Indio Hills drainage area 0.11 million ft^3/yr. Actual sediment yield from the Indio Hills may be higher than this estimate due to the abundant loose sediment available on hillslopes in these drainages.

Sediment yield from the non-channel area (all but **Qayy**) of the Desert Hot Springs bajada, also calculated using the Renard (1972) relation, is an estimated 0.74 million ft^3/yr (table 6), or about 12 percent of the total estimate for all tributary drainage areas. The flood-frequency, rating-curve technique for estimating sediment yield could not be applied to these poorly-defined drainage areas. However, the estimate using the Renard equation should be considered a maximum value, at best, because the sediment-yield relation used was developed for an area with more than twice the mean annual precipitation than occurs on the alluvial fans.

Most sediment production occurs in high-relief parts of the San Bernardino, Little San Bernardino, and San Jacinto Mountains. On average, 56 percent of the area of contributing drainages has a ground slope in excess of 30 percent (table 7), with an additional 27 percent having a slope of 10 to 30 percent. The steepest drainages, such as Snow Canyon, which heads at San Jacinto Peak (10,804 feet), can have more than 80 percent of their area steeper than a 30 percent slope. In contrast, 95 percent of the alluvial fans have less than a 10 percent slope (table 7), and sediment production would be expected to be much lower than from the steeper mountain drainages. This interpretation is supported by the Quaternary geologic mapping, which labels most of the alluvial fans as alluvium that dates to as long ago as the late Pleistocene (**Qay**), in contrast to the younger, more active sediment of the tributary channels (**Qayy**; fig. 4).

Table 6. Estimates of sediment yield from drainages entering the northern Coachella Valley for historic (predevelopment) and modern periods.

Tributary	HISTORIC SEDIMENT YIELD[1] ($10^6 \cdot ft^3/yr$)			MODERN SEDIMENT YIELD[1] ($10^6 \cdot ft^3/yr$)		
	Drainage area (mi^2)	Renard (1972) equation	Flood-frequency method	Drainage area (mi^2)	Renard (1972) equation	Flood-frequency method
San Gorgonio/Whitewater depositional area						
San Gorgonio River[2]	154	2.1	3.3	132	1.8	2.5
Whitewater River	60	0.87	1.5	60	0.87	1.5
Snow Canyon	19	0.32	0.78	19	0.32	0.78
Stubbes Canyon	8	0.16	0.47	8	0.16	0.47
Cottonwood Canyon	7	0.14	0.44	7	0.14	0.44
Garnet Wash	6	0.11	0.38	6	0.11	0.38
Blaisdell Canyon[3]	6	0.11	0.38	0	0	0
San Jacinto 2	3	0.069	0.27	3	0.069	0.27
San Jacinto 1	2	0.051	0.22	2	0.051	0.22
TOTAL	266	3.9	7.8	238	3.5	6.6
Mission/Morongo depositional area						
Mission Creek	38	0.59	1.18	38	0.59	1.18
Little Morongo (lower)	34	0.54	1.10	34	0.54	1.10
Dry Morongo	11	0.19	0.55	11	0.19	0.55
Big Morongo (lower)	9	0.16	0.49	9	0.16	0.49
TOTAL	92	1.5	3.3	92	1.5	3.3
Long Canyon depositional area						
Long Canyon	26	0.42	0.94	26	0.42	0.94
Willow Hole depositional area						
Indio Hills	6	0.11	0.38	6	0.11	0.38
TOTAL (all drainage areas)	390	6.0	12.4	362	5.5	11.2
Alluvial fans	49	0.74	–	49	0.74	–

[1]Estimates have been converted from mass to volume by assuming a sediment density of 0.0375 tons/ft^3.
[2]The San Gorgonio River above Banning, California, does not contribute sediment in the modern era.
[3]Blaisdell Canyon does not contribute sediment in the modern era.

Historical Changes in the Size of the Depositional Areas

Fluvial sediment from each contributing drainage area is deposited onto one of four depositional areas (figs. 3 and 6, table 6). The nine westernmost tributaries deposit sediment downstream from the confluence of the San Gorgonio and Whitewater Rivers in the Whitewater depositional area, which extends from Windy Point to the east and from the railroad south (figs. 3 and 6). Immediately to the east, Mission Creek and Morongo Wash (a composite of three drainages) deposit in an area between the west splay of Mission Creek and the east splay of Morongo Creek north of Interstate 10 and south of the Banning (San Andreas) Fault (figs. 3 and 6). Long Canyon deposits at a third area, stretching southwest from the mouth of the wash onto the Desert Hot Springs bajada. Sediment from the Indio Hills tributary was historically deposited directly into Willow Hole and the Willow Hole Reserve. As stated previously, recent storms have channelized the reach through Willow Hole, causing sediment to be deposited outside the southern boundary of the Reserve and temporarily decreasing the potential for eolian additions directly from the channel. This poorly defined area was not evaluated as a distinct depositional area.

Table 7. Slope classes of sediment source areas and alluvial fans in the northern Coachella Valley.

Tributary	Drainage area (mi^2)	DRAINAGE AREA IN SLOPE CLASS (percent) > 30 percent slope	10 - 30 percent slope	< 10 percent slope
San Gorgonio River	153.5	46	22	32
Little Morongo	67.7	63	25	13
Whitewater River	59.6	78	14	8
Mission Creek	38.4	74	19	7
Big Morongo	31.0	62	21	17
Long Canyon	26.3	73	24	4
Snow Canyon	19.3	84	10	6
Dry Morongo	10.7	54	31	15
Stubbes Canyon	8.4	78	12	10
Cottonwood Canyon	7.5	70	22	9
Garnet Wash	6.0	11	28	62
Blaisdell Canyon	6.0	77	15	9
"Indio Hills"[1]	5.9	8	50	42
"San Bernardino 1"[1]	5.8	37	47	16
"San Bernardino 2"[1]	3.8	55	30	15
Blind Canyon	3.4	52	39	9
"San Jacinto 2"[1]	3.4	69	11	20
"San Jacinto 1"[1]	2.4	69	17	14
West Wide Canyon	1.9	49	31	20
MEAN	–	56	27	17
Alluvial fans	49.3	1	4	95

[1]Tributary has no official name.

Before the construction of infiltration galleries, retention dikes, railroad, and major highways (the predevelopment period), the areal extent of the three main depositional areas strongly reflected the amount of annual sediment deposited in each zone (tables 6 and 8; fig. 6a). The historic Whitewater depositional area received roughly three times the sediment received by the Mission Creek–Morongo Wash depositional area and was about 2.5 times larger (7 mi^2 as opposed to 3 mi^2). Similarly, the Mission Creek–Morongo Wash depositional area received roughly three times the sediment deposited in the Long Canyon depositional area and was also about three times larger (3 mi^2 as opposed to 1 mi^2).

In the modern era, the extent of two depositional areas – the Whitewater and Long Canyon depositional areas – has been reduced by alteration of channels and floodplains (fig. 6b, table 8). The Whitewater depositional area has been reduced by nearly 50 percent to 3.6 mi^2 by the installation of the infiltration galleries along the south edge of the river (fig. 6b). These galleries necessarily trap fluvial sediment, which is then unavailable for eolian transport owing to the geometric arrangement of the galleries perpendicular to wind direction. In addition, there is a loss of fetch area between the infiltration galleries and the reserve; the Whitewater depositional area has been reduced to a thick band along what was the northern edge of the river. Similarly, the Long Canyon depositional area has been truncated by major roads on three sides, reducing depositional area by over 80 percent to 0.2 mi^2. Although small culverts pass beneath the roads, most sediment appears to be effectively trapped within the reduced depositional area unless flow substantially overtops the roads.

Table 8. Change in depositional areas upwind of reserves in the Northern Coachella Valley

Depositional area	Historic area (mi^2)	Modern area (mi^2)	Change (mi^2)	Change (percent)
San Gorgonio/ Whitewater	7.1	3.6	-3.5	-49.2
Mission/Morongo	2.7	2.7	0	0
Long Valley	1.1	0.2	-0.9	-80.2
TOTAL	10.8	6.5	-4.3	-40.1

The modern Mission Creek – Morongo Wash depositional area is approximately the same size as the historic area. Dikes associated with Interstate 10 and railroad construction limit the depositional area to mostly north of the freeway and reduce the connectivity with the Whitewater depositional area. Because these washes fan out over a broad depositional area upstream from the freeway dikes, most habitat-building sand is likely deposited in a position that makes it available for eolian transport. This condition may have been the case in the predevelopment period.

Depth of Deposition

After converting sediment-yield estimates from mass to volume, we distributed fluvial sediment over the three historic depositional areas, both as a check on the magnitude of the fluvial sediment yields and to determine if prevailing winds could entrain this amount of sediment. The depth of fluvial sediment deposited in the historic period is very consistent among the three

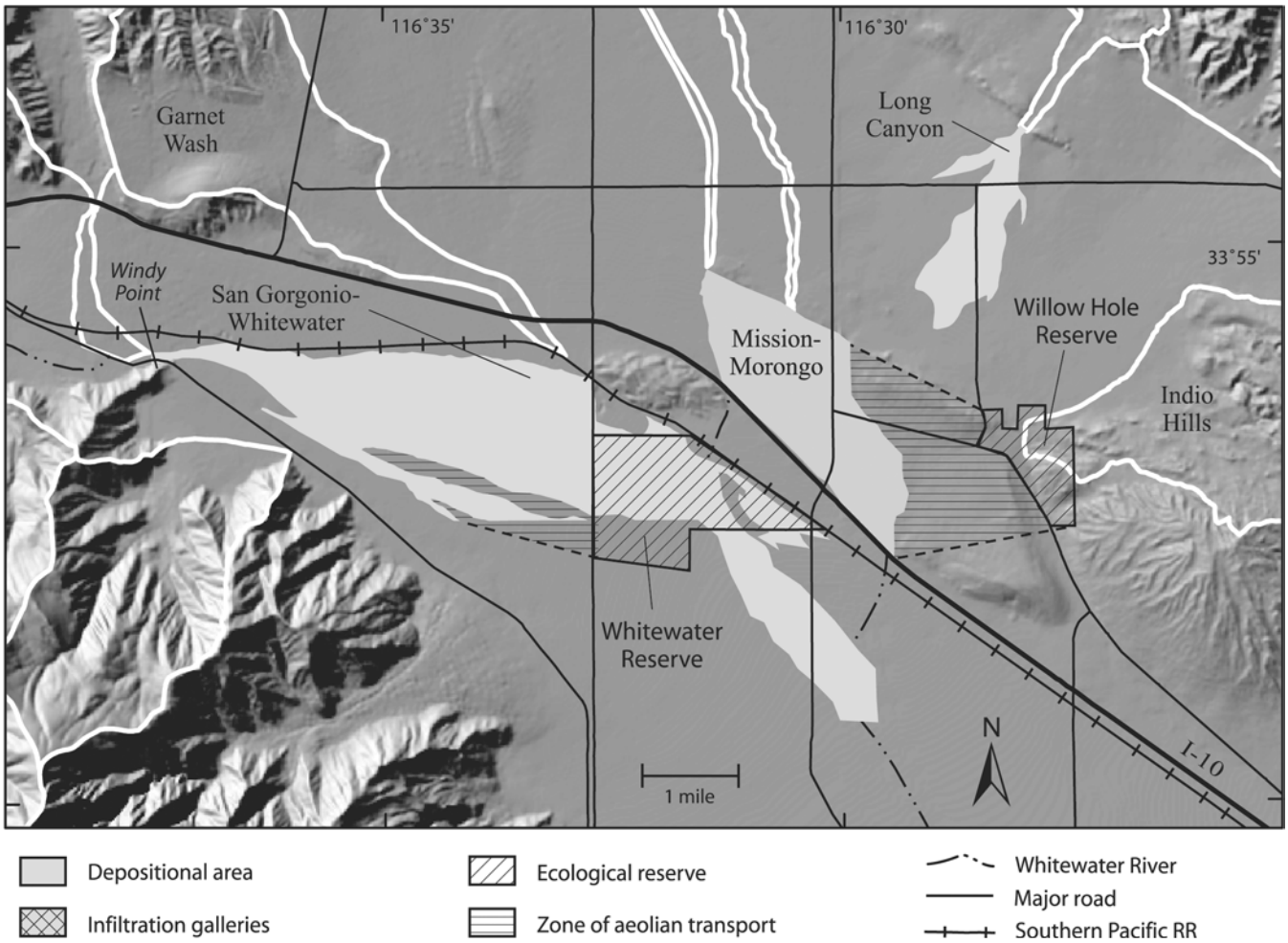

Figure 6. Shaded relief map showing the location of historic and current areas of fluvial deposition for the San Gorgonio – Whitewater River, Mission Creek – Morongo Wash, and Long Canyon drainages. White lines indicate drainage boundaries.

A. Historic (predevelopment) areas of fluvial deposition.

depositional areas, about 0.2 in./yr (table 9). This depth agrees well with field observations made at the depositional areas and suggests that the sediment-yield estimates made using both approaches are of an appropriate order of magnitude.

The artificial reduction of the size of the depositional areas is clearly evident in the large increase in estimated deposition depth on the Whitewater depositional area from 0.2 (predevelopment) to 0.4 in./yr (modern). Similarly, the increase is particularly large on the Long Canyon depositional area (from 0.2 to 0.9 in./year). The modern estimate of depth of deposit at Long Canyon is high, perhaps too high, with an unknown quantity of material spilling over the adjacent roads at higher flows to be deposited further downstream. The estimate for the Whitewater depositional area, however, does not take into account the trapping of sediment in the infiltration galleries and therefore should be considered a maximum.

Given that the diversion dikes are designed to breach above a given flood level, it is difficult to effectively estimate the amount of sand actually trapped by the infiltration dikes. In 1996, 8.1 million ft^3 of “silt” was dredged from 3 of the 19 percolation ponds (Daniel Farris and Patti Schwartz, Coachella Valley Water District, oral commun., 2002), and the remaining ponds were ripped to enhance infiltration. Without knowing the period over which the trapping occurred, it is impossible to evaluate precisely what percentage of total sediment yield from the San Gorgonio – Whitewater system this sediment

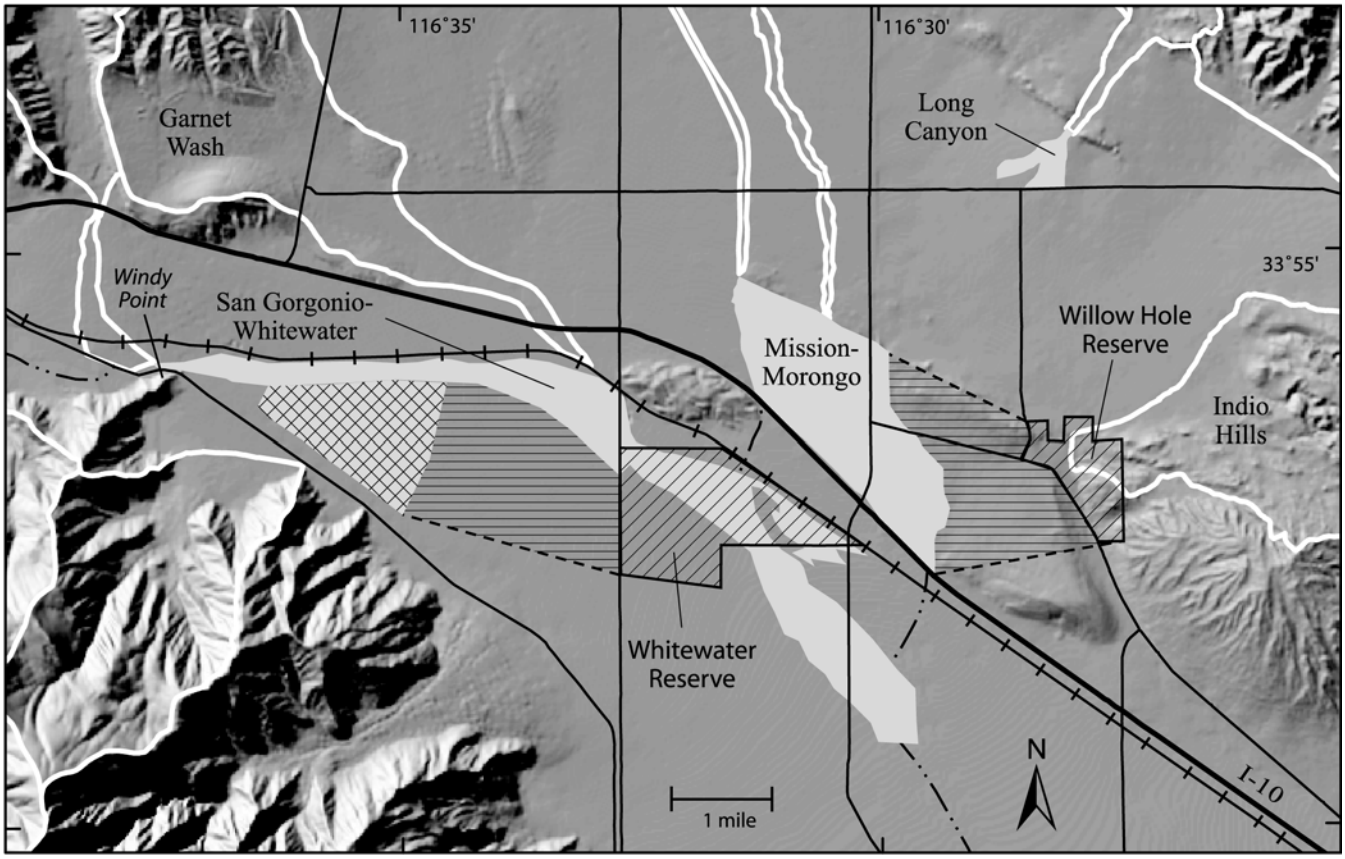

Figure 6. *Continued.*

B. Current (1993) areas of fluvial deposition and the infiltration galleries (also known as percolation ponds) in the Whitewater River.

Table 9. Estimates of total sediment delivered to zones of deposition in the northern Coachella Valley.

	HISTORIC SEDIMENT YIELD (in/yr)			MODERN SEDIMENT YIELD (in/yr)		
Depositional area	Depositional area (mi^2)	Renard (1972) equation	Flood-frequency method	Depositional area (mi^2)	Renard (1972) equation	Flood-frequency method
San Gorgonio/Whitewater	7.1	0.24	0.47	3.6	0.41	0.79
Mission/Morongo	2.7	0.24	0.53	2.7	0.24	0.53
Long Canyon	1.1	0.17	0.38	0.2	0.86	1.91
MEAN	–	0.22	0.46	-	0.51	1.08

represents. In its entirety, this volume of sediment represents 100 to 230 percent of the average annual sediment yield. However, the same amount of sediment distributed over a twenty-year period results in an average annual sediment loss of 5 to 12 percent. Actual sediment loss probably is somewhere between these extremes. In addition, the particle-size distribution of the trapped sediment must be known in order to calculate what percentage of this sediment is eolian sand, let alone lizard habitat sand. If this trapped material was largely silt-sized particles with very little sand, its loss has had little direct effect on *Uma* habitat. Both the time period of trapping as well as an accurate understanding of the particle-size distribution of the trapped sediment is necessary to understand the long-term sediment trapping that occurs in these infiltration galleries and the effects it has on the sediment-delivery system in the northern Coachella Valley.

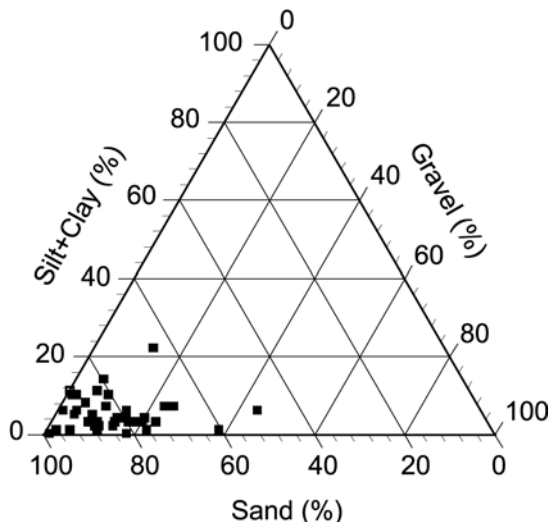

Figure 7. Ternary diagram showing sediment particle-size distributions for samples collected from washes in the northern Coachella Valley.

Table 10. Percent of total fluvial sediment yield composed of sand sizes preferred by *Uma inornata*.

Source	Preferred sand[1] (wt percent)	Standard deviation (±wt percent)	Sample (n)
San Gorgonio – Whitewater River	18.7	8.6	8
Mission Creek – Morongo Wash	17.6	6.3	15
Long Canyon	17.1	8.3	15
Edom Hills	35.0	9.1	2
ALL SITES	18.5	8.3	41

[1]The range in sand preferred by *Uma* has an intermediate diameter ranging between 0.172 and 0.328 mm ($1.6 < \phi < 2.5$; Barrows, 1997).

Particle-size Distributions

The sediment transported in channels of the northern Coachella Valley is relatively well sorted and is composed of 82.5 percent sand-size particles (fig. 7). The proportion of fluvial sediment in the 0.172 to 0.328 mm range preferred by *Uma* was remarkably consistent across the study area and had a mean value of 18.5 ± 8.3 percent (table 10). By source area, sand in the 0.172 - 0.328 mm range comprised 18.7 percent of the San Gorgonio – Whitewater River sediment yield, 17.6 percent of the Mission Creek – Morongo Wash sediment yield, 17.1 percent of the Long Canyon sediment, and 35.0 percent of the Indio Hills sediment yield. The eolian origin of much of the Indio Hills sand is evident in the significantly higher percentage of preferred sand – double that of the other sand sources – making this a particularly rich potential source of sand for *Uma* habitat.

Climate, Precipitation, and Flood Frequency

As shown in table 4, mean annual precipitation varies by a factor of five within the drainages that supply sediment to the northern Coachella Valley. Because the valley floor receives only 5 in. of precipitation, sediment yields from alluvial fans such as those that comprise the Desert Hot Springs bajada would be lower than the overall average sediment yield from the higher elevation sites. Because of this, the sediment contribution from the Desert Hot Springs bajada is expected to be much lower than the 11 percent calculated by assuming equal contributions from the entire drainage area.

The range in annual precipitation at each station is even larger than the elevational differences in annual precipitation. Interannual precipitation ranges by a factor of more than 5 at higher-elevation sites to a factor of more than 15 on the valley floor. This climatic variability undoubtedly affects fluvial sediment delivery to the Coachella Valley in significant ways. During drought years, little sediment is expected to be delivered from the headwaters to the valley floor. During wet periods, sediment delivery is greatly increased.

Periods of negative Southern Oscillation Index (SOI), otherwise known as El Niño conditions, have a large influence on the climate of the Coachella Valley and its surrounding mountains. Although El Niño strictly speaking is an oceanic phenomena off the western coast of Peru, the term has come to apply to overall changes in the equatorial Pacific Ocean that create conditions favorable to increases in winter precipitation in the southwestern United States. One definition of El Niño calls for 5 or more months of negative SOI (Cayan and Webb, 1993); El Niño recurs every 4-7 years in the equatorial Pacific Ocean with no definite historical change in frequency (Webb and Betancourt, 1992). The SOI is shown in (fig. 8a).

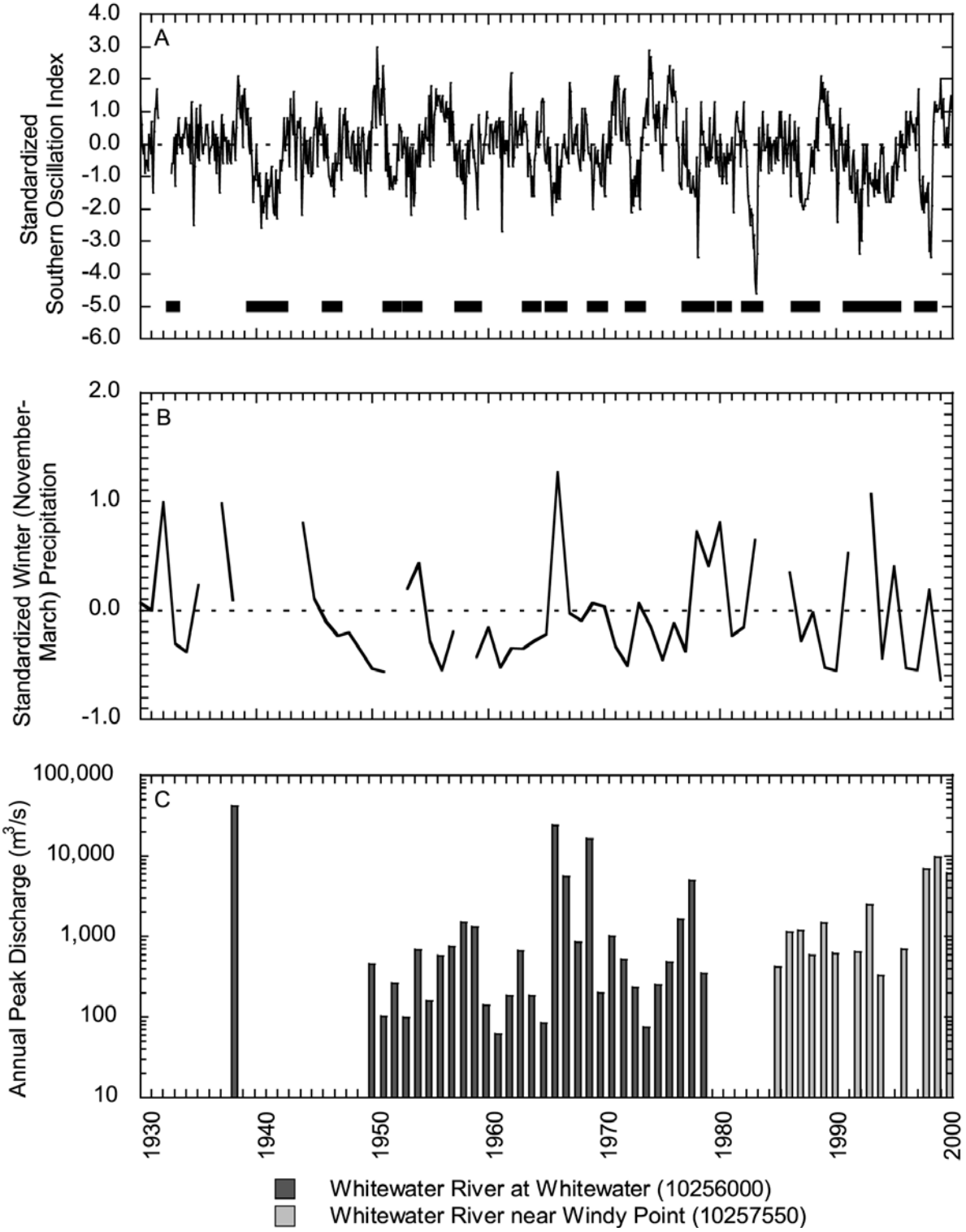

Figure 8. Climate, precipitation, and flood-frequency data for the northern Coachella Valley.

A. The Southern Oscillation Index (in standardized form) from 1930-2000. El Niño conditions are considered to occur when the SOI is negative for protracted periods (*e.g.*, greater than about 5 consecutive months) and are shown in thick lines at bottom.
B. Standardized precipitation for Palm Springs, California. C. The annual flood series for the Whitewater River, combined from the gaging stations at Whitewater and Windy Point, California.

Precipitation within the Coachella Valley is affected by the SOI (fig. 8b). El Niño periods are generally periods of above-average precipitation at Palm Springs. Unfortunately, the Palm Springs precipitation record has many missing values (fig. 8b), which precludes a quantitative assessment of El Niño effects. As is evident in a close comparison of figures 8a and 8b, not all periods with El Niño conditions correspond to periods of increased precipitation. For example, average or below-average conditions prevailed at Palm Springs during 3 of 4 El Niño periods in the 1960s.

With the exception of 1938, most significant floods on Whitewater River have occurred during El Niño conditions (fig. 8c). In the last 25 years, floods have occurred in 1978, 1983 (not recorded in the gaging record of figure 8c), 1993, and 1998, which represent four of five El Niño episodes in that period. Streamflow is greatly increased in the southwestern United States during El Niño conditions (Cayan and Webb, 1993), and historically El Niño conditions produce wet periods and some of the largest flood years in the history of the southwestern United States (Webb and Betancourt, 1992), but drought conditions may occur also, as was the case in many areas during the El Niño conditions of 1986-1987.

La Niña conditions are the opposite of El Niño conditions and are likewise defined as a protracted period of positive values of the SOI. Unlike El Niño, however, La Niña conditions reliably produce drought conditions. As is apparent in figure 8, periods of positive SOI are related to both below-average precipitation at Palm Springs and low-flood years on the Whitewater River.

Some observers have forecasted 20-30 years of protracted drought for the region, partially in response to expected future patterns of the Pacific Decadal Oscillation (PDO), which is related to the SOI (Schmidt and Webb, 2001). If such protracted drought were to occur, the delivery of fluvial sand to the northern Coachella Valley would be reduced because of the decrease in flood occurrence. However, as discussed in a later section, drought could potentially increase eolian sand-transport rates by decreasing the cover of perennial vegetation and thereby decreasing surface roughness, although the amount of sand available for transport would be greatly reduced owing to less frequent floods.

EOLIAN TRANSPORT

Historical Wind Speed and Direction

Abundant wind energy is available in the northern Coachella Valley to transport eolian sand. Data are available for National Weather Service stations at Palm Springs and Thermal, and for instruments maintained by SeaWest at Edom Hill during the period 1999-2002. Because the wind data were recorded for different purposes and with different instrumentation, rigorous inter-comparison of wind speeds, for example, is not possible, but the data provide useful information about changes in wind regimes in this part of the Coachella Valley (Tables 11 and 12). Table 12 shows the annual frequency of winds from different directions recorded at Palm Springs for the period 1998-2001 (these data are also shown as a rose diagram in fig. 9a). About 63 percent of all winds at this station are from directions between northwest and north, giving rise to a wind vector of 343° or northwesterly. This concentration of winds from one directional sector is because wind directions are strongly controlled by the topography of the area, in which winds are funneled through the San Gorgonio Pass and blow down the Coachella Valley.

Table 12 also shows the percentage of winds from different directions at Edom Hill (these data are also shown as a rose diagram in fig. 9b). At this locality, 47 percent of all winds are from directions between west and northwest, with westerly directions dominating (20.4 percent of all winds). The annual wind vector for Edom Hill is 298° or west-northwest. Because suitable data at Edom Hill are available for only one year (2001), the remaining analyses are for the wind data from Palm Springs International Airport, which has a longer record. We assume that the characteristics of wind other than direction are similar between Palm Springs and Edom Hill.

The strongest winds experienced at Palm Springs are from the NW and NNW (average speed = 11.7 mi/hr) and occur mostly during the afternoon (fig. 10). There is a regular daily cycle of wind speed, as shown in figure 10. In the early morning hours, wind speed is low (< 5 mi/hr) and direction is variable. After about 8 am, wind speed increases, and wind direction becomes steady at 310-320° (NW). Maximum wind speed usually occurs in the late afternoon or early evening (4 to 8 pm). Average scalar wind speed varies through the

Table 11. Percentage frequency of winds at Palm Springs International Airport (1998-2000).

	WIND SPEED (mi/hr)									
Direction	0-5	6-10	10-15	15-20	20-25	25-30	30-35	35-40	40+	All speeds
N	22.7	3.0	1.0	0.5	0.2	0.0	0.0	0.0	0.0	27.4
NNE	0.4	0.6	0.2	0.1	0.1	0.0	0.0	0.0	0.0	1.4
NE	0.3	0.4	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.9
ENE	0.3	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.0
E	1.0	2.8	0.3	0.1	0.0	0.0	0.0	0.0	0.0	4.2
ESE	1.0	3.9	0.8	0.1	0.0	0.0	0.0	0.0	0.0	5.8
SE	1.3	2.8	0.4	0.1	0.0	0.0	0.0	0.0	0.0	4.6
SSE	1.3	1.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	3.0
S	1.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
SSW	1.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.7
SW	1.2	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.0
WSW	1.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1
W	1.8	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3
WNW	1.4	2.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	4.1
NW	1.7	6.2	5.0	3.4	1.0	0.1	0.0	0.0	0.0	17.4
NNW	1.5	8.2	3.9	3.0	1.3	0.2	0.0	0.0	0.0	18.1
All directions	40.1	37.3	12.3	7.4	2.6	0.3	0.1	0.0	0.0	100.0

Table 12. Comparison of winds at Palm Springs Airport and Edom Hill.

	PROBABILITY OF OCCURRENCE (percent)			
	All winds		Sand-transporting winds	
Wind direction	Palm Springs	Edom Hill	Palm Springs (>12 mi/hr)	Edom Hill (>14.3 mi/hr)
N	27.4	7.3	6.8	1.9
NNE	1.4	4.1	1.9	1.0
NE	0.9	1.9	1.0	0.1
ENE	1.0	1.0	0.0	0.0
E	4.2	1.7	1.0	0.2
ESE	5.8	5.0	1.0	1.1
SE	4.6	6.6	1.0	0.0
SSE	3.0	6.0	0.0	0.0
S	3.0	2.9	0.0	0.0
SSW	1.7	1.4	0.0	0.0
SW	2.0	1.8	0.0	0.5
WSW	2.1	5.1	0.0	7.3
W	3.3	20.4	0.0	50.5
WNW	4.1	12.4	0.0	23.8
NW	17.4	14.0	43.7	12.6
NNW	18.1	8.3	43.6	1.0
Wind Vector Direction	343º	298º	282º	282°

year, but the months of maximum wind speed typically are April through June, with May having the highest average wind speed (9.9 mi/hr), as shown in figure 11. The overall character of the wind regime at Thermal is similar to that at Palm Springs International Airport, but with much lower wind speeds. For example, mean annual wind speed at Palm Springs International Airport is 7.2 mi/hr, but the mean annual wind speed is only 6.1 mi/hr at Thermal. The wind regime at Edom Hill follows a similar pattern to elsewhere in the valley, but average wind speeds in this area are somewhat higher, with a mean annual wind speed of 11.4 mi/hr. Therefore, eolian transport calculations based on wind data from Palm Springs International Airport should be considered minimums, given that actual velocities upwind of the reserves may be more than 50 percent higher.

Sand-Transport Potential

Wind data from Palm Springs and Edom Hill were analyzed using the methods of Fryberger (1979) as described in the Methods section. For the period 1998-2000, Palm Springs has a drift potential (DP) of 277 VU and an RDP of 261 VU (velocity units). This classifies the area as a moderate-energy, near unimodal

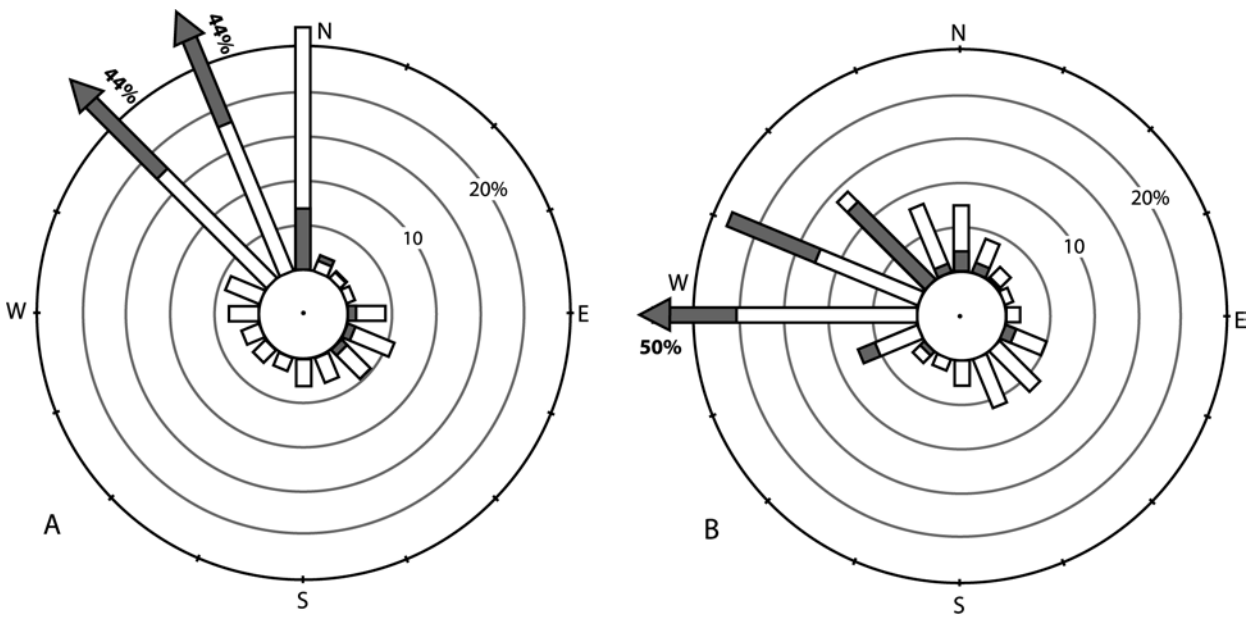

Figure 9. Rose diagram showing annual directional frequency of winds at selected sites in the Coachella Valley.
A. Palm Springs International Airport for the period 1998-2000. B. Edom Hill (Willow Hole Reserve) for the period of 2001. White bars represent all wind velocities; gray bars represent winds of sufficient velocity to transport sand.

wind regime. The annual resultant (vector sum) potential sand transport direction is 342°. For Edom Hill, the total DP is 646 VU, with a RDP of 556VU and a resultant direction of 282°.

For the period 1998-2000, 89 percent of the annual drift potential at Palm Springs is generated by winds from the NW and NNW directions. These directions are important in all months with a range from 15 percent in December to 97 percent in May. Winds from the NNE and N contribute significantly (up to 74 percent) to drift potential during the winter months of November-February, but these months are a time of generally low drift potentials (fig. 12). At Edom Hill, 72 percent of the potential sand transport is generated by winds from the west and west-northwest, with the majority from the west.

Drift potential varies with the percentage of the time that the wind is blowing with higher velocity. At Palm Springs, monthly drift potential varies with the seasons, and reaches a peak in May (fig. 12). About 65 percent of the annual drift potential (DP) and 67 percent of the resultant drift potential (RDP) occurs in the period March through June. There is very little drift potential (15 percent of the annual total) during the winter months (November–February). The pattern at Edom Hill is similar.

In February 1998, the system used to measure wind speed at Palm Springs International Airport changed. One result of this change is that the magnitude of DP and RDP changes significantly after that time and is reduced by a factor of 3.6, compared to the period 1992-1998. However, the interannual variability of the sand drift potential does not change. Annual drift potential varies from 67 to 122 percent of the mean value and is mainly caused by changes in the duration and frequency of strong winds from year to year.

Spatial Variations in Sand-transport Potential

There is a very large drop in wind energy between Palm Springs and Thermal, as evidenced by the change in DP values from 277 VU at Palm Springs to only 7 VU at Thermal. This change reflects the expansion of airflow and reduction in wind speed away from the San Gorgonio Pass. Such expansion of the airflow and reduction of wind speed leads to deposition of sand down valley, as evidenced by the areas of dunes occurring in this part of the valley (*e.g.*, Coachella Valley Reserve). As expected, the acceleration of wind over Edom Hill produces a high energy wind regime at this location, with a total DP of

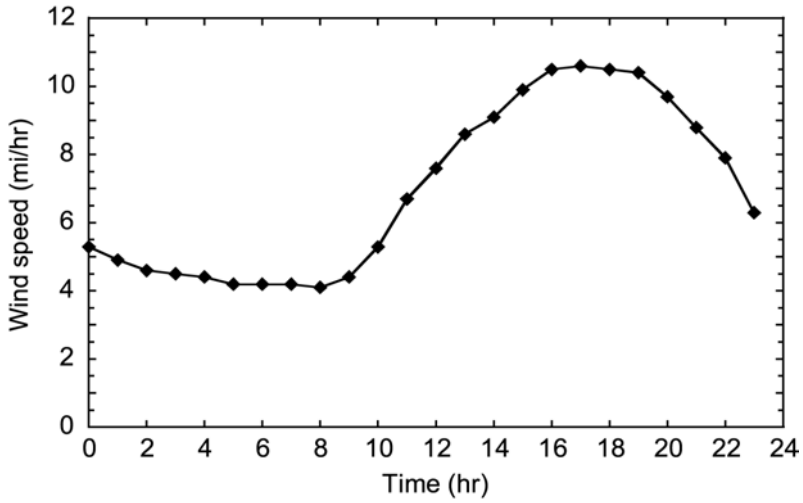

Figure 10. Diurnal cycle of winds at Palm Springs International Airport.

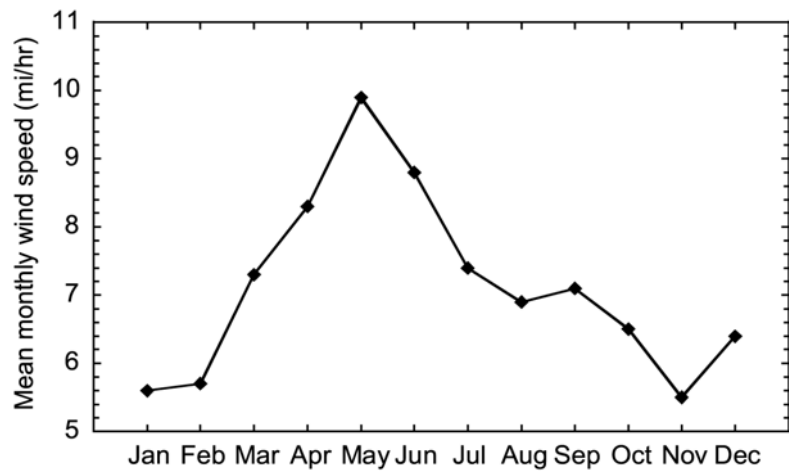

Figure 11. Variation in monthly wind speeds at Palm Springs International Airport.

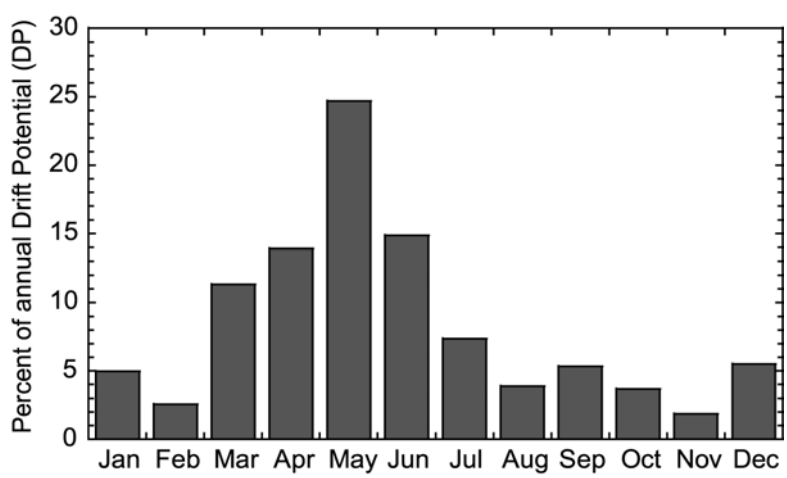

Figure 12. Variation in monthly values of Drift Potential (DP) calculated from wind data at Palm Springs International Airport.

646 VU. There is also a change in the vector sum sand-transport potential direction from 295° at Edom Hill to 332° at Palm Springs and 312° at Thermal.

Dune Mobility

The dune mobility index, M, was calculated from the wind data at the Palm Springs. Values of W, or the percentage of time the wind was above the sand-transport threshold, were estimated using a threshold value of 12.3 mi/hr (10.6 knots). Wind exceeding this threshold were observed 25-30 percent of the time on an annual basis before 1998 and dropped to 15-20 percent of the time once 24-hour readings became available. This is an artifact of the inclusion of the usually calmer early morning period of 12 am to 6 am. Because of the change in the recording system in 1998, increasing the amount of valid data, the mobility index values for 1998 on were adjusted to take account of this extra time.

Over the period of record, the average M for Palm Springs was 557, indicating that the northern Coachella Valley is a very active eolian environment with fully active dunes. As in many other parts of southern California, the actual state of dunes tends to be less active than predicted by the mobility index (Bach, 1995), and field observations suggest that locally this is the case in the Coachella Valley. Over the period of record, changes in the amount of rainfall received gave rise to changes in the mobility index (fig. 13a). The index was above the threshold value of M=200 (dunes fully active) for 71 percent of the period of record (1973-2000), and within the range 100<M<200 (dunes are active but lower slopes are vegetated) for 28 percent of the time (fig. 13b). The period 1984-1991 was the longest interval in which the index was consistently above 200. Intervals and individual years when dune mobility was low occurred in 1978-1980, 1983, and 1992-1993. The temporal variation in the dune mobility index was generally similar to that observed elsewhere in the southwestern United States (Lancaster and Helm, 2000), with low values of the index being recorded in or following El Niño years.

Actual Sand Transport

The calculated sand drift potential discussed above represents the amount of sand that could be transported by the winds of the area, assuming that sand is available for transport (i.e., the sand supply is unlimited). In the case of the flood plain of the Whitewater River, this is unlikely, given the seasonal or ephemeral nature of flow in the river and the armoring of the surface by gravel.

Some information on actual rate of sand transport in the area is provided by Sharp (1964, 1980). He maintained sand traps in the area of the Whitewater River, just south of Garnet Hill and likely within the current boundaries of the Whitewater Floodplain Preserve, for 5 periods from1953 through 1955. His data on sand-transport rates were later analyzed by Williams and Lee (1995). Sand-transport rates in the study area varied from $1.0 - 6.5 \cdot 10^{-6}$ lbs ft^{-1} s^{-1} (table 13).

The variation in sand transport rates could be explained by reference to changes in the discharge of the Whitewater River (fig. 5). The highest sand-transport rates follow periods of high discharge in the river, and low rates either preceded or coincided with high runoff. These data suggest that changes in fluvial sediment supply significantly influence rates of eolian sediment transport in this environment.

Table 13. Eolian sand transport rates in the Whitewater River floodplain (from Williams and Lee, 1995).

Measurement interval	Sand transport rate (lbs ft^{-1} $s^{-1} \cdot 10^6$)
2/3 – 3/4, 1953	3.0
7/18 – 12/11, 1953	1.0
4/16 – 11/25, 1954	1.6
3/2 – 5/27, 1954	6.5

Historical Changes in Area of Sand Dunes

Historical changes in the area of sand dunes proved difficult to quantify for the Whitewater Floodplain Preserve and the area between the Mission Creek – Morongo Wash depositional area and Willow Hole. Existing aerial photography lacked a consistently sufficient resolution to allow differentiation of the small coppice dunes characteristic of these eolian plains from perennial vegetation or other features on

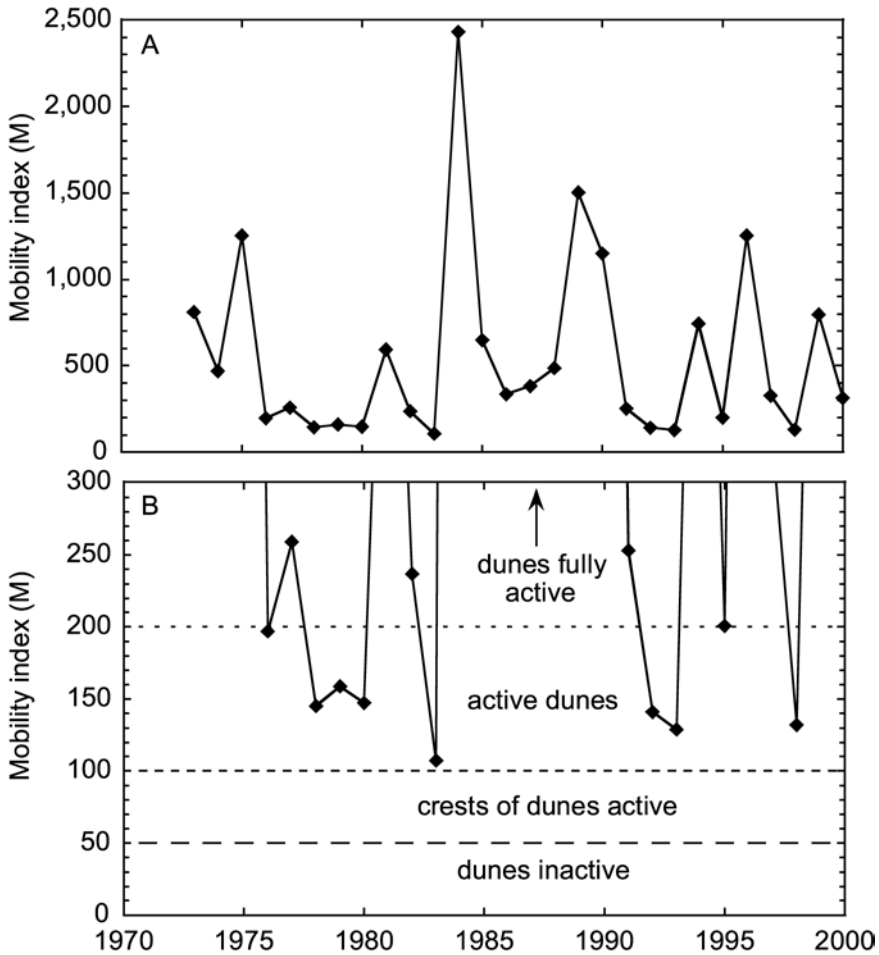

Figure 13. Dune Mobility Index calculated for the northern Coachella Valley.
A. Variation of the Dune Mobility Index (M) from 1973-2000. B. The same data for M up to 300 showing exceedence of several classes of dune activity.

the landscape. A summary of the observations from the aerial photography of the study area appears in tables 14 and 15.

The 1939 aerial photography shows active channels and abundant fluvial sediment in the aftermath of the 1938 floods on both the Whitewater River and Mission Creek. By 1953, modifications were significant on the Whitewater River floodplain, and the infiltration galleries were established by 1984 (table 14; fig. 14a). In 1953, sand cover and nebkha dunes were extensive on the Whitewater Floodplain Reserve, and even by the late 1980s, active sand sheets extended eastward from active fluvial channels. By 1996, this sand cover appeared to be depleted.

Comparison of the aerial photographs from 1939 to 1996 indicate that there have been minor changes in the vegetation cover in the Willow Hole area but important changes to the channels of some of the washes in the area, and significant changes in land use in the areas immediately north and west of the dunes (table 15; fig. 14b). From 1939 to 1953, there are slight decreases in the density of mesquite in both western and eastern parts of the dunes; vegetation cover also decreased in the lower reaches of Wide and Long Creeks. In 1953, there is more bare sand in the northern part of the Willow Hole area that at any other time. Between 1953 and 1972, vegetation cover decreases in the western parts of the area, but increases slightly in the east. The outlet channel to the south from Willow Hole is less vegetated, and becomes vegetation free after 1972. From 1972 to 1996, there are no significant changes in the mesquite cover, but the area of bare sand

Table 14. Historical changes in the eolian environment of the Whitewater depositional area detected in aerial photographs, 1939-1996.

Year	Observed Changes
Cultural features in channel west (upwind) of Whitewater Preserve	
1953	Large dike across western channel; small dike on western side
1972	Cross channel dike breached in several places
1977	Percolation ponds breached causing outwash channel
1979	Percolation ponds breached causing outwash channel
1984	Infiltration basins established west of preserve, southern dike is re-aligned
1989	Wind generators constructed by this year
Fluvial and aeolian features	
1939	Effects of the 1939 flood deposition are considerable along Whitewater River and Mission Creek; a channel avulsion appears in Mission Creek on the Desert Hot Springs bajada
1953	Active channel (darker tone) in center of preserve area Extensive sand cover and nebkha dunes
1972	Area east of road is very featureless either as a result of a poor photograph or extensive thin eolian sand sheet cover
1977	Well-developed active channel to south of preserve formed after breaching of percolation ponds by flood. Alluvial morphology very clearly developed
1984	Flow in Whitewater River to gaging station Clear fluvial morphology with bars and channels visible Wide active channel to south
1989	Active flow in Garnet Wash (August) and across flood plain in eastern part of Reserve Drainage channel across southern part of preserve Active sand sheets extend east of fluvial channels
1993	Well developed channel with active flow south of Garnet Hill and gravel pit
1996	Fine-grained fluvial deposits appear to be stripped from the Whitewater depositional area downstream of infiltration galleries

Table 15. Historical changes in the eolian environment of the Willow Hole area detected in aerial photographs, 1939-1996.

Year	Observed Changes
Cultural features	
1972-1975	Mission Creek channelized
1984-1989	Golf course established north west of Willow Hole Reserve
Fluvial and aeolian features	
1953	Thin sand sheets cover most of area east of depositional zone of Mission Creek and Morongo Wash
1972	Thin sand sheets cover most of area east of depositional zone of Mission Creek and Morongo Wash
1984	Sand sheets replaced by sand streaks extending from depositional area
1989	Sand streaks very thin
1996	Sand streaks extremely thin and discontinuous east of depositional zone
Vegetation changes	
1939-1953	Slight decreases in density of mesquite in Willow Hole area
1953-1972	Decrease vegetation cover to west, increased to east
1972-1996	No significant changes in mesquite cover infiltration galleries

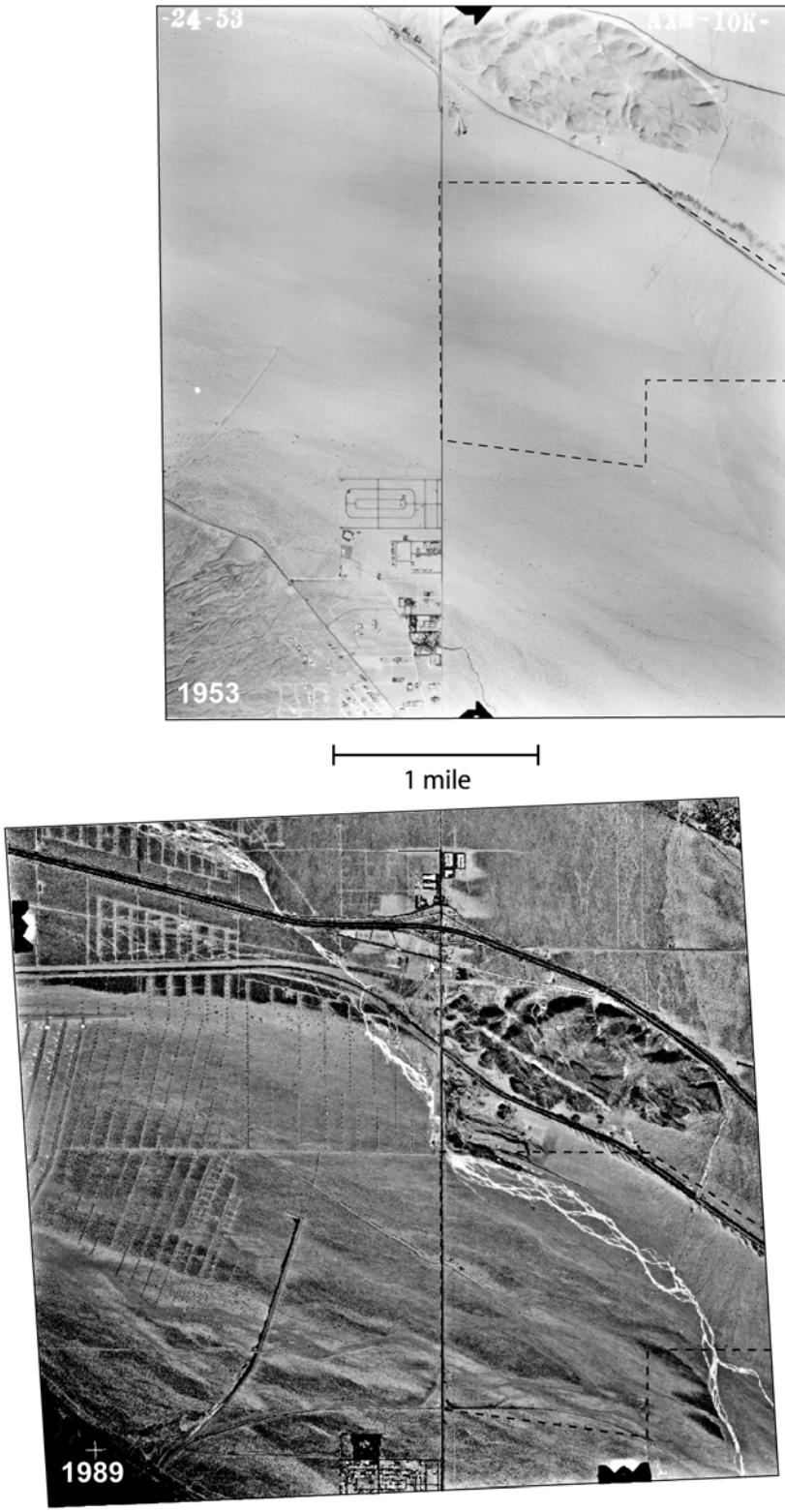

Figure 14. Aerial photographs showing historical changes in sedimentary deposits in the Whitewater depositional area.

A. Aerial photographs of the Whitewater River floodplain in the area of the Whitewater reserve (dashed lines) in 1953 and 1989. Note extended dike across river and extensive wind-generator arrays in 1989. There also appears to be much more extensive sand cover in 1953 compared to 1989.

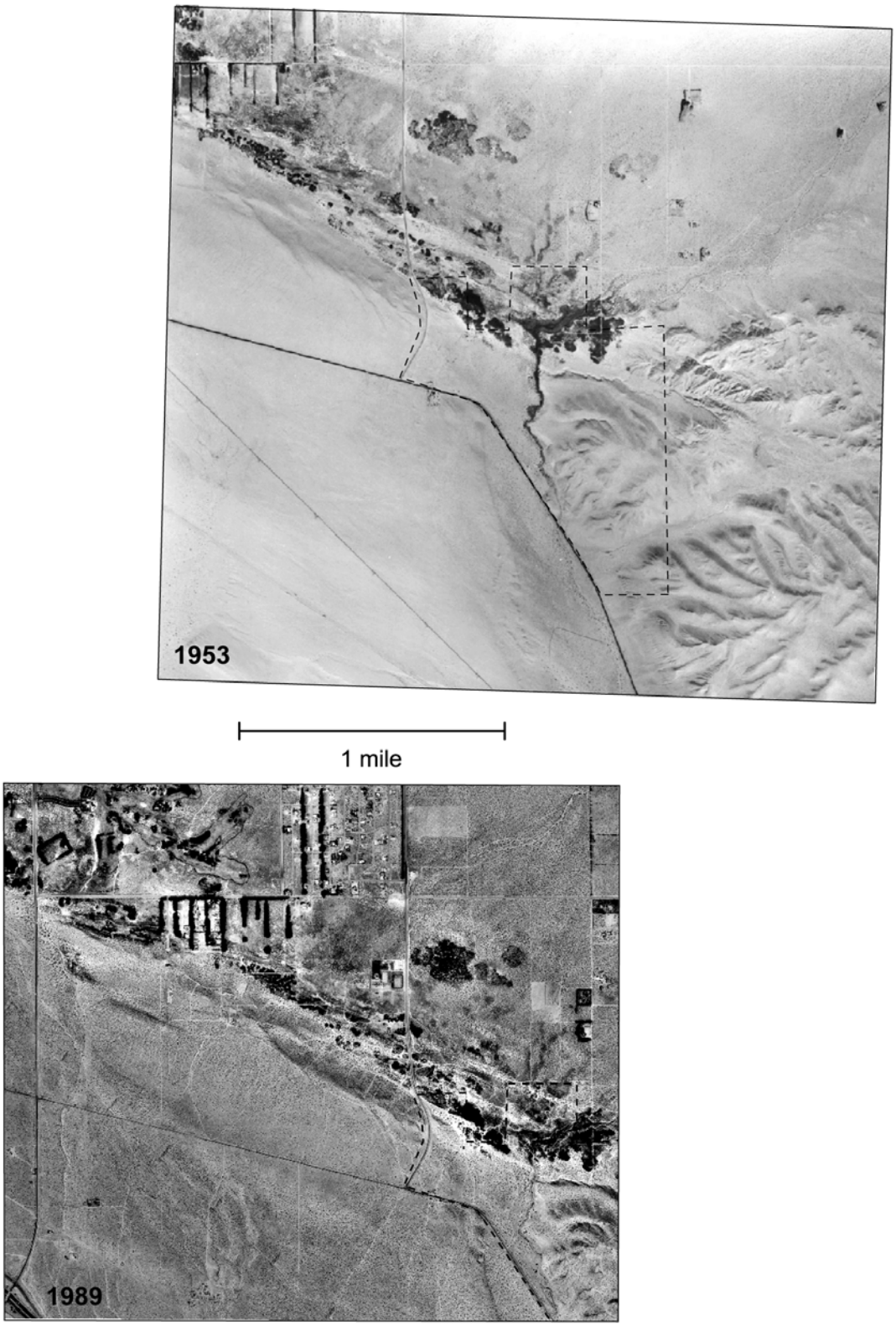

Figure 14. *Continued.*

B. Aerial photographs of the area of the Willow Hole reserve (dashed lines) in 1953 and 1989. Amount of change in mesquite dunes appears to be minimal.

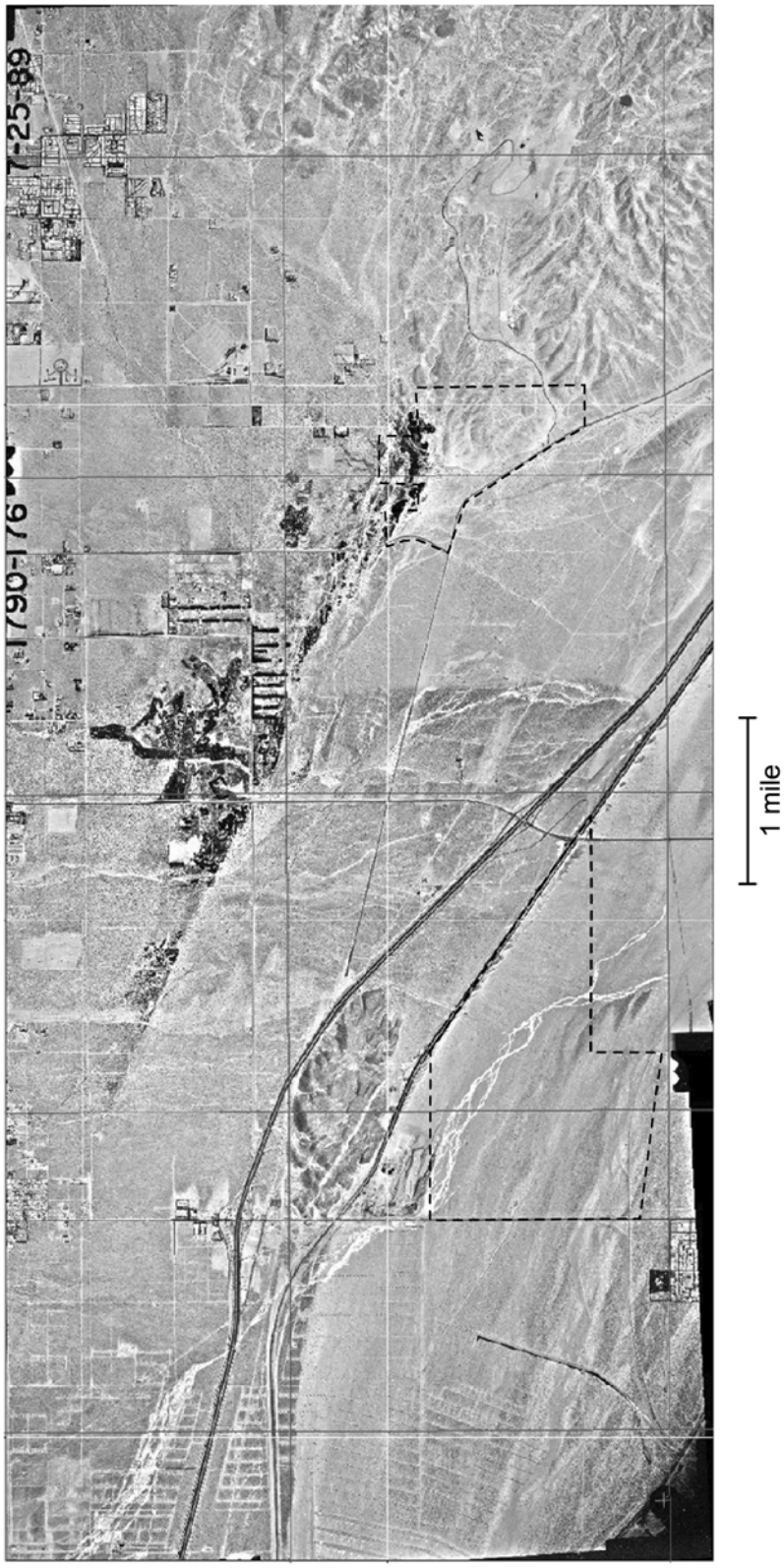

Figure 14. *Continued.*

C. Photomosaic of the depositional areas and eolian-transport zones upwind of both reserves in 1989. Dashed lines indicate reserve boundaries.

near Mountain View Road decreases in size. A golf course was constructed immediately north of the dunes in the late 1980s.

The 1953 photographs indicate thin sand sheets covering as much as 75 percent of the area east of Mission Creek and especially Morongo Wash. The sand sheets persisted in this manner until at least 1972, and probably 1977, although Mission Creek had been artificially channelized by the latter date. By 1984, the extensive sand sheets had largely dispersed, and the most prominent eolian features were sand streaks and tongues of sand (sand sheets) that extend east or east-southeast from the depositional area of these washes for several hundred yards. By 1989, these sand sheets appear to have thinned considerably (fig. 14c). This trend is continued to 1996, when these features are barely discernible on the images.

LINKAGES BETWEEN THE FLUVIAL AND EOLIAN TRANSPORT SYSTEMS

Rates of Eolian Transport

The supply of wind-blown sediment to the Whitewater and Willow Hole Reserves is determined by two factors: (1) the supply of sand-size sediment by the fluvial system (as discussed in the previous section on Fluvial Sediment Yield) and (2) the rates of eolian transport. Comparison of these two sediment-transport systems was carried out the following way. Data on fluvial sediment yields and the area of the depositional zones (table 9) was used to estimate a volume of sediment being deposited in each of these areas on an annual basis. The total volume of sediment was adjusted in proportion to the amount of this material that is of sand size (mean = 82.5 percent), as well as the proportion of the sediment that is of a size preferred by *Uma* (table 10).

Rates of eolian sediment transport potential were derived from the Palm Springs wind record and the velocity units were converted to an estimate of sediment volume transported based on the relation illustrated by Fryberger (1979). This relation is expressed as volume per unit width per year. The rate of eolian sediment removal from each of the depositional zones was estimated as:

$$Q_e = A^{0.5} \cdot q_r, \qquad (12)$$

where

Q_e is the eolian transport rate,

A is the area of entrainment, and

q_r is the volumetric transport rate.

The relations between eolian and fluvial deposition can also be expressed in terms of the time required for the fluvial sediment supply to be depleted. This is expressed as:

$$t_{ed} = V / Q_e, \qquad (13)$$

where

t_{ed} is the time for eolian depletion (months), and

V is the volume of fluvial sediment available for transport (ft^3).

These relations assume that all available sediment can be transported, and the surface cannot be armored with the accumulation of sediment that is larger than the eolian system can transport.

The estimated depletion times for both historic and modern scenarios, using the Renard (1972) and flood-frequency methods for estimating fluvial sediment yield are given in table 16. Our results indicate that periods ranging from several months to two years are required for eolian processes to deplete sediment supplied by the fluvial system. In the predevelopment setting, all sand was removed from the Whitewater area in 13 months, from the Mission – Morongo area in 8 months and from the Long Canyon area in 4 months. With reduced fetch areas and deeper fluvial deposits in the modern scenario, it requires 16 months to remove all sand from the Whitewater area and 8 months to do so from the Long Canyon depositional area. Rates of sand removal from the Mission – Morongo depositional area remain constant. In all cases, sand of a size suitable for *Uma* habitat is removed in about one-fourth the time required for all sand (table 16).

When the record from the aerial photographs is compared to depletion estimates, it is clear that eolian sand persists in the immediate vicinity of the fluvial-depositional zones for periods that are much longer than the estimated depletion times discussed above. This is likely because the amounts of sediment deposited in episodic floods to these zones are much

greater than the time-averaged rates used in this analysis. It is also likely that the eolian-transport rates are less than used in this analysis, because they are reduced by the presence of vegetation in the transport corridors. As a result, the depletion times in table 16 should be regarded as minimum values. In general, however, the eolian removal of expected annual sediment yields in approximately one year – both before and after development – is consistent with the presence of persistent sand dunes in the Coachella Valley.

Table 16. Eolian depletion rates of fluvial sediment deposited in depositional areas upwind of the Coachella Valley reserves.

Depositional area	MONTHS TO REMOVE ALL SAND		MONTHS TO REMOVE "UMA SAND"	
	Renard (1972) equation	Flood-frequency method	Renard (1972) equation	Flood-frequency method
		Historic record		
San Gorgonio/ Whitewater	12.9	25.3	2.5	4.9
Mission/Morongo	8.0	17.6	1.7	3.8
Long Canyon	3.6	7.4	0.8	1.7
		Modern record		
San Gorgonio/ Whitewater	15.7	30.3	4.1	8.1
Mission/Morongo	8.0	17.6	1.7	3.8
Long Canyon	7.8	17.3	2.0	4.4

Mission Creek – Morongo Wash Depositional Area

Although the Indio Hills drainage area – and Long Canyon by way of the Indio Hills drainage – has the potential to contribute sand to the Willow Hole Reserve, almost all sand delivered to the Reserve in the modern setting comes from the Mission Creek – Morongo Wash depositional area. The existence of wind data collected within the Willow Hole Reserve itself allows us to begin to differentiate subsections within the Mission Creek – Morongo Wash depositional area in terms of potential to contribute sand to the Reserve. By analyzing the frequency of wind directions bearing on Willow Hole, we calculated the probability that a given sand-transporting wind will be headed toward the Willow Hole Reserve for subsections of the Mission Creek – Morongo Wash depositional (table 17 and fig. 15). (Absence of local wind data precludes a similar analysis for the San Gorgonio – Whitewater depositional area.) Across the Mission Creek – Morongo Wash depositional area as a whole, winds of velocity sufficient to transport sand are headed toward Willow Hole 83 percent of the time. Segregating these data into the seven 10° compass sectors, keyed from one sector that represents westerly winds from directions of 265° to 275°, that cross the depositional area, the probability that sand-transporting winds will be headed toward Willow Hole is highest through the middle of the depositional area, drops off rapidly to the south to a low of 1.1 percent, and declines less rapidly to the north to a low of 10.4 percent (figure 15).

These probability values can be used as a rough measure of the relative value of each subsection of the depositional area in terms of potential sand transport to Willow Hole. A more precise measure of the relative amounts of sand actually contributed to Willow Hole from each subsection would require the consideration of other variables in addition to wind direction. The depositional subsection illustrated in figure 15 are not of equal area, and the larger subsections to the north would consequently contribute more sand to Willow Hole than the smaller southern subsections. Additionally, it is unlikely that fluvial sediment is distributed equally over the depositional area. Sand deposited per unit area likely decreases in the downstream direction so that sand deposits thin from north to south. Similarly, particle-size distribution typically varies in the direction of flow, with mean particle sizes decreasing with flow energy from north to south, resulting in a variation in the presence of preferred sand. The presence of local wind breaks may also vary from subsection to subsection hindering the eolian transport of *Uma* sand to varying degrees. The proximity of the interstate and railroad to the southern subsections may be a significant factor in this regard. A more precise measure of relative sand contribution from the Mission Creek – Morongo Wash sectors would require the quantification of these variables. However, it is evident that such data would weight sand contribution toward the northern subsections of the depositional area.

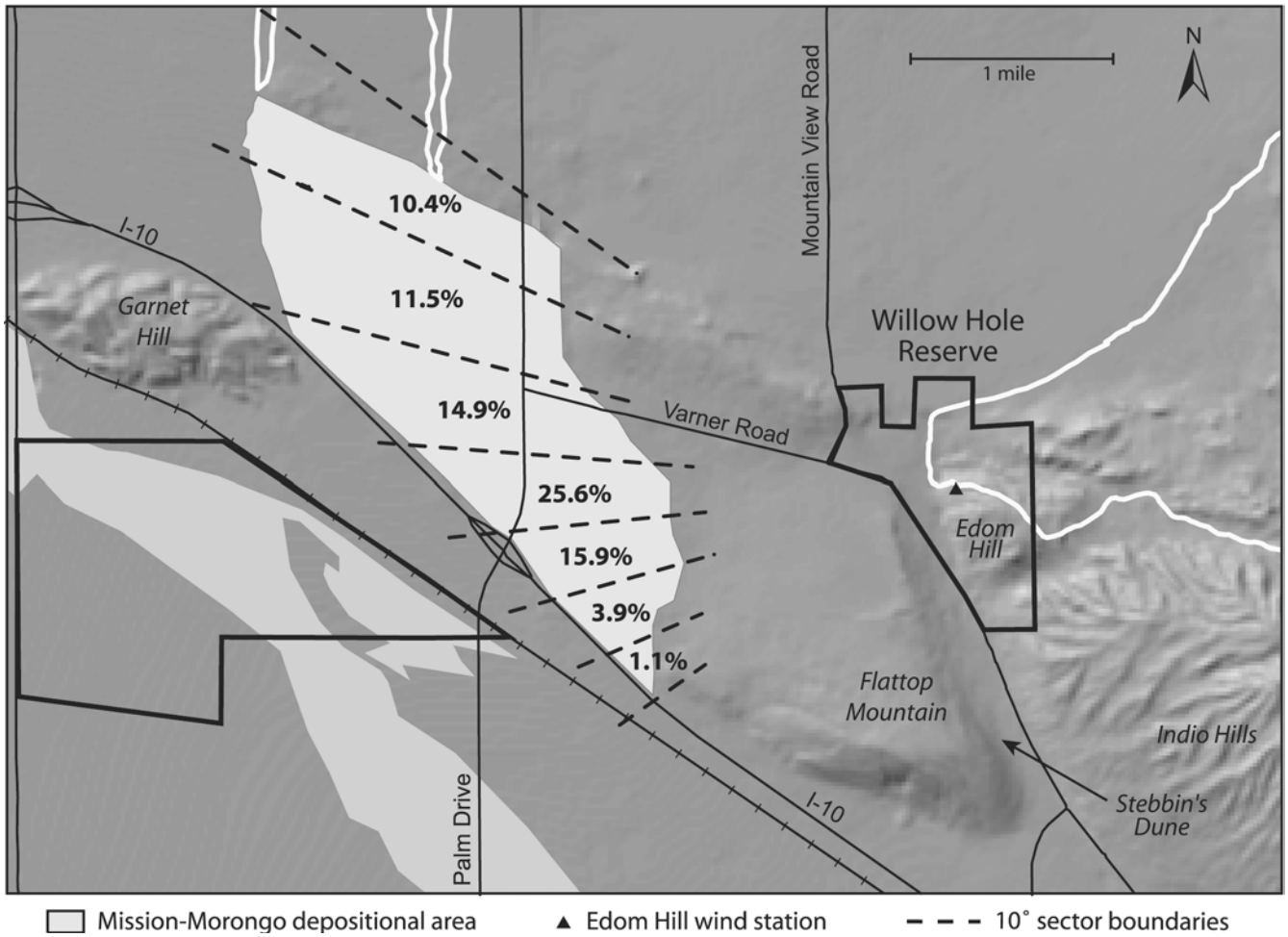

Figure 15. Map showing the percent probability that any sand-transporting wind (>14.3 mi/hr) headed directly toward the center of the Willow Hole Reserve will cross a given 10° sector of the Mission – Morongo depositional area. White lines indicate drainage boundaries.

Winds favorable for sand transport directly to Willow Hole cross some part of the depositional area 83.4 percent of the time. Sector boundaries are arbitrary lines that divide a continuous wind field into discrete 10° segments. Probabilities that sand transporting wind is headed to any other point location – such as Stebbin's Dune – would require a separate set of data collected at that point location and result in different sector boundaries.

Table 17. Percent probability that a sand-transporting wind headed toward Willow Hole will cross each sector of the Mission Creek-Morongo Wash depositional area.[1]

COMPASS SECTORS (22.5°)[2]		10° SECTORS	
Sector	Probability (percent)	Sector	Probability (percent)
		295-305°	10.4
281 - 304° / WNW	23.8	285-295°	11.5
		275-285°	14.9
259 - 281° / W	50.5	265-275°	25.6
		255-265°	15.9
236 - 259° / WSW	7.3	245-255°	3.9
		235-245°	1.1

[1]Data is for winds >14.3 mph measured at Edom Hill in 2001.
[2]Complete compass sector data is presented in Table 12.

CONCLUSIONS

The sand-delivery system to Coachella Valley fringe-toed lizard reserves in the northern Coachella Valley have been significantly altered historically. Much of the alteration has been in the stream channels that deliver fluvial sediment from the headwaters to the depositional areas upwind of the reserves. With the exception of the San Gorgonio River upstream from Banning, California, the fluvial part of the sediment delivery system is intact to the edges of the valley floor.

Modifications of channels within the northern Coachella Valley have had both positive and negative effects on sediment delivery to the depositional plains. The construction of dikes and infiltration galleries on

the Whitewater River downstream from Windy Point has both trapped some fluvial sediments upstream from the Whitewater depositional area as well as blocked westerly eolian sand transport from crossing much of the depositional area. Channelization of Mission Creek probably has increased delivery of sediments from the bedrock headwaters to the depositional area by minimizing within-bajada sediment storage. Recent flooding has incised channels through Willow Hole that drain the western Indio Hills, shifting at least some of the deposition of fluvial sand from within the Willow Hole Reserve (and just south of the main mesquite-stabilized dunes) to just south of the Reserve, potentially limiting eolian contributions from this sediment source.

Estimated eolian-transport rates predict that annual sand yields delivered to depositional areas are entrained and removed in 8 to 16 months given modern conditions, suggesting a continued balance between the fluvial and eolian transport systems and a constant sand supply to *Uma* sand dunes at present. Analysis of local wind directions at Willow Hole suggests that the potential to supply sand to the Willow Hole Reserve is not uniform among subsections of the Mission – Morongo depositional area. Quantification of the actual amounts of sand contributed by depositional area subsections would require the collection of additional data concerning the evenness of fluvial sediment deposition across the depositional area, as would the making of similar distinctions at other depositional areas.

Abbreviated Answers to Questions Posed by the U.S. Fish and Wildlife Service

Is there sufficient sand supply (in the fluvial system) to maintain the Willow Hole and Whitewater Floodplain Reserves?

Answer: The answer is a very tentative yes, there appears to be a sufficient sand supply to maintain the reserves, but the following issues are pertinent. (1) Sediment delivery in the northern Coachella Valley is highly episodic, and long periods of no delivery must be anticipated during drought conditions. These periods of deficient fluvial sediment supply will likely result in degraded *Uma* habitat irrespective of anthropogenic factors. Therefore, separation of human-induced from climate-induced changes to sediment supply will be difficult to determine with confidence. (2) The sediment-delivery system is largely intact except the headwaters section of the San Gorgonio River, which currently is blocked by a sand-and-gravel in-stream mining operation, resulting in an estimated 14 percent reduction in sediment yield. (3) Sediment source areas are largely unaffected by development and are mostly managed by the State of California and the federal government. (4) Depositional areas have been reduced, but some of this reduction may be reversed by redesign of the infiltration galleries east of Windy Point. (5) Historical alteration of the channel issuing from Long Canyon for flood-control purposes may affect the already much reduced depositional area within the northern Coachella Valley, further limiting eolian transport to the Indio Hills and – indirectly – to Willow Hole. (6) Fluvial sediment from the Indio Hills that once deposited directly within Willow Hole now is mostly deposited downstream and south of the reserve due to recent channel entrenchment, making this a potential but unreliable source of eolian sediment for Willow Hole.

Problems: The infiltration galleries at Windy Point affect the Whitewater depositional area, pushing this critical depositional area downstream from where eolian sand is desired. Redesign of these galleries to allow for throughflow of eolian sediment and entrainment of fluvial sediment may be expensive.

How would channelization of Mission and Morongo Creeks and urban development on their adjacent floodplains affect sand supply to both reserves?

Answer: Channelization, if designed to minimize sediment storage on the alluvial fans, would probably benefit the sand-delivery system to the reserves by minimizing in-channel storage of sediments on the Desert Hot Springs bajada. Channelization would not reduce sediment yields because most of the sediment that reaches the depositional areas is not generated within the Desert Hot Springs bajada.

Problems: This conclusion involves <u>only</u> the sediment-delivery system and does not consider other biological impacts of channelization. Channelization in the depositional areas would decrease wind entrainment of fluvial sediment by decreasing the area available for fluvial sediments to accumulate as well as disrupting the wind fetch.

Do the retention dikes along the Whitewater River affect sand supply to the Whitewater Floodplain Reserve, and by how much? Could the design of the recharge ponds be modified to provide a continued sand supply to the reserve?

Answer: Given that 8.1 million ft^3 of sediment was excavated from the retention ponds in 1996 the retention ponds clearly do trap fluvial sediment. This material may include a substantial amount of *Uma* sand, but an accurate estimate is not possible without evaluating both the time period over which this sediment was deposited as well as the proportion of *Uma* sand it contains. This sediment is entrained from the Whitewater River channel at flows of 200-400 ft^3/s between the Colorado River aqueduct crossing and the infiltration galleries, although some of this material is deposited in the channel immediately upstream from the galleries. This sediment is trapped upstream from the Whitewater River depositional area owing to diversion dikes designed to channel water into the infiltration galleries and would be available for downstream transport if the diversion dikes are breached by a flood capable of transporting this sediment.

Alignment of the infiltration galleries perpendicular to the prevailing winds and the high slope angles on the downwind dikes minimize the amount of sand that can be entrained by eolian processes. Sediments dredged from the galleries and upstream channel could be spread in a flat surface in the historic Whitewater depositional area, allowing it to be entrained for eolian transport. Alternately, the galleries might be redesigned such that the long dimension is parallel to prevailing winds (long direction east-west instead of north-south), and the eastern dike of each gallery could be designed with a shallow slope to allow eolian sand to escape.

Problems: The redesign and modification of the infiltration galleries may be expensive.

How much of the floodplain of the washes supplying sand upwind of the reserves has to be preserved to ensure a perpetual sand supply? What areas are essential to preserve and maintain an adequate sand supply and sand-transport corridor for these two preserves?

Answer: Floodplains on the bajadas produce minimal sediment owing to the arid environment and infrequent nature of high-intensity rainfall. Most of the sediment that eventually is deposited upwind of the reserves is generated in mountainous headwaters areas to the west and north of the valley floor. Channelization of major washes is beneficial to the sand-delivery system in the Coachella Valley reserves because sediment storage on the bajada upslope from the depositional areas is minimized. Thus, it is the channels on the fans that should be preserved, or enhanced, as they are the critical feature linking fluvial sediment sources in the mountains to the eolian sediment source areas downstream.

Low-elevation drainages at the western end of the Indio Hills north of Edom Hill are a potential source of eolian sand and should be preserved in their entirety. These drainages are not strictly part of the alluvial floodplain, nor are they typical of the high-elevation fluvial source areas in other drainage areas. This source is unique in that it has already been sorted by eolian processes, so that it is nearly twice as rich in potential habitat sand than other sources, and the sand supply, though largely a relict of the Pleistocene and not strictly renewable, is very large. Transport of this sand to Willow Hole is dependent on fluvial, rather than eolian processes. Given the potential of increased urbanization to further interrupt eolian sources of habitat sand, this fluvial source may become increasingly important in the future. Current natural channelization of the washes through Willow Hole reduces the potential for entrainment of this sand, but this channelization could be healed through natural processes or human intervention and should not be eliminated as a potential source of fluvial-eolian sand.

In contrast to the alluvial floodplains, the historical depositional plains at the downstream end of the channels depicted in figure 6a should be preserved in their entirety or developed with respect to the relative contribution of different area subsections to the overall *Uma* sand budget. Variables that should be measured to determine relative sand contribution include differential distribution of fluvial sediment across depositional areas, both in terms of volume and proportion of *Uma* sand, plan area of subsections, and frequency with which sand-transporting winds are directed toward the appropriate reserve, as illustrated in figure 15. The San Gorgonio – Whitewater and Mission Creek – Morongo Wash depositional areas are the fundamental source areas of eolian sand that maintain lizard habitat in both reserves. The construction of infiltration galleries to the west of the Whitewater Reserve has reduced the amount of sand available for eolian transport both by trapping sand and reducing the total area of sand exposed to the wind. At a minimum,

areas between historic deposition zones and downwind reserves should also be preserved to maintain an unobstructed eolian transportation corridors (fig. 6). Similarly, general consideration should be given to the effect that development of additional windbreaks in the area of the deposition zones would have on available wind energy.

The substantial reduction of the Long Canyon depositional area to the northern 20 percent of its historic extent has the duel effect of greatly decreasing the rate at which fluvial sediment is removed by eolian transport and shifting the dominant direction of transport northward, reducing sand supplied to the Indio Hills drainage north of Edom Hill. This alteration is unlikely to have an immediate effect on Willow Hole given that this sand is only indirectly supplied to the reserve through the Indio Hills, that there is an substantial amount of relict sand stored in the Indio Hills drainage area, and that fluvial sediment from the Indio Hills drainage currently pass through the reserve entirely. The long term effects of the Long Canyon alterations, however, are unknown.

Problems: This conclusion does not consider other potential biological impacts of channelization, including loss of ephemeral wash habitat and disruption of migration corridors.

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APPENDICES

APPENDIX 1. DESCRIPTIONS OF QUATERNARY GEOLOGIC MAP UNITS

Alluvial Units

Alluvial units mapped in the northern Coachella Valley include deposits created by the processes of streamflow, hyperconcentrated flow, and debris flow. The following characteristics apply to all alluvial units below, which are further subdivided on soil development and associated characteristics related to age. Alluvial deposits consist of sandy gravel and interbedded sand. Gravel clasts are angular to subrounded, range in size from pebbles to boulders, and generally are composed of granitic and gneissic rock types from the San Bernardino and Little San Bernardino Mountains, as well as reworked from older gravel sedimentary units. Deposits commonly are matrix-supported, but include some clast-supported beds. Bedding is massive to crudely stratified, and is defined by changes in clast size and sorting, which ranges from well sorted to poorly sorted.

Qayy. Youngest fan alluvium is of late Holocene age and is associated with intermittently active channels. Vegetation is absent to sparse in intermittently active channels, which are more abundant in this unit than in adjoining units. In the fan that emanates from the Wide Canyon area, the top of **Qayy** generally includes a cemented coarse-sand-rich, clast-poor bed, and a discontinuous eolian sand mantle. The eolian sand is usually fine sand that includes common biotite. Surface soil is very weakly developed with almost no oxidation. There is some cementation mainly as case-hardening along natural exposures. Depositional bar and swale morphology generally is well expressed but is more muted in areas of high rates of eolian sand deposition.

Qay. Young fan alluvium is of Holocene and latest Pleistocene age. Surface soil is generally very weakly developed, similar to that of **Qayy** and **Qayi** which are locally subdivided from this unit, but **Qay** includes areas of greater soil development up to the degree found in **Qayo** (see below) which is also locally subdivided from this unit. Pedogenic carbonate morphology does not exceed stage I–II, and occurs as thin carbonate and silica coatings on clast undersides. Depositional bar and swale morphology generally is characteristic of this unit, but its expression decreases with maximum clast size, which generally decreases away from upland source areas.

Qayi. Intermediate young fan alluvium is of late Holocene age. This unit is only locally differentiated as a subdivision of **Qay** along Mission Creek and Morongo Wash where sharper bar and swale morphology occurs relative to adjoining areas of **Qay**.

Qayo. Older young alluvium of fan remnants and terraces is of early Holocene and latest Pleistocene age. The surface soil of this unit has a distinctive oxidized, eolian dust-rich cambic Bw horizon but has not attained the development of the reddened argillic horizon that is characteristic of **Qai** and older units. Pedogenic carbonate morphology does not exceed stage I-II, and occurs as thin carbonate and silica coatings on clast undersides. Depositional bar and swale morphology is apparent but is muted relative to adjacent **Qay**. Surface clasts include greater varnish, and give this unit a darker tone on aerial photographs.

Qfy. Young fan alluvium of the San Jacinto Mountains includes debris-flow deposits of Holocene and latest Pleistocene age. This unit is extremely bouldery. Surface soil is generally very weakly developed. Pedogenic carbonate morphology does not exceed stage I-II and occurs as thin carbonate and silica coatings on clast undersides. Depositional bar and swale morphology generally is characteristic of the unit, but its expression decreases with maximum clast size, which generally decreases away from upland source areas.

Qai. Intermediate age alluvium in fan remnants and terraces is of late and middle (?) Pleistocene age. Strong soil development (McFadden, 1982) includes a characteristic red-brown argillic horizon within the top 1 ft of the unit. Pedogenic carbonate morphology is variable within the map area and probably related to a climatic gradient of effective moisture decreasing eastward from San Gorgonio Pass. Along the west side of the Desert Hot Springs quadrangle, carbonate morphology does not exceed stage I-II and is probably largely Holocene. In the Seven Palms Valley quadrangle, carbonate morphology is typically stage III, with the deposit moderately to well cemented below the argillic horizon. Depositional morphology is generally absent; instead the surface has been somewhat reworked and eroded during and preceding formation of the argillic horizon. Surface clasts are commonly highly pitted and eroded, though some resistant rock types have developed dark coatings of

desert varnish. Along Mission Creek in the northwestern part of the map area, a sample from a silty sand bed at a depth of about 13 ft yielded a thermoluminesence date of about 60 ka to 80 ka, depending on assumptions about moisture history (S. Mahan, written commun., 2001).

Qaiy. Younger intermediate alluvium of fan remnants and terraces is of late Pleistocene age. **Qaiy** is a locally distinguished subdivision of **Qai** where **Qaiy** forms an inset terrace within the **Qai** fan remnant complex at the mouth of Mission Creek in the northwest part of the map area. It has a similar surface soil to **Qai** and is characterized by a red-brown argillic Bt horizon within 1.6 ft of the surface.

Qao. Older alluvium of Pleistocene age is characterized by erosional surface morphology and the lack of remnants of an upper depositional surface. This unit forms resistant ridges in the Indio Hills, is generally poorly exposed, and is mantled and flanked by eolian sand (**Qe) and** colluvium (**Qcf**). Much of the surface area of **Qao** in the Indio Hills and Garnet Hill includes marble and other metasedimentary rock types that are probably derived from the San Jacinto Range. **Qao** forms poorly exposed deformed sediments cemented by pedogenic carbonate at Garnet Hill.

Qau. Undivided Pleistocene alluvium includes faulted and folded alluvial gravel and sand in ridges along the Banning and Mission Creek strands of the San Andreas fault system.

Qtpc. As mapped by Allen (1957) and Proctor (1968), the Painted Canyon Formation is a deformed and dissected fanglomerate that occurs between the Banning and Mission Creek Faults near the western boundary of the map area. This map unit includes the intercalated basalt flow near Devils Garden (Matti and Morton, 1993).

Qtps. The Palm Spring Formation consists of unconsolidated gravel, sand, silt, and mud to consolidated conglomerate, sandstone, siltstone, and mudstone and is exposed in badlands in the dissected, folded core of the Indio Hills.

Colluvial and Eolian Deposits

Colluvial deposits in the northern Coachella Valley are created by mass wasting processes, such as landslides, avalanches, and isolated rockfalls. Eolian deposits in the map area generally are thin, ephemeral sand dunes or sheets that change greatly in size with time as the fluvial sand supply on the depositional areas increases after a flood or is depleted by wind erosion.

Qcf. Colluvium and interbedded alluvium and eolian deposits generally occur in a footslope position.

Qe. Eolian sand and sandy colluvium and alluvium form sheets and sand ramps on slopes.

Qd. Eolian sand dunes of Holocene age are intermittently active but may be locally vegetated with mesquite.

Afd. Artificial fill and disturbed ground are created by human disturbance or development.

APPENDIX 2. AVAILABLE DAILY STREAM-FLOW DATA FOR THE NORTHERN COACHELLA VALLEY THROUGH 2001

Station name[1]	Period of record (water year)[2]	Missing record (water years)	Drainage area (mi^2)	USGS station umber	Latitude[3]	Longitude[3]
Whitewater River at Whitewater	1949-1979 (discharge)	None	57.5	10256000	33°56’48”	116°38’24”
	1972 (suspended sediment)	None	57.5	10256000	33°56’48”	116°38’24”
Whitewater MWC Diversion at Whitewater	1966-1981	1971, 1974, February 1977	–	10256050	33°56’44”	116°38’25”
Whitewater River at Whitewater Cut at Whitewater	1986-1987, 1989-1990	None	59.1	10256060	33°55’31”	116°38’07”
San Gorgonio River near Banning	1976-1977	None	14.8	10256200	33°59’54”	116°54’29”
San Gorgonio River at Banning	1981	First 4 months	44.2	10256300	33°55’52”	116°49’37”
San Gorgonio River near Whitewater	1963-1978	First 5 months	154.0	10256400	33°55’14”	116°41’45”
Snow Creek near Whitewater	1921-1931 (missing 36 months), 1960-2001	1932-1959	10.9	10256500	33°52’14”	116°40’49”
Snow Creek and Div Combined	1921-1931 (missing 36 months), 1960-2001	1932-1959	10.9	10256501	33°52’14”	116°40’49”
Snow Creek Div near Whitewater	1978-2000	1985, 1989	–	10256550	33°52’14”	116°40’49”
Falls Creek Div near Whitewater	1995-2001	None	4.1	10257499	33°52’10”	116°40’15”
Falls Creek near Whitewater	1923-1926, 01/28- 07/31, 1995-2001	1932- 1994	4.1	10257500	33°52’10”	116°40’15”
Combined Flows Falls Creek near Whitewater + Diversions	1995-2000	None	–	10257501	33°52’10”	116°40’15”
Whitewater River at Windy Point Main Channel	1999-2001	13 days	264.0	10257548	33°53’56”	116°37’13”
Whitewater River at Windy Point Overflow Channel	1999-2001	14 days	264.0	10257549	33°53’56”	116°3713”
Whitewater River at Windy Point near Whitewater	1985-1987, 1989-2001	September 1989	264.0	10257550	33°53’56”	116°37’13”
Mission Creek near Desert Hot Springs	1968-2001	9 days	35.6	10257600	34°00’40”	116°37’38”
Chino Canyon Creek near Palm Springs	1975-1985	13 days + last 2 months	3.8	10257710	33°50’21”	116°36’45”
Chino Canyon Creek below Tramway near Palm Springs	1987-2001	10 days	4.7	10257720	33°50’39”	116°36’16”
Long Canyon Creek near Desert Hot Springs	1964-1971	None	19.6	10257800	33°57’53”	116°26’35”

[1]R, river; MWD, Metropolitan Water District; Div, diversion; BL, below
[2]Records are daily-value streamflow discharge, unless otherwise noted.
[3]Referenced to the North American Datum of 1927 (NAD 27).

Griffiths, Webb, Lancaster, Kaehler, and Lundstrom—LONG-TERM SAND SUPPLY TO COACHELLA FRINGE-TOED LIZARD HABITAT IN THE NORTHERN COACHELLA VALLEY, CALIFORNIA—U.S. Geological Survey Water-Resources Investigations Report 02–4013

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Effects of Reduction in Windblown Sand on the Abundance of the Fringe-Toed Lizard (*Uma inornata*) in the Coachella Valley, California

FREDERICK B. TURNER, DONALD C. WEAVER AND JAMES C. RORABAUGH

The habitat of *Uma inornata* consists solely of windblown sand deposits in the Coachella Valley, Riverside County, California. Densities of this lizard in ten 2.25-ha plots were estimated by capture-recapture analysis during the spring and summer of 1980. Six plots were arranged in pairs, with one member of each pair in apparently undisturbed habitat upwind of a tamarisk windbreak and the other member downwind of the obstruction. The other four plots were in areas with sandy hummocks or mesquite dunes. The abundance of *Uma* varied in different plots, ranging from as high as ~45 ha^{-1} to zero. The three plots downwind of tamarisk windbreaks where sand depletion and surface stabilization have been underway for a number of years were essentially unoccupied by *Uma*. The upwind plots supported densities ranging from 11 to 45 ha^{-1}.

In general, variations in abundance of *Uma* were not statistically correlated with individual physical attributes of sand. By focusing on the quality of sand in dunes on the lee sides of shrubs we developed two models relating to densities of *Uma*. Variables of interest were: penetrability of sand in lee areas, surface coarseness, diameter of sand grains at the 75th percentile of gradation by weight, and years since surface stabilization. Both models explained about 81% of observed variation in *Uma* densities. Increased sand penetrability is a positive environmental factor and surface coarseness a negative one. Increasing surface stabilization is reasoned to be detrimental to *Uma*.

Methods of capture-recapture analysis used in this study sometimes resulted in unsatifying upper bounds of confidence intervals for density estimates. Future density estimates should be derived from analyses of a chain of at least three samples.

THE Coachella Valley fringe-toed lizard (*Uma inornata*) is restricted to windblown sand deposits in the Coachella Valley, Riverside County, California, from Cabazon in San Gorgonio Pass to near Thermal in the southern end of the valley. According to A. S. England and S. G. Nelson (pers. comm.), the historical range of the species was about 839 km^2, which probably included some 518 km^2 of suitable habitat (A. S. England, pers. comm.). In 1979, it was estimated that only about 256 km^2 of suitable habitat remained (A. S. England, pers. comm.). The United States Fish and Wildlife Service proposed listing *Uma inornata* as a Threatened Species in 1978, but was forced to withdraw the proposed Critical Habitat because of amendments to the Endangered Species Act (Federal Register, 1980). However, in September 1980, the USFWS listed *Uma inornata* as a Threatened Species and designated its Critical Habitat. *Uma inornata* was declared an Endangered Species by the State of California in June 1980.

The status of this species and the protection of at least some of its remaining habitat are clearly critical environmental issues. Actions by federal or state agencies, or by private corporations, impinging on areas inhabited by *Uma inornata* must be carefully evaluated, both in terms of immediate and long-term ecological consequences.

Both flood control projects and development of wind energy facilities raise questions of this nature. For example, a flood control plan considered by the US Army Corps of Engineers in 1980 might have resulted in a near 50% reduction of windblown sand entering the Coachella Valley from the west. Additional sand control measures could have eliminated sand movements almost entirely. Changes in wind characteristics imposed by large wind energy "farms"

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could also work to reduce sand flow. The presumed consequence of partial or complete immobilization of source sand would be a gradual reduction or coarsening and stabilization of surface sands in downwind areas.

Because *Uma inornata* is restricted to aeolian sand deposits, environmental changes of this nature could be extremely deleterious to the lizard. Effects of sand depletion and stabilization can be tested by examining the influences of windbreaks. These obstructions act as barriers to natural sand transport. Tamarisk trees have been planted in various portions of the Coachella Valley to impede the flow of sand. The most commonly used species (*Tamarix aphylla*) is native to Asia and Africa. Such windbreaks reduce wind velocity and lead to deposition of sand around the impediments. The interruption of flow produces, beyond the area directly shielded from natural wind conditions, an area with gradually reduced sand deposits and an increasingly stabilized surface. Some insight as to effects of sand depletion and surface stabilization on *Uma* habitats may be gained by contrasting the status of the lizard in areas upwind and downwind of obstructions.

A study of *Uma inornata* in the Coachella Valley was conducted between 2 April and 20 June 1980. Six areas (three pairs) were identified, with members of each pair separated by an obstruction to sand flow. Four other areas representative of *Uma* habitat in the Coachella Valley were also selected. Previous work by D. C. Weaver on the quantitative dynamics of aeolian sand transport guided selections of plot sites and measurements of appropriate sand characteristics. Densities of *Uma* were estimated in all plots and abundance of the lizard analyzed in terms of sand attributes.

Methods

The ten study sites were established between 2–18 April 1980. Each area was a square 150 m on a side (2.25 ha) staked at 25 m intervals. Up to seven days were devoted to plots, unless early efforts gave clear evidence that no *Uma* were present in the area.

Plots 1–6 were paired plots. The first member of each pair (1, 3 and 5) was an undisturbed area unshielded from natural receipt of windblown sand and where *Uma inornata* would be expected to occur. The second member of each pair was downwind of the undisturbed area, and lying leeward of tamarisk trees. The downwind member of each of the three pairs was carefully positioned so that it lay along the same path of prevailing sand transport as the upwind member. Thus, these lee areas were historically exposed to the same sand fluxes occurring in the undisturbed plots. Fig. 1 illustrates the general scheme for locating pairs of plots. Sand sources, directions and rates, and years of stabilization of various areas were derived from studies of the regional aeolian sand transport system conducted by D. C. Weaver for the California Department of Transportation and the US Army Corps of Engineers (Weaver, 1979).

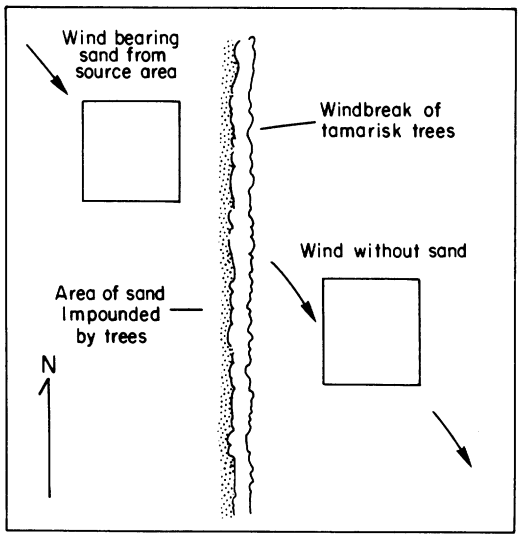

Fig. 1. Generalized plan for disposition of paired sampling sites. Plot in upper left is exposed to normal flow of wind bearing sand particles from source area. Plot in lower right is shielded by windbreak and receives little or no windblown sand.

Plots 7–10 were representative of mesquite dunes and sandy hummocks. Mesquite dunes are ordinarily 5–10 m high (A. S. England and S. G. Nelson, pers. comm.). Mesquite (*Prosopis glandulosa*), creosotebush (*Larrea tridentata*), saltbush (*Atriplex canescens, A. polycarpa*) and croton (*Croton californicus*) are common perennials. Other species of lizards commonly observed on dunes were *Callisaurus draconoides, Dipsosaurus dorsalis, Urosaurus graciosus* and *Cnemidophorus tigris*. Less common species were *Gambelia wislizenii, Uta stansburiana* and *Phrynosoma m'callii*. All of our plots lay within 3–4 km of Interstate 10 from 10 km north of Palm Springs to 8 km northwest of Indio, Riverside County (Fig. 2). Exact locations of plots are available on request.

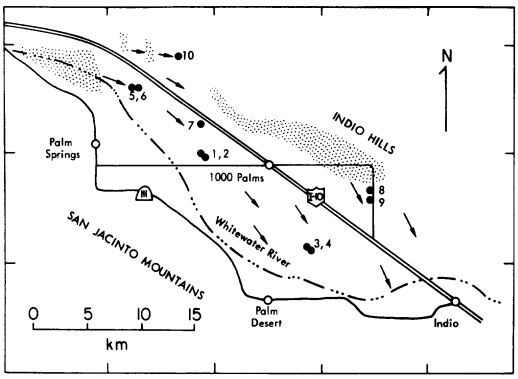

Fig. 2. Locations of 10 study sites in Riverside County, California. Stippling indicates source sand areas and arrows illustrate prevailing wind patterns.

Both Norris (1958) and Pough (1970) have emphasized the importance of sand grain size as it affects the local occurrence of *Uma*. Soils with high proportions of very small silty particles have generally been considered unsuitable, and coarse soils with high percentages of particles >1 mm in diameter are also inhibitory. Because the local distribution of *Uma* is so closely linked with availability of suitable substrates, the physical makeup of sands in the ten study plots was evaluated. All plots were photographed during the spring of 1980, and sampling and testing carried out at locations representative of 1) windward and 2) lee sides of sand deposits caused by trees or shrubs, 3) typical sandy substrates in the open and 4) the coarsest substrates in the open. Relative extents (%) of these four microenvironments were estimated for each plot.

Three basic textural characteristics of existing sand deposits were examined—penetrability, size gradation and surface coarseness. Tests were conducted within each plot and samples taken at locations representative of the four microenvironments just described. Windward test locations were selected directly upwind and ~1 m from the vegetation responsible for the deposit. Lee locations were selected slightly to the south of center, within 1–2 m of vegetation. Intervening sandy substrate locations were examined near the center of relatively open areas where deposition was least influenced by vegetation.

Penetration tests were made using a 0.454 kg surveyor's plumb bob dropped from 0.3 m. Three drops were made at each test location—each into undisturbed areas. Penetration depths were measured to the nearest 0.1 cm from the tip of the bob, and results averaged.

Sand samples were extracted with a thin-walled cylinder 6.35 cm in diameter depressed vertically to a depth of 8 cm. At each location four such samples were taken and combined, providing a total sample weight of ~1.5 kg. The coarsest intervening sandy substrates were sampled by placing Scotch tape over a 2.5 × 8 cm opening cut in a thin metal plate.

Further procedures included analysis and measurement of surface samples. Granulometric analyses were performed on all samples. Unwashed samples were split and sieved according to current American Society for Testing Materials procedures, using U.S. Standard Sieve sizes of 12.7 mm, 9.5 mm, 6.4 mm, #4, #8, #12, #16, #30, #40, #50, #80, #100 and #200. Cumulative gradation curves were prepared from these results. Mean grain size diameter was determined for each sample using the following formula:

$$d_{\text{mean}} = (\phi_{10} + \phi_{30} + \phi_{50} + \phi_{70} + \phi_{90})/5 \quad (1)$$

with $\phi_p = -\log_2 d_p$ and d_p the grain size (mm) at percentile p. Percentages finer than 0.1 mm, coarser than 1.0 mm and grain diameter at the 75th percentile of gradation by weight, were taken directly from gradation curves. Surface coarseness values were determined as the mean of the diameter of the five largest grains displayed in each surface coarseness sample. Other measurements included crustiness, surface stabilization, mean and median diameters of sand grains and sorting coefficients. Further details relating to sand analyses are available from Weaver on request.

In Plot 3, *Uma* were captured, marked and released on April 7, 9, 11 and 15. Lizards were marked by toe-clipping and with quick-drying model airplane paint. All records for this area were based on animals actually caught and examined. Capture-recapture data were analyzed as a chain of four samples (Schumacher and Eschmeyer, 1943). The 95% confidence range for the population estimate was computed as given by DeLury (1958). No *Uma* were observed in Plots 2 and 6.

In Plots 1, 4, 5 and 7–10 *Uma* were captured over periods of 4 to 5 days. Captured animals were marked with paint. Captures of new individuals were made more efficient because no effort was expended in recapturing animals already marked. On the last day of work in each

of these areas, a series of 6–8 separate censuses was carried out. Workers walked slowly and systematically through a plot, recording numbers of marked (painted) and unmarked lizards. After the area had been traversed, the procedure was repeated with 15-min waits between individual censuses. This system provided from 6–8 separate censuses from which numbers of *Uma* could be estimated. If a was the number of marked lizards at risk after the period of marking, n_i was the total number of lizards seen during the i_{th} census, and r_i was the number of painted lizards observed during the i_{th} census, then:

$$\hat{N}_i = a(n_i + 1)/(r_i + 1) \quad (2)$$

We computed the variances of the various N_i for a given plot, as suggested by Bailey (1952):

$$\mathrm{Var}(\hat{N}_i) = a^2(n_i + 1)(n_i - r_i)/(r_i + 1)^2(r_i + 2) \quad (3)$$

We could then calculate a mean variance ($\bar{s}^2$) associated with the mean population estimate for each area. We estimated 95% confidence intervals as $\pm 1.96\ \bar{s}$. Lower limits of confidence ranges were always less than numbers of different *Uma* marked in areas, so we defined lower limits of these populations as the number of different *Uma* registered. If no *Uma* were observed in an area (Plots 2, 6), or if *Uma* were marked and no unmarked individuals were taken in subsequent censuses (Plots 1, 4), we estimated the abundance of *Uma* as zero or as the number of different *Uma* marked.

Results

Sand delivered by flood waters to the Whitewater River flood plain in the northwestern portion of the Coachella Valley is swept down the valley by a strong, persistent and unidirectional wind regime. This is the source sand for Plots 1–7. The sand in plots 8 and 9 is from the Indio Hills, that in Plot 10 from the Mission and Morongo creek washes. Direction of sand movement is roughly from the northwest across all plots but 5, 6 and 10. In these three plots it comes from a more westerly direction. Locations of source sands and prevailing wind patterns are illustrated in Fig. 2.

Because of sand source locations and gradual diminution of wind velocity down the Coachella Valley, rates at which sand passes across plots are highest towards the western end of the valley. For example, the historical mean annual rate of passage in Plots 5 and 6 has been around 50 m^3 per meter-wide path. In Plot 7 it is around 29 m^3 per meter-wide path, diminishing to about 15–18 m^3 in Plots 1–4. Plots 8–10 are exposed to only 3–5 m^3 per year per meter-wide path. Because of windbreaks protecting Plots 2, 4 and 6, present mean annual rates of sand reception are zero.

TABLE 1. ATTRIBUTES OF SAND IN 10 PLOTS IN THE COACHELLA VALLEY. All but "Years of stabilization" and "Surface coarseness" are weighted means based on varying amounts of four different microhabitats in plots.

Plot	Years of stabilization	Mean grain size diameter (mm)	Percent (by weight) less than 0.1 mm diameter	Percent (by weight) more than 1.0 mm diameter	Penetrability, cm (0.3 m drop)	Surface coarseness (diameter of coarsest surface grains in plot, mm)
1	4	0.38	12.0	19.9	6.3	3.10
2	7	0.29	13.4	9.0	6.9	3.18
3	4	0.32	9.6	3.1	6.8	2.08
4	12	0.31	12.3	3.6	6.8	2.18
5	0	0.32	9.3	10.6	6.4	2.86
6	17	0.29	22.3	19.4	4.7	8.00
7	4	0.33	7.6	6.1	7.8	3.00
8	4	0.29	10.6	1.3	5.7	1.66
9	4	0.18	13.7	0	6.2	1.36
10	0	0.28	8.6	2.0	7.4	3.26

About 90% of Plot 6 was non-sandy, and the ensuing discussion pertains only to the other nine plots. From 20–30% of Plots 7 and 8 was non-sandy, but from 95–100% of the other seven plots was sandy. Areas of coarse substrates ranged from 10–20%. In most plots, open areas of typical sand made up from 35–80% of the area, but only 15–25% of Plots 7, 9 and 10 was of this nature. Because varying proportions of plots were composed of different sorts of microhabitats, we computed weighted means for most variables. Table 1 summarizes attributes of sand in plots. Plot 6 clearly differed from all other plots. It has been 17 years since new sand entered the area (Weaver, 1979). The soil surface is extremely stabilized against further wind erosion and is relatively impenetrable. Over 40% (by weight) of soil particles were <0.1 mm or >1.0 mm in diameter.

In all plots, 103 male and 89 female *Uma* were registered, but no hatchlings were observed.

TABLE 2. ESTIMATES OF DENSITY OF *Uma inornata* IN 10 2.25-HA PLOTS IN THE COACHELLA VALLEY.

Plot	Sampling dates	Different *Uma* caught	Man-hours	*Uma* per man-hour	Density estimate ($n \cdot ha^{-1}$)	Confidence range for density estimate ($n \cdot ha^{-1}$)
1	May 30, June 2–6	10	18	0.46	4.4	
2	May 26	0	20	0	0	
3	Apr 7, 9, 11, 15	38	34	1.12	43.0	39.1–47.6
4	Apr 8, 10, 14, 16	1	28	0.04	0.4	
5	May 19, June 2–6	35	35.8	0.98	45.0	15.6–96.2
6	June 16, 20	0	20	0	0	
7	June 10–14	30	47.3	0.63	17.2	13.3–24.1
8	Apr 22, 24, 29, May 2, 6	25	43.5	0.57	16.8	11.1–25.1
9	Apr 21, 23, 28, May 1, 5, 7	43	61	0.70	45.5	19.1–84.0
10	May 8, 12, 13, 14, 16, 20	10	51.2	0.20	8.8	4.4–17.0

These numbers do not differ significantly from those expected assuming a sex ratio of 1:1 ($\chi^2 = 1.0$, $P = \sim 0.3$). Mean snout–vent lengths of 44 females measured in Plots 1, 5, 7 and 9 ranged from 67.4 mm (Plot 5) to 78.8 mm (Plot 7). Mean snout–vent lengths of 61 males in these same plots ranged from 82.8 mm (Plot 9) to 104.7 mm (Plot 1). Body sizes of males are more variable than those of females, and males up to 121 mm in snout–vent length were recorded. Overall median body sizes were 77 mm among females and 90 mm among males.

Three of the ten plots examined (2, 4 and 6) were either unoccupied or sparsely populated by *U. inornata*. In the course of 20 man-hours of work under favorable weather conditions, one *Uma* was captured in Plot 4. Twenty man-hours of effort were expended in each of Plots 2 and 6, but no *Uma* were observed.

Table 2 summarizes experience in plots. The most important feature of these observations is the contrast between paired plots. In all instances the plots upwind of tamarisk windbreaks (1, 3 and 5) sustained populations of *Uma* (in two cases, fairly high densities) while downwind plots were sparsely inhabited (Plot 4) or uninhabited (Plots 2, 6).

To what extent can the estimated densities of *Uma* be understood in terms of sand characteristics given in Table 1? Table 3 gives the correlation matrix for these variables. The abundance of *Uma* is not significantly correlated with any of these variables, and non-parametric rank correlation tests (Snedecor, 1956: 190) give the same results. Although high proportions of very small (<0.1 mm) or coarse (>1.0 mm) sand grains have been found to inhibit burrowing by *Uma* (Norris, 1958; Pough, 1970), these measures were of little use in understanding the densities of *Uma* in Plots 1–5 and 7–10. In fact, when *Uma* densities were regressed on 32 other variables based on sand measurements in different microenvironments in plots, only two significant correlations emerged. Densities

TABLE 3. CORRELATION MATRIX FOR *Uma inornata* DENSITY AND SAND VARIABLES IN 10 PLOTS IN THE COACHELLA VALLEY.

	Years of stabilization	Penetrability	Mean grain size	% <0.1 mm	% >1.0 mm	Surface coarseness
Uma density	−0.551	0.064	−0.339	−0.374	−0.411	−0.475
Years of stabilization	—	−0.547	−0.027	0.849	0.403	0.653
Penetrability	—	—	0.163	−0.798	−0.465	−0.526
Mean grain size, mm	—	—	—	−0.244	0.552	0.156
% <0.1 mm	—	—	—	—	0.535	0.745
% >1.0 mm	—	—	—	—	—	0.721

TABLE 4. MEASURES OF PENETRABILITY, PERCENT OF SAND GRAINS <0.1 MM, PERCENT OF SAND GRAINS >1.0 MM AND GRAIN SIZE AT THE 75TH PERCENTILE OF GRADATION BY WEIGHT BASED ON MEASUREMENTS OF LEE SANDS IN 10 PLOTS IN THE COACHELLA VALLEY.

Plot	Penetrability, cm (0.3 m drop)	% <0.1 mm	% >1.0 mm	$d_{0.75\,mm}$
1	6.4	10	4	0.54
2	6.9	14	3	0.64
3	8.8	8	3	0.47
4	5.7	6	3	0.66
5	7.1	8	0	0.33
6	5.6	18	6	0.38
7	9.1	9	3	0.52
8	5.2	10	2	0.53
9	7.0	14	0	0.18
10	7.7	7	1	0.45

were positively correlated with surface crustiness in deposits on windward sides of shrubs and negatively correlated with amounts of sand coarser than 1.0 mm in deposits leeward of shrubs. In general, then, observed densities of *Uma* were statistically uncorrelated with the individual sand variables we measured.

The six independent variables in Table 1 were next used in multiple regression analyses. Five variables entered (all but surface coarseness), giving a multiple R of 0.74. This explained about 55% of the observed variation in *Uma* density.

Uma often burrow in dunes on the lee sides of shrubs. Stebbins (1944:330) stated: "Where barchanes, dunes or hummocks abound, the lizards are seldom . . . on the windward side but rather occur more commonly toward the base of the more precipitous lee side of such deposits." Norris (1958) also commented on the selection of the leeward sides of shrubs by *Uma*—both for basking and burrowing. Both authors emphasized the finer grain size of lee sands relative to those on the windward sides of hummocks.

We next considered attributes of sand in the lee of shrubs or trees in the Coachella Valley plots. Variables selected for consideration were: surface penetrability (P), sand grain diameter at the 75th percentile of gradation by weight ($d_{0.75}$), % of sand grains <0.1 mm in diameter (p_1), and % of grains >1.0 mm in diameter (p_2). Values for lee sand variables are given in Table 4. These variables were used together with years of stabilization (Y) and surface coarseness (C) in another multiple regression analysis (Table 5). The first three variables entered were diameter$_{0.75}$, surface coarseness and penetrability. These variables produced a multiple R of 0.90 ($R^2 = 0.81$). None of the other variables had much effect on the value of R. The three-variable model for predicting *Uma* density (N) was:

$$N = 3.7P - 92.8d_{0.75} - 4.8C + 51.0 \quad (4)$$

As an alternative we combined four of the variables used in these analyses into one hybrid variable:

$$\frac{P}{(Cd_{0.75}) + 0.13Y} \quad (5)$$

When *Uma* densities were regressed on this variable $r = 0.91$, explaining about the same amount of variation in the dependent variable as the multiple regression model. The resulting equation was:

$$N = 7.0\left[\frac{P}{Cd_{0.75} + 0.13Y}\right] - 13.5 \quad (6)$$

TABLE 5. RESULTS OF MULTIPLE REGRESSION ANALYSIS INVOLVING ESTIMATED DENSITIES OF *Uma inornata* IN 10 PLOTS IN THE COACHELLA VALLEY AND SIX SAND VARIABLES.

Variables entered	Multiple R	Multiple R^2	F-value to enter
Sand grain diameter at 75th percentile (mm), lee sand	0.695	0.483	7.48
Surface coarseness	0.868	0.754	7.70
Penetrability, lee	0.900	0.811	1.79
Percent of sand >1.0 mm in diameter, lee	0.903	0.815	0.10
Years of stabilization	0.905	0.819	0.10
Percent of sand <0.1 mm in diameter, lee	0.911	0.830	0.18

TABLE 6. ESTIMATED DENSITIES OF *Uma inornata* IN TEN PLOTS IN THE COACHELLA VALLEY AND HABITAT QUALITY INDEXES BASED ON QUALITY AND EXTENT OF SAND IN LEEWARD DUNES. Ranks are given in parentheses.

Plot	Estimated density of *Uma inornata* ($n \cdot ha^{-1}$)	Estimated extent of lee sand in plots (%)	Habitat quality index
1	4.4 (7)	20	0.77 (6)
2	0 (9½)	10	0.34 (8)
3	43.0 (3)	17	1.53 (5)
4	0.4 (8)	8	0.32 (9)
5	45.0 (2)	30	2.26 (3)
6	0 (9½)	1	0.02 (10)
7	17.2 (4)	30	1.74 (4)
8	16.8 (5)	10	0.59 (7)
9	45.5 (1)	40	11.44 (1)
10	8.8 (6)	45	2.36 (2)

The coefficient of Y was determined by trial and error, so as to maximize the correlation coefficient.

Equations (4) and (6) make some biological sense because sand penetrability is a positive environmental factor and surface coarseness a negative one. Equation (6) also incorporates the expected negative effect of increasing years of stabilization. When considered in conjunction with other variables, sand grain diameters at the 75th percentile of gradation by weight were found to be the single size gradation parameter most closely associated with observed *Uma* densities. While it is reasonable to expect that *Uma* densities are influenced by sand size gradation, it is not clear why they should be sensitive to grain diameters at that particular percentile.

Observations (y_i) and predictions ($\hat{y}_i$) by Equations (4) and (6) may be compared as suggested by Fraleigh (1978). If $\bar{y}$ is the mean of observations, one computes $\Sigma(y_i - \bar{y})^2$ or MS_T, and $\Sigma(y_i - \hat{y}_i)^2$, or MS_E. The relative magnitude of these values is a measure if fit. If MS_E/MS_T is greater than one the model predictions do not "fit" observations as well as a straight line drawn through the mean of the observations. The value of MS_E/MS_T for predictions based on Equation (4) is 0.19 and for predictions by Equation (6) 0.18, so there is no way to choose between Equations (4) and (6) on this basis. Both models may predict negative *Uma* densities, possibly implying a degradation of conditions beyond that necessary to eliminate the species. For both models, values of R^2 were increased somewhat if negative predictions were set equal to zero.

If our emphasis on "lee sand" as an important feature of total habitat is correct, then *Uma* numbers should reflect the quality of lee sands *and* their relative extent in the areas studied. Table 6 gives estimated percentages of plots composed of lee sand (A) and a habitat "quality index" computed as:

$$(A)(P)/Cd_{0.75} \qquad (7)$$

The correlation between *Uma* densities and the habitat quality index is statistically significant ($r = 0.65$), but just barely so ($F = 5.9$, $F_{0.05} = 5.3$). A rank correlation test gives $r_s = 0.82$, significant at the 1% level. Taking this analysis at face value implies that Plots 3 and 5 sustain much higher densities of *Uma* than would be expected from the quality and extent of lee sands.

DISCUSSION

It is hard to judge how well the models developed in the foregoing section are rooted in biological reality. Because the geographic distribution and local occurrence of *Uma inornata* are strongly influenced by substrates, it is reasonable to emphasize the nature of these sands in our study. However, general area attributes (like those in Table 1) did not afford any insight as to causes of variations in densities. It was not until we concentrated on characteristics of lee sands that possible interpretations of plot differences began to emerge. Nor could we simply look at individual characteristics of lee sands, only one of which was significantly correlated with *Uma* density. However, combinations of several factors relating to lee sand quality (and/or the history of the study areas) explained substantial amounts of variation observed in abundances of *Uma*.

Historical precedents certainly justify a focus on sand in leeward situations (Stebbins, 1944; Norris, 1958) but some of Pough's (1970) observations are at odds with these earlier ideas. Pough observed that *Uma* retreated at night to the windward ends of small dunes. He also stated that, "In laboratory choice experiments lizards preferred sand from the windward ends of these dunes to coarser or finer sand." This remark suggests that sand grain size is really what is important, and this is in keeping with the earlier assertions of Stebbins and Norris. The contradiction lies in where the most favorable sand is expected to occur. Stebbins (1944) wrote:

"Most of the sand in the dune area and on the lee side of . . . hummocks is extremely fine, measuring, on the average, under 0.5 mm." and Norris (1958) stated: "The windward slope [of sand hummocks] is composed of coarse sand . . . while the leeward side . . . possesses a long stringer of fine sand." Our measurements of grain diameters in windward and leeward positions do not clarify the situation. The overall mean diameter of windward grains (based on means from 10 plots) was 0.278 mm; the overall mean diameter of leeward grains from the same plots was 0.273 mm. The mean diameter of leeward grains in Plot 4 was about twice the diameter of windward grains; in Plot 6 the windward grains were 1.85 times the size of the leeward grains. In the three most densely populated plots (3, 5 and 9) ratios of mean diameters of leeward grains to mean diameters of windward grains were 1.11, 0.71 and 0.78, respectively.

The 3-term multiple regression model (Equation 4) and the model based on a single hybrid variable (Equation 6) both explained about 81% of the observed variation in the dependent variable. The second model was a little more flexible in that it gave more scope for intuition and permitted us to force variables to act in an incremental or decremental way. Both models incorporated one variable ($d_{0.75}$) which has no obvious ecological significance relative to other sand size gradation parameters. The predictive capabilities of the models can be gauged only in terms of the actual sites evaluated. Investigations of other areas, where attributes of sand might range beyond those values encountered in Plots 1–10, would lead to models with different coefficients for variables—although not necessarily of differing structure.

It is clear that the density of *Uma* varies conspicuously in different habitats in the Coachella Valley. Although we do not understand all the bases for this variation, data from the six experimental plots (1–6) show that obstructions to sand flow and ensuing sand depletion and surface stabilization definitely affect the occurrence of *Uma inornata.* The three plots downwind of obstructions (2, 4, 6) have been subjected to these processes for 7, 12 and 17 years, respectively. In all three situations changes in aeolian sand characteristics, and possibly in related biological variables, have rendered the areas unsuitable as *Uma* habitat. The continuing reception of new sand appears, then, to be an indispensable ecological process insofar as the survival of fringe-toed lizards is concerned. The importance of rates of sand passage is less clear. The three plots exhibiting highest densities of *Uma* (3, 5 and 9) sustain, respectively, passages of 15, 50 and 2.5 m^3 per meter-wide path per year. These observations suggest that some active passage of sand is necessary, with the rate of sand transport less important.

The reliability of population estimates has obvious bearing on the analyses we made. As can be seen from Table 2, numbers of *Uma* in Plots 5 and 9 were not well defined. The low incidence of marked lizards in census data implied that a high proportion of lizards remained unmarked in these plots. When census data were amenable to analysis as a chain of samples (Plot 3), the Schumacher-Eschmeyer technique gave tighter confidence intervals than estimated for other plots. Our recommendation is that future censuses be carried out so as to permit use of the Schumacher-Eschmeyer method of analyzing data.

Finally, all of the foregoing discussion must be tempered by the fact that various biological factors—as well as sand variables—influence the occurrence and abundance of *Uma.* England and Nelson (pers. comm.) concluded that apparent numbers of *Uma inornata* were positively correlated with the vigor of vegetation, possibly because of increased numbers of insects on which *Uma* subsists. Future studies of the present status and future of *Uma inornata* in the Coachella Valley must take all of these factors into account.

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LABORATORY OF BIOMEDICAL AND ENVIRONMENTAL SCIENCES, UNIVERSITY OF CALIFORNIA, LOS ANGELES, CALIFORNIA, 90024; DONALD C. WEAVER, P.E., CORP. PO BOX 5415, RIVERSIDE, CALIFORNIA, 92517; AND 3285 EAST HIGHWAY 80 #22, YUMA, ARIZONA, 85365. Accepted 11 July 1983.

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Abundance and Preferred Habitat of the Leopard Darter, *Percina pantherina*, in Glover Creek, Oklahoma

RAY N. JONES, DONALD J. ORTH AND O. EUGENE MAUGHAN

Leopard darters (*Percina pantherina*) were collected from 13 of 14 locations in Glover Creek, McCurtain County, Oklahoma during the period Aug. 1977 to July 1980. Although present in only small numbers (N = 139), leopard darters occurred throughout most of the main drainage system. Densities ranged from 0 to .0170/m^2 with the highest numbers and densities occurring in the East and West Fork tributaries. The orangebelly darter, *Etheostoma radiosum*, dominated the darter community (96% of the total catch), and leopard darters were the most abundant of the remaining six darter species present in the study area. Small numbers and low densities appeared characteristic of the darter community in Glover Creek. Previous descriptions of leopard darter habitat have defined riffles as their preferred areas. However, quantitative data on habitat use and availability in this study demonstrated a preference for pools during all seasons.

THE leopard darter, *Percina pantherina*, an endemic fish of the Little River system in southeastern Oklahoma and southwestern Arkansas (Miller and Robison, 1973), was first collected by O. P. Hay in 1884 (Robison, 1978). However, the species was not formally described until 1955 (Moore and Reeves, 1955) and received very little attention until the 1970's. Before 1977, only 165 specimens had been collected (Robison, 1978) and little was known of the leopard darter's life history. The rareness of the species led several authors to recommend that the leopard darter be given special protection (Cloutman and Olmsted, 1974; Robison et al., 1974; Hubbs and Pigg, 1976). On 27 Jan. 1978, the US Fish and Wildlife Service (1978) declared the leopard darter threatened, and designated several areas within the Little River

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ORIGINAL PAPER

Effects of an invasive plant on a desert sand dune landscape

Cameron W. Barrows · Edith B. Allen · Matthew L. Brooks · Michael F. Allen

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Abstract Given the abundance of non-native species invading wildland habitats, managers need to employ informed triage to focus control efforts on weeds with the greatest potential for negative impacts. Our objective here was to determine the level of threat Sahara mustard, *Brassica tournefortii*, represents to meeting regional goals for protecting biodiversity. Sahara mustard has spread throughout much of the Mojave and lower Sonoran Deserts. It has occurred in southern California's Coachella Valley for nearly 80 years, punctuated by years of extremely high abundance following high rainfall. In those years the mustard has clear negative impacts on the native flora. Using mustard removal experiments we identified reductions in native plant reproduction, shifting composition increasingly toward Sahara mustard while decreasing the fraction of native species. High between-year variance in precipitation may be a key to maintaining biodiversity as the mustard is less abundant in drier years. Sahara mustard impacts to the native fauna were much less evident. Of the animal species evaluated, only the Coachella Valley fringe-toed lizard, *Uma inornata*, demonstrated a negative response to mustard abundance; however the impacts were short-lived, lasting no more than a year after the mustard's dominance waned. Without control measures the long-term impacts to desert biodiversity may rest on the changing climate. Wetter conditions or increased periodicity of high rainfall years will favor Sahara mustard and result in reduced biodiversity, especially of native annual plants. Drier conditions will keep the mustard from becoming dominant but may have other negative consequences on the native flora and fauna.

Keywords Sahara mustard · *Brassica tournefortii* · Weed management · Native biodiversity · Natural communities

C. W. Barrows (✉) · E. B. Allen · M. F. Allen
Center for Conservation Biology, University of California Riverside, Riverside, CA 92521-0334, USA
e-mail: cbarrows@ucr.edu

M. L. Brooks
US Geological Survey, Western Ecological Research Center, Yosemite Field Station, El Portal, CA 95318, USA

Introduction

Exotic species invasions are second only to habitat destruction as a threat to biodiversity (Wilcove et al. 1998; Ludsin and Wolfe 2001; Simberloff 2004). Simberloff's (2003) pragmatic call to remove exotic species before they become established, rather than conduct research to determine their potential impacts, may seem prudent, but fails to address the fact that not all plant invasions result in negative effects (Brown and Sax 2005; Ricciardi and Cohen 2007). An emphasis on predicting the relative invasiveness of species and

invasibility of landscapes has contributed to a lag in research on the relative impact of invaders (Thomson 2005). The focus on early detection and eradication also does not address the myriad of exotic species already ensconced in otherwise protected habitats worldwide (Usher 1988). Is an exotic species benign, does it directly compete with native species, does it alter ecosystem processes, or does it have potentially desirable effects? Answering these questions has direct implications for the magnitude of response resource managers need to marshal to address each exotic invasion. For those established invaders, management triage is the prudent path, which requires insight into their relative levels of impact (Simberloff 2004; Ricciardi and Cohen 2007; Rinella and Luschei 2007).

While invasive species can have overwhelming negative impacts on native species (Elton 1958), for an exotic species to have broad community impacts, it will likely have to alter ecosystem processes (Vitousek 1986). A number of studies have demonstrated that ecosystem properties would be different in the absence of an invader (Vitousek 1986; Walker and Smith 1997; Gordon 1998; Ehrenfeld 2003). Ecosystem-level changes are most likely when the introduced species possesses characteristics that are divergent from native species (Chapin et al. 1996; Ehrenfeld 2003). Where research has demonstrated invasions of exotic plants having impacts to ecosystem processes, such as nitrogen cycles (Pickart et al. 1998), and fire regimes (Brooks et al. 2004), there have been broad negative impacts to biodiversity. The impacts of invaders can be particularly acute when both the amplitude and frequency of disturbance regimes are altered (Brooks et al. 2004).

It should be noted that not all exotic species invasions result in the loss of species or ecosystem function (Simberloff 1981; Williamson 1996; Brown and Sax 2005). For example, in Hawaii, 4,600 exotic plant species have become established. Of those alien species, 800 are considered invasive and 86 species represent a serious threat to native species or ecosystems (Smith 1985; Vitousek 1990). More specific to the current study, Barrows (1997) reported that adult Coachella Valley fringe-toed lizards (*Uma inornata*), a federally threatened species, did not seem to be affected by the presence of exotic tumbleweed (*Salsola tragus*) on desert sand dunes, whereas hatchling lizards had a positive response, using the tumbleweeds as cover to avoid predation. It is possible that persistent drought typical of the Coachella Valley never allows *Salsola* to reach densities where floristic diversity or ecosystem functions are negatively impacted. These examples highlight why it should not be assumed that all plant invasions threaten biodiversity, and emphasize the need for reliable and comprehensive information on their effects.

Our objective here was to document the establishment and environmental impacts of the invasive species Sahara mustard, *Brassica tournefortii,* across an aeolian sand landscape. Rather than focus on the effects of this invasion on a single conservation target, we evaluated the impacts at various scales including populations, communities and ecosystem processes. We describe the abundance of Sahara mustard varying with respect to precipitation and responses of the native biota across multiple aeolian sand community types. Through mustard removal experiments we were able to partition impacts of mustard abundance on native plant and animal species and ecosystem processes from otherwise typical community dynamics. Sahara mustard initially invaded the Coachella Valley aeolian sand habitats as early as 1927 and has since expanded over much of the Mojave and lower Sonoran Deserts (Sanders and Minnich 2000). While continuously present in the Coachella Valley since its introduction, this species has been a conspicuous component of the region's flora only in years when annual precipitation has been in excess of long-term means, such as in 1977–1983 (Sanders and Minnich 2000), 1994–1995 and again in 2005 (Barrows, unpubl. data). The ephemeral "explosions" of this exotic species have created an opportunity to examine short and long-term impacts to individual taxa as well as to environmental variables those taxa depend on. Such episodic periods of numerical dominance allowed us to address conditions that promote establishment of an exotic species and to consider how changes in those conditions may impact native species.

Methods

Study sites

We analyzed fluctuations of Sahara mustard and native species in the Coachella Valley near Palm Desert, Riverside County, California, from 2002 to 2008 (Fig. 1). The Coachella Valley is a shrub desert with a west to east mean annual rainfall gradient of

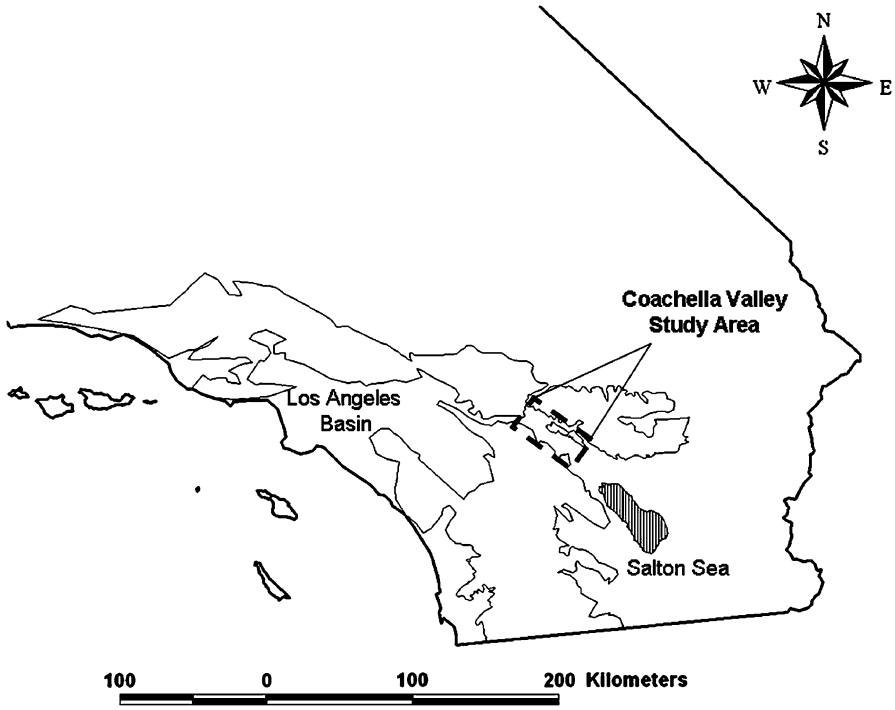

Fig. 1 Study area with respect to southern California, USA. Gray-shade outlined areas represent mountain ranges

125–79 mm (most recent 60 year means, Western Regional Climate Center, Palm Springs and Indio reporting stations). The lowest rainfall years occurred in 2002 and 2007, with just 7–4 mm respectively recorded across the valley floor. In contrast, in 2005 326–210 mm of rainfall was measured, the largest annual rainfall total recorded in the past 50 years for some Coachella Valley locations. Temperatures are also extreme, ranging from a low approaching 0°C in the winter to highs exceeding 45°C commonly recorded during July and August. All precipitation data reported here are based on a July–June rain year.

The experimental mustard removal portion of our study was conducted in the eastern portion of the valley, within the Thousand Palms Preserve (33°47′ N, 116°20′ W). Additional data, not associated with mustard removal, were collected within the entire rainfall gradient of the valley's available aeolian habitats. The Preserve includes approximately 1,300 ha of contiguous aeolian sand habitats characterized by two primary communities (Barrows and Allen 2007): (1) active sand dunes (low shrub density, high levels of sand movement, high topographic relief); and (2) stabilized sand fields (relatively high shrub density, low hummock topographic relief and low to moderate sand movement). Survey plots in the western end of the Coachella Valley included a third aeolian community type, ephemeral sand fields. Ephemeral sand fields occurred only near the wetter, windier portion of the valley where there was relatively high perennial shrub density and hummock topography, but also a high degree of sand movement (Holland 1986; Barrows and Allen 2007).

Study design

One hundred and twelve 10 m × 100 m (0.1 ha) study plots were established during 2002 to evaluate correlations with rainfall and aeolian community type on the abundance and species composition of annual plants, including Sahara mustard, and associated wildlife species. Eighty-six of those plots were within the Thousand Palms Preserve and 36 occurred at more western locations within the valley. Each plot was marked along its long axis with a short wooden stake at the beginning, middle and end. Study plots were located in a stratified random manner within the three aeolian community types.

Thirty of the study plots in the stabilized sand fields on the Thousand Palms Preserve were selected to conduct mustard removal experiments during 2005. Fifteen of the plots were selected for mustard

removal treatment and 15 were retained as non-weeded control plots. Treatment and control plots alternated across the landscape, with approximately 50 m between paired treatment–control plots. The arrangement of the overall 112 plots was random, however the selection of treatment–control plot pairs was regular-alternating; this allowed for paired plot analyses, minimizing between plot differences that could otherwise confound results. Treatment plots were cleared by hand of Sahara mustard; entire mustard plants, including taproots, were removed from weeded plots and from a 5 m buffer around each plot. Mustard plants germinated after each major rain event in the fall of 2004, and plots were weeded once in late January 2005 when there were at least three age/size classes of mustard seedlings present; no further mustard germination occurred that season. The objective was to weed the sites as early in the growing season as possible in order to minimize any effects (either from the mustard or the weeding effort) on native species germinating at the same time, but late enough so that all mustard plants could be removed in one effort. The tap-rooted mustard seedlings were readily pulled from the loose sand without disturbing adjacent plants. Mean effort required to remove mustard plants was 9.1 person hours/0.1 ha plot, and varied depending on the mustard density (range 3.75–17.5 person hours). Weeded mustard plants were placed outside the experimental areas and were allowed to decompose there.

The distribution of Sahara mustard on the active dune community was patchy compared to the more continuous distribution on the stabilized sand fields. In order to assess its impacts on the endangered Coachella Valley milkvetch, *Astragalus lentiginosus* var. *coachellae*, a plant restricted to communities with more dynamic aeolian sand transport such as the active dunes, paired plots (one weeded, one adjacent control) were selected non-randomly here to capture both high density mustard as well as the occurrence of the sensitive native plants. These plots were smaller than those described previously (5 m × 10 m, 0.005 ha). Initial weeding occurred in mid February 2005, using the same technique as described above. To assess impacts to sensitive fauna on active dunes, paired 2.5 ha sites were selected (again one weeded, one control). Within those sites, six 10 m × 100 m plots were randomly located and surveyed.

Vegetation and soil measurements

Vegetation density and species composition were measured on each of the 112 plots, including those used in the mustard removal experiments, each year in March–April from 2002 to 2008. Annual plants were also sampled on experimental treatment and control plots in November 2005 after October rains resulted in early plant germination that year. Perennial shrub density was recorded within the entire 10 m × 100 m treatment plot. Annual plant density and cover were measured within a 1 m^2 sampling frame placed at 12 locations along the midline of the plot. Four frames were sampled on alternating sides of the center line leading into the plot from both the beginning and ending stakes; an additional four frames were sampled at the center point (two on each side of the stake) of each plot. In each frame all individual plants were counted by species to determine their densities, and each species was estimated for its percent cover. For frames with mustard present, an estimate of mustard cover to the nearest 1% was made first, and then the mustard was removed so that cover estimates could be made for those plant species occurring below the mustard canopy within the same frame. These values were then averaged for each species for the 12 frames of each plot.

Soil seedbank composition in the mustard removal experiment was measured from samples collected in the fall of 2006. Approximately 300 g soil surface samples (from a depth of roughly 2 cm and an area of 400 cm^2) were collected at the center stake and at each end of the 30 plots used in the mustard removal experiment. A ½ cup (111 cm^3) portion was grown in a greenhouse during winter 2006–2007 following methods adapted from Brenchley and Warington (1930) and modified by Young and Evans (1975). Seed bank density and species richness were measured by counting the number of germinated seedlings for each species.

Sand compaction has been described as a key habitat variable for Coachella Valley fringe-toed lizards (Barrows 1997) and serves as a quantitative measure of sand stabilization. Sand compaction was measured at 25 points, approximately 4 m apart, along the midline of each plot, each year, using a hand-held pocket penetrometer with an adapter foot for loose soils (Ben Meadows Company, Janesville, WI, USA).

Vertebrate measurements

Vertebrates were sampled during May–July 2002–2007. The fine aeolian sand of the Thousand Palms Preserve created an opportunity unique to sand dunes to quantify the occurrence and abundance of all terrestrial species occurring within plots with equal detectability. Each vertebrate species and many arthropods that traversed the sand surface could be identified to species and age class by their diagnostic tracks left in the sand. Ground-based species left easily identifiable tracks, and so their ability to avoid detection by differences in activity times, cryptic coloration, or stealthy behavior was nullified. Because late afternoon and evening breezes would "wipe the sand clean" the next day's accumulation of tracks could not be confused with those from the previous day. Vertebrate surveys began each morning after the sand surface temperature had risen sufficiently so that diurnal reptiles were observed to be active. In this way surveys documented tracks that occurred during the previous night and the current early morning. Surveys often did not include tracks created mid-day through early evening, because afternoon and evening breezes typically removed evidence of them prior to surveys conducted the following morning. Surveys continued until late morning when the high angle of the sun reduced the observer's ability to distinguish and identify the tracks across the sand. One or two observers working in tandem completed a survey on a given plot in 10–15 min, recording all fresh tracks observed within the plot. Tracks were followed off the plot if it was necessary to confirm a species' identification and to ensure that the same individual was not crossing the same plot repeatedly, thus avoiding an inflated count of the individuals active on that plot. Each plot was re-surveyed six times between May and July each year from 2002 to 2007. Data from the repeated samples were then summarized as means per plot per year.

Invertebrate measurements

Arthropods were sampled using dry pitfall traps in April of 2003–2007, and again in September of 2005. Pitfall traps, cups with an 11 cm diameter mouth and 14 cm deep, were placed at both ends and at the middle of each plot for a total of three pitfalls/plot for each of the 112 plots. All arthropods were identified to the species level. Arthropod data are presented here as the total individuals/plot (combined counts for the three pitfall traps).

Data analyses

Our data did not conform to a normal distribution and so nonparametric statistics were used throughout. For analyses not based on paired plots, Mann–Whitney U tests were employed to detect between treatments or between year differences (Zar 1974). For analyses that were based on paired plots (i.e. experimental mustard removal), a Wilcoxon Signed Ranks test was employed, which is nonparametric analogue of a paired t-test (Zar 1974). This allowed us to determine treatment effects and minimize idiographic plot differences. In all cases $P \leq 0.05$ was used as a threshold for statistical significance.

Results

Patterns across the aeolian sand landscape

Mustard responses varied temporally and spatially with both rainfall and community type (Fig. 2). No annual plants, including Sahara mustard, occurred on any of our plots in 2002 or 2007 due to drought conditions; spatial and temporal variation in the percent cover of native annual plants were similar to that of the mustard (Fig. 3). Between 2004 and 2005 we measured increases in mustard cover in both stabilized sand field (Mann–Whitney U test, $P < 0.0001$), and active dune (Mann–Whitney U test, $P < 0.0001$) communities. As the active dunes and stabilized sand fields occurred within the same rainfall regime. The different levels of increase were community-specific rather than due to differences in available water.

Native annual plants responded to annual variation in precipitation as well. In 2003 and 2004 the overall percent cover of native annual plants exceeded that for Sahara mustard (Wilcoxon Signed Rank test, $P < 0.0001$ for both years) (Fig. 4). Even in 2005 the cover of native annuals exceeded that of mustard (Wilcoxon Signed Rank test, $P < 0.032$). Once again in 2007 there was insufficient rain to germinate plants. However, in 2006 and 2008 there was a shift

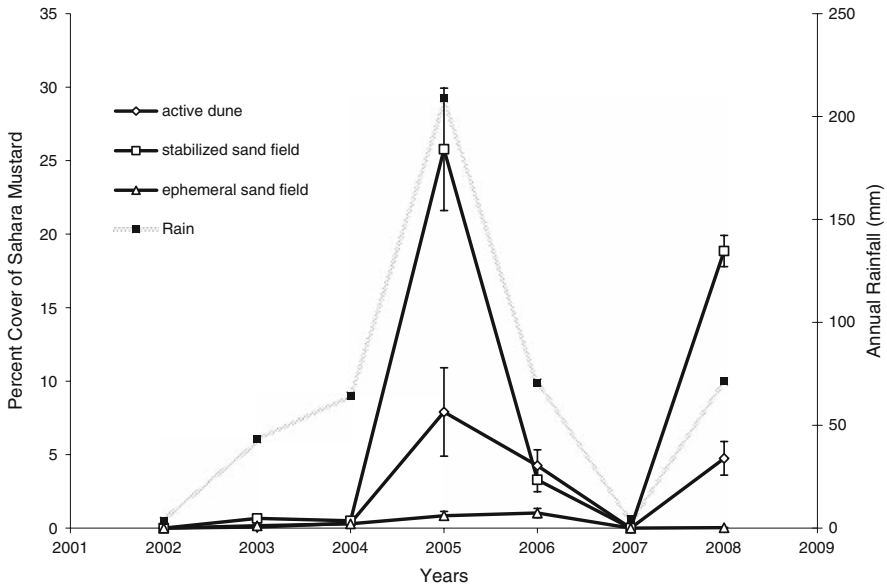

Fig. 2 Temporal and spatial patterns of Sahara mustard percent cover, compared to rainfall, across the aeolian sand communities of the Coachella Valley during March–April 2002–2008. Error bars indicate one standard error

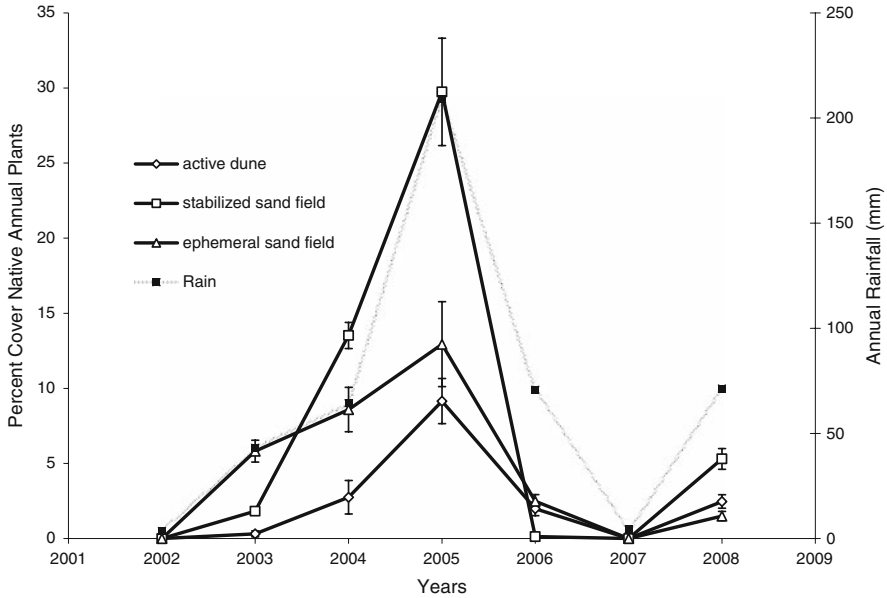

Fig. 3 Temporal and spatial patterns of percent cover of native annual plants, compared to rainfall, across the aeolian sand communities of the Coachella Valley during April 2002–2008. Error bars indicate one standard error

when Sahara mustard cover exceeded native cover (Wilcoxon Signed Rank test, $P < 0.001$, both years).

Mustard removal experiments

Differences in native annual plant species richness, density and percent cover between weeded and control (non-weeded) plots are shown in Table 1. There was no detectable impact on species richness. In both 2005 and 2008, annual plant species occurring on both weeded and control plots with densities $\geq 0.1/m^2$ included *Abronia villosa*, *Camissonia claviformis*, *Cryptantha* spp. *Geraea canescens*, *Eremalche exilis*, *Oenothera deltoides*, and *Palafoxia arida*. The strongest effect was on the percent cover of native annuals, with nearly double the native annual plant cover on weeded plots in 2005. Functionally, reduced cover resulted in fewer stems and fewer flowers. *Oenothera deltoides*,

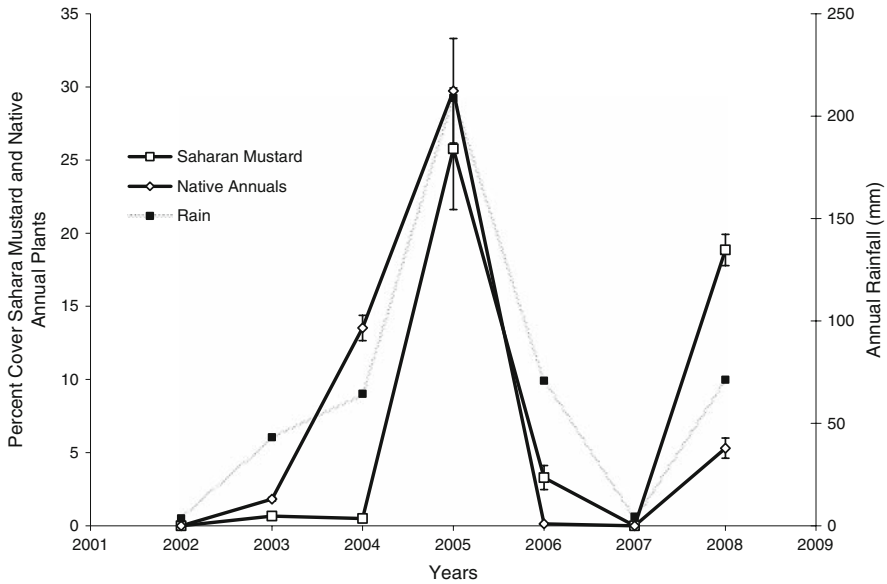

Fig. 4 Temporal patterns of Sahara mustard and native annual plant percent cover on stabilized sand fields with respect to variation in annual precipitation during April 2002–2008. Annual plant species included here are listed in Table 1. Error bars indicate one standard error

Table 1 Impacts of Sahara mustard on native annual plant species

	Weeded	Control
Species richness		
Mean	9.4	8.4
Standard Error	0.476	0.412
Wilcoxon Signed Ranks test	$P = 0.136$	
Density		
Mean	14.063	10.030
Standard Error	2.430	1.847
Wilcoxon Signed Ranks test	$P = 0.036$	
Percent cover		
Mean	41.232	23.343
Standard Error	5.952	3.743
Wilcoxon Signed Ranks test	$P = 0.036$	

(dune primrose), on weeded plots averaged more than 50 flowers per plant whereas those on control plots averaged less than ten flowers (Wilcoxon Signed Ranks test, $P = 0.005$). No additional mustard weeding occurred in 2008; however each of the experimental plots were re-surveyed to determine if there were lasting impacts to the weeding experiments of 2005. In 2008 dune primrose was the only native annual to occur in lower densities on plots weeded in 2005 compared to the non-weeded control plots (Wilcoxon Signed Ranks test, $P = 0.007$).

Active sand dunes are an important habitat for a federal and California State designated endangered annual plant species, the Coachella Valley milkvetch. Although the density and cover of mustard was lower and patchier on active sand dunes, some dense mustard patches did occur there. Two and a half months after the milkvetch were "released" from the dense mustard canopy by weeding they averaged more than 40 seed pods per plant ($n = 52$, range 0–270, 13% had no pods) whereas those that remained beneath the mustard canopy averaged less than five pods ($n = 29$, range 0–20, 41% of the plants had no seed pods). These differences between weeded and control plots were significant (Mann–Whitney U test, $P < 0.0001$).

Comparisons of the cummulative density of native annual plants on weeded and control plots are shown in Fig. 4. After the near record precipitation in the 2005 rain year, another 54.5 mm of rain fell on the plots in October 2005. This event catalyzed a second wave of annual plant germination in the fall of 2005 (Table 2). The difference in native annual plant density between the weeded and control plots in the November of 2005 was significant (Wilcoxon Signed Ranks test, $P = 0.001$) (Fig. 5). In addition to native annual plant germination, the mustard germinated as well. Mean Sahara mustard densities on the previously weeded plots was 124.5 plants/m^2 (range 47–284) whereas on the control plots the mean density was 289.2 plants/m^2 (range 46–920) (Table 2). Only 11.5 mm of rain fell

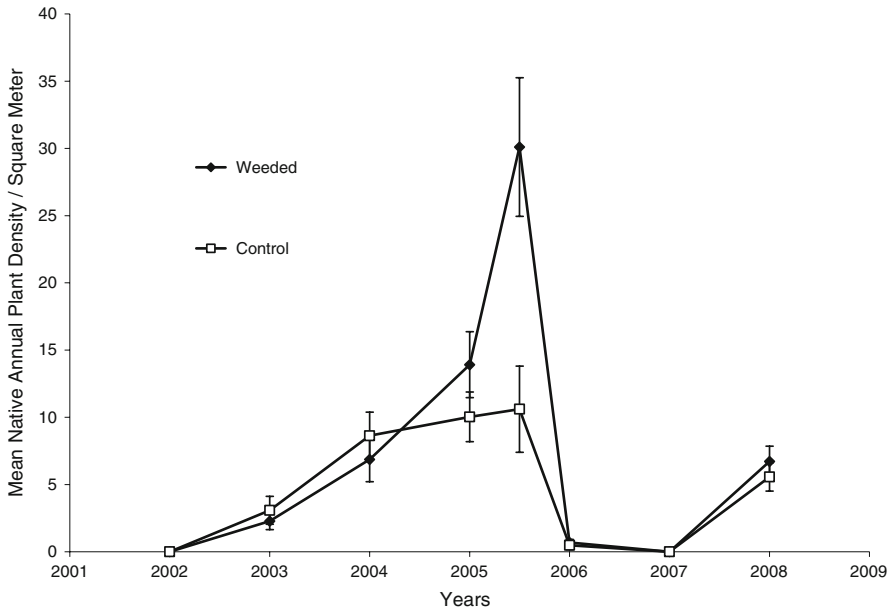

Fig. 5 Temporal comparison of the density of native annual plants on 15 paired plots where all Sahara mustard was removed (weeded) versus un-weeded (control). Weeding occurred in January 2005 prior to the germination of most native annual plants. Plant density was recorded as a mean count/m^2 for all native species combined during April 2003–2008, and additionally during November of 2005. Error bars indicate one standard error

through the following winter and spring; all annual plants within the stabilized sand field community, including the mustard, withered and died prior to setting seed. The only exception was on the active dunes where plants were able to flower and set seed. There was insufficient additional rain to stimulate any annual plant germination through 2007. In 2008 there were no statistical differences in mustard density between weeded and non-weeded plots (Wilcoxon Signed Ranks test, $P = 0.116$), although there was a significant increase of native annual plants on the weeded plots (Wilcoxon Signed Ranks test, $P = 0.036$).

To evaluate longer-term impacts to native plants we collected soil samples from the weeded and control plots in the fall of 2006 to analyze seed bank composition. Relatively few plants germinated from our soil samples, either due to small samples and/or high spatial variance or due to a depletion of the seed bank with no seed set following the October 2005 rain event. The mean number of native annuals germinating from three samples/plot for the weeded sites was 1.364, or roughly 34 plants/m^2; for the control plots just 0.364 plants germinated (9 plants/m^2) (Mann–Whitney U test, $P = 0.268$). The mean number of Sahara mustard plants germinating from three samples/plot for the weeded plots was 1.636 (41 plants/m^2); for the control plots it was 5.273 (132 plants/m^2) (Mann–Whitney U test, $P = 0.333$). Although these mean values indicate a potential treatment effect, the sampling effort appeared to be insufficient to statistically detect one.

Harvester ant (*Pogonomyrmex californicus, P. magnacanthus*, and *Messor perganderi*) mean abundance appeared unaffected by the presence or absence of mustard in the stabilized sand fields (Wilcoxon Signed Rank test, $P = 0.124$). Similarly on the active dunes there were no significant differences for harvester ants between weeded and control plots in either during or immediately following the dense mustard conditions in 2005 or 2006 (Mann–Whiney U test, $P = 0.719$, 0.216). Total beetles, which comprised the pooled abundance of approximately 40 species, were more abundant on the stabilized sand field weeded treatments in 2005 (Wilcoxon Signed Rank test, $P = 0.018$), but showed no differences between weeded and control plots on active dunes in either 2005 or 2006 (Mann–Whiney U test, $P = 0.942$, 0.215).

Five species of vertebrates, two reptiles and three mammals, were analyzed to determine their response to the weeding treatments (Table 3). Flat-tailed horned lizards (*Phrynosoma mcallii*), round-tailed ground squirrels (*Spermophilus tereticaudus chlorus*), and Merriam's kangaroo rats (*Dipodomys merriami*) demonstrated no response to the mustard removal. Only Coachella Valley fringe-toed lizards had a positive response to mustard removal in 2005. There were no

Table 2 Differences in germination rates of annual plants measured after a large rainfall event in October 2005

	Weeded	*P*	Control
Native annual species richness			
Mean density	7.857		5.929
Wilcoxon Signed Ranks test		0.002	
Abronia villosa			
Mean density	3.143		2.185
Wilcoxon Signed Ranks test		0.152	
Oenothera deltoides			
Mean density	3.476		0.649
Wilcoxon Signed Ranks test		0.002	
Geraea canescens			
Mean density	7.214		1.333
Wilcoxon Signed Ranks test		0.013	
Palafoxia arida			
Mean density	7.929		2.952
Wilcoxon Signed Ranks test		0.001	
Camissonia claviformis			
Mean density	2.536		1.048
Wilcoxon Signed Ranks test		0.101	
Baileya pauciradiata			
Mean density	0.226		0.042
Wilcoxon Signed Ranks test		0.012	
Cryptantha sp.			
Mean density	5.571		2.393
Wilcoxon Signed Ranks test		0.001	
Brassica tournefortii			
Mean density	124.488		289.190
Wilcoxon Signed Ranks test		0.002	
Schismus barbatus			
Mean density	28.524		15.060
Wilcoxon Signed Ranks test		0.006	

Density values represent means (plants/m^2) from 15 plots for both weeded and control treatments. There were 13 degrees of freedom for each of the *t*-tests conducted; values presented here are *P*-values resulting from those tests

Table 3 Impacts of Sahara mustard on indigenous vertebrate species

	Weeded	Control
Coachella Valley fringe-toed lizard		
Mean	2.505	1.629
Standard Error	0.787	0.641
Wilcoxon Signed Rank test	$P = 0.027$	
Percent change 2004–2005	37%	−17%
Flat-tailed horned lizard		
Mean	0.138	0.111
Standard Error	0.057	0.046
Wilcoxon Signed Rank test	$P = 0.717$	
Percent change 2004–2005	−49%	−55%
Round-tailed ground squirrel		
Mean	0.915	1.004
Standard Error	0.158	0.171
Wilcoxon Signed Rank test	$P = 0.433$	
Percent change 2004–2005	44%	59%
Desert kangaroo rat		
Mean	6.213	5.287
Standard Error	0.324	0.383
Wilcoxon Signed Rank test	$P = 0.209$	
Percent change 2004–2005	46%	33%
Merriam's kangaroo rat		
Mean	3.287	3.695
Standard Error	0.433	0.368
Wilcoxon Signed Rank test	$P = 0.211$	
Percent change 2004–2005	78%	81%

differences between these paired plots in any of the years prior to or following 2005 (Fig. 6). Additional plots were established in the active dunes to determine if the lizard responded similarly in that community. Unlike the stabilized sand fields, mustard plants that germinated after the October 2005 rains continued to grow and produced flowers and seed. Here we weeded those plots designated for treatment in both 2005 and 2006 (unlike the stabilized sand fields where there was nothing left to weed). The differences in fringe-toed lizard abundance between weeded and control plots increased from a mean of 1.97 in 2005 (Mann–Whitney *U* test, $P = 0.022$) to a mean of 3.36 in 2006 (Mann–Whitney *U* test, $P = 0.015$), (Fig. 6).

Comparing sand compaction from 2004 to 2005 on aeolian sand habitats throughout the Coachella Valley, sand compaction increased on 89% of our plots. On our weeded and control plots in 2005 the difference in sand compaction was slight (weeded mean = 0.202 kg/cm^2; control mean = 0.228kg/cm^2), but compaction was consistently less on weeded plots as compared to adjacent control plots (Wilcoxon Signed Ranks test, $P = 0.012$). Compared to 2004, there was a mean decrease in sand compaction of 0.017 kg/cm^2 on the weeded treatments, whereas there was a mean increase of 0.032 kg/cm^2 on the

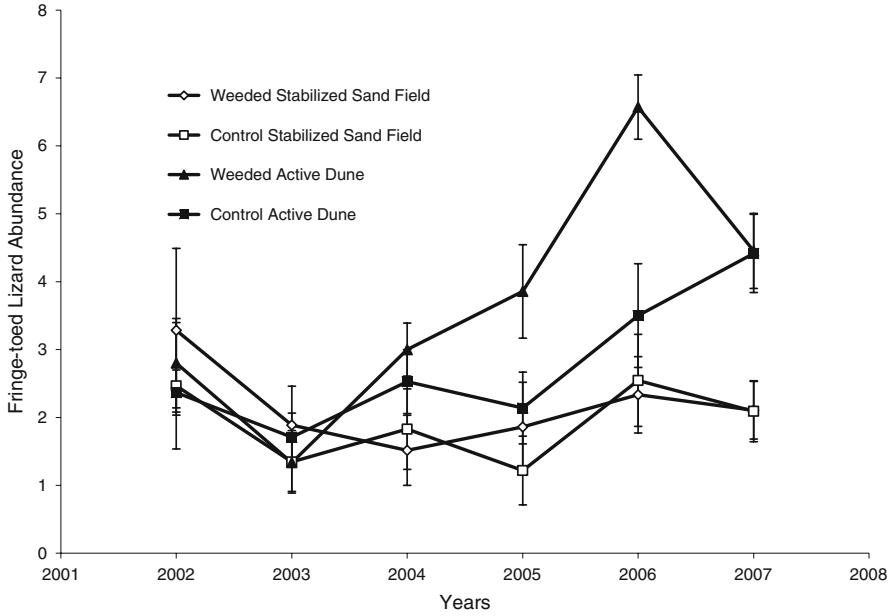

Fig. 6 Patterns of Coachella Valley fringe-toed lizard abundance on paired plots where Sahara mustard was removed (weeded) and left in situ (control) on both active dune and stabilized sand field community types. Lizard abundance was recorded as the mean detections/0.1 ha during May–July 2002–2007. Error bars indicate one standard error

control plots. However, that difference may have been the result of the activity associated with physically removing the mustard plants on the experimental plots. Within the stabilized sand field community on the 20 plots where there was no mustard removal, there was no correlation between percent mustard cover and a percent change in sand compaction from 2004 to 2005 (Pearson's pairwise correlation, $r = 0.134$).

Discussion

Our analyses were conducted at two scales: across the remaining aeolian sand landscape of the Coachella Valley, and more intensively within the eastern valley where mustard densities far exceeded those in the windier and wetter western valley. This allowed us to describe broad spatial and temporal patterns as well as specific species response to experimental mustard removal. Sahara mustard's occurrence and effects were uneven across the aeolian sand communities and native species that comprise them. The mustard's impact on arthropods and vertebrates was generally benign except with regard to the endemic fringe-toed lizard, a species listed as threatened (Federally) and endangered (State of California) and a focus for local conservation efforts. This species is consistently more abundant in aeolian sand communities with higher sand dynamics such as the active dunes (Barrows and Allen 2007) where the mustard densities were lower, yet measurable negative impacts were still evident.

Differences between fringe-toed lizard abundance on weeded versus control plots on both active dunes and stabilized sand fields lasted only as long as the mustard did. After 2005 on the stabilized sand fields, and 2005 and 2006 on the active dunes, any measurable negative impact from the mustard had disappeared. From the perspective of fringe-toed lizards the aeolian sand communities appear to be resilient to this perturbation. Temporal fluctuations in fringe-toed lizard populations are closely tied to annual precipitation, especially in active dunes (Barrows 2006). The decline in lizard numbers was therefore not surprising after low rainfall in 2006 and essentially no rain in 2007. However, the lizard population on the active dune control plots increased through 2007. Harvester ant and beetle populations, both important lizard foods (Barrows 2006), also increased on the active dune control plots relative to the weeded plots in 2007 (Barrows, unpubl. data). Whether these latent resource increases were related to the mustard density the prior year is tantalizing but untested.

Persistence of Sahara mustard on active dunes in 2006 was a result of the greater ability of deep aeolian sand to hold water (Seely 1991; Lei 2004; Rosenthal et al. 2005). The high rainfall of the winter of 2005 coupled with a short but intense rainfall period in the

fall of 2005 provided ample water storage in the dunes. Annual plants germinating after the fall 2005 rains were able to utilize that stored water and complete their flowering and seed set cycles in the spring of 2006. The stabilized sand field sands are shallow and are interspersed with clay lenses both which limit water storage capacity. Plants germinating there after the fall 2005 rains withered and died before flowering and setting seeds.

Sahara mustard's effects on native annual plants were negative for all species we measured. In 2005 on the stabilized sand fields the mustard formed a thick, inter-meshed canopy between 0.3 m and 1.0 m from the ground. Native annuals under the mustard canopy were often taller, and were etiolated, at the expense of producing branches, flowers and fruits. For those species measured, the result was an 80–90% reduction in flower and seed production for native annuals growing beneath the mustard canopy compared to those released from mustard competition. The following year's composition of germinating annual plants shifted from being native to Sahara mustard dominated. Subsequent seed bank analyses trended in the same direction, but were not statistically significant, possibly due to high spatial variance in seed distributions and insufficient sample size.

It is important to remember that this was not the first invasion of Sahara mustard in the Coachella Valley. Sahara mustard has occurred there for nearly 80 years, with years of "explosive" abundance in 1977–1983, 1994–1995 and again in 2005 (Sanders and Minnich 2000; Barrows, unpubl. data). Each of these periods of mustard dominance corresponded to periods of precipitation that were at least double annual means. While we were not able to quantify the pre 1927 mustard invasion conditions, there likely were impacts to the abundance and relative frequency of the native flora and fauna. Nevertheless, the native species were able to re-establish numerical dominance during moderate rainfall years following each "explosion" by the mustard. A key to understanding these patterns may lie in the variability of precipitation in the lower Sonoran Desert. Pake and Venable (1995) were able to model coexistence in Sonoran Desert annual plants, including a non-native invasive grass, *Schismus barbatus*, by including the variation in precipitation and the plants' differential responses to that variation.

The high degree of variation in desert rainfall provided conditions for intermittent "explosions" of Sahara mustard as well as the continued coexistence of native annuals and follows the theoretical framework proposed by Davis et al. (2000). Our data showed that native desert annuals' cover exceeded that for Sahara mustard during the low to moderate rainfall years of 2003 and 2004, despite a similar mustard explosion in 1994–1995. Based on their work with Sahara mustard in greenhouse studies, J. Holt and R. Marushia (unpubl data) concluded that rather than having any particular ability to withstand heat or drought, its success in an arid ecosystem may be due to its rapid phenology during wet years. Our data are consistent with that conclusion. Fall and early winter rains may favor Sahara mustard's abundance whereas the onset of rains in later winter and early spring may give a competitive edge to the native flora. Larger rainfall accumulations occurred in February and March in both 2003 and 2004 whereas in 2005 and 2008 the greater rainfall events were in November and December. The ability of native desert annuals to tolerate moderate droughts, and complete their life cycles during those conditions may prevent an erosion of biodiversity.

Within the adaptive strategies for plants presented by Grime (2001), native sand dune plants are most closely aligned with his "stress tolerant" category. The stresses that dune plants tolerate include wind erosion, sand abrasion, drought and low nutrients (Pickart et al. 1998). As long as those processes and characteristics are present, this community may be resistant to invasions from weeds, or ruderal species (sensu Grime 2001). This prediction is supported by our empirical data. Sahara mustard became dominant within the aeolian sand communities only when and where stresses from drought and wind erosion were reduced. Our results are consistent with community ecology theory as well; there were higher levels of "niche opportunity" (low resistance to invasibility) (Shea and Chesson 2002) and by far the highest Sahara mustard densities in the stabilized sand field community where wind erosion was reduced due to higher shrub densities and lower sand movement. The community with the highest levels of wind erosion and abrasion, the ephemeral sand fields, had the lowest niche opportunities (highest resistance to invasibility) and the lowest occurrence of Sahara mustard. The intensity and interaction between wind abrasion and available soil moisture appears to dictate where and when Sahara mustard can dominate aeolian sand communities;

rainfall dictates mustard density on a temporal scale, and wind and sand abrasion determines its density on a spatial scale.

A long-term threat to the biodiversity of the aeolian sand communities of the Coachella Valley would be manifested variability in annual rainfall was reduced, especially if late fall and winter rains were higher and more consistent. Some climate change models (i.e. McCabe et al. 2004) indicate the potential for increasing wet patterns for the southwestern US. Increased rain with fewer intervening droughts would result in higher mustard density, and so put the dunes on a trajectory to reduced plant diversity and increased stabilization (Lancaster 1995; Lancaster and Baas 1998). Such a scenario could alter the aeolian processes that maintain the dynamic character of these communities and perhaps cross a resilience threshold cascading these communities toward further and permanent stabilization. However, Hayhoe et al. (2004), the IPCC (2007) and Seager et al. (2007) all suggest that the southwestern US. will likely experience reduced precipitation, a prediction consistent with observed weather patterns of the past decade. The changing dynamic of drought and wet weather fluctuations will impact the intensities and location of future Sahara mustard invasions by changing the stresses, and niche opportunities that currently restrict or facilitate its occurrence. While a drier weather pattern would inhibit Sahara mustard, impacts to native desert biodiversity would depend on the severity of the predicted drought patterns.

Applied research should provide decision support for managers (Buckley 2008) and our results, by putting the threats posed by Sahara mustard into a temporal and spatial context, inform land managers how they could allocate their limited resources for controlling this exotic species. The modest mustard control we conducted during the course of our research produced short-term measurable benefits to species and processes. Three years later there were few lasting indications of the previous mustard removal. However dune primrose, a species positively associated with active dunes and higher levels of sand and wind abrasion, continued to have higher densities on the previously weeded plots. The dune primrose response indicates a shift in ecosystem processes toward reduced sand movement and abrasion on the non-weeded plots, consistent with predictions based on Lancaster and Baas' (1998) results. In the region encompassed by our study, species associated with high aeolian sand movement, such as the Coachella Valley fringe-toed lizard and milkvetch, had the greatest potential to be negatively effected by Sahara mustard invasions. Those species occur in their greatest densities on the active dunes and ephemeral sand fields (Barrows and Allen 2007), communities that appear to be resistant to mustard invasions. Managers should be vigilant for increased mustard dominance on these communities, but if current patterns continue control of mustard there may not be warranted.

Beyond endangered species management, our experimental mustard removal plots had an additional visual benefit to area visitors who were able to see a desert wildflower display "released" from the monochrome canopy of the mustard. Native wildflower densities are highest in the more stabilized habitats where the Sahara mustard can dominate. If land managers value maintaining those wildflower displays, or value maintaining the lower densities of aeolian sand movement-sensitive species also found there, then control of the mustard on those communities during wetter years may be an appropriate management direction. If mustard control is pursued, another consideration is that less than complete mustard control may have little impact on future mustard abundance during wet years. Trader et al. (2006) found that Sahara mustard thinning, without complete removal, increased the volume of seeds produced by those mustard plants that remained and could result in a greater contribution to seed banks than with no control at all. Managers need to put these findings into the context of their local rainfall regimes, soil types and wind characteristics.

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Desert Renewable Energy
REAT Biological Resource Compensation/Mitigation Cost Estimate[1]
Breakdown
for use with the REAT-NFWF Mitigation Account

July 23, 2010

DOCKET
09-AFC-7
DATE JUL 23 2010
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	Task	Cost
1.	Land Acquisition	$1000 per acre[2]
2.	Level 1 Environmental Site Assessment	$3000 per parcel[3]
3.	Appraisal	$5000 per parcel
4.	Initial site work - clean-up, enhancement , restoration	$250 per acre[4]
5.	Closing and Escrow Costs – 2 transactions at $2500 each; landowner to 3rd party and 3rd party to agency[5]	$5000 for 2 transactions
6.	Biological survey for determining mitigation value of land (habitat based with species specific augmentation)	$5000 per parcel
7.	3rd party administrative costs - includes staff time to work with agencies and landowners; develop management plan; oversee land transaction; organizational reporting and due diligence; review of acquisition documents; assembling acres to acquire....	10% of land acquisition cost (#1)
8.	Agency costs to review and determine accepting land donation - includes 2 physical inspections; review and approval of the Level 1 ESA assessment; review of all title documents; drafting deed and deed restrictions; issue escrow instructions; mapping the parcels....	15% of land acquisition costs (#1) × 1.17 (17% of the 15% for overhead)
	SUBTOTAL *- Acquisition & Initial Site Work*	*$*
9.	Long-term Management and Maintenance (LTMM) - includes land management; enforcement and defense of easement or title [short and long term]; region-wide raven management; monitoring....	$1450 per acre[6]
	NFWF Fees	
10.	Establish the project specific sub-account[7]	$12,000
11.	Pre-proposal Modified RFP or RFP processing[8]	$30,000
12.	NFWF management fee for acquisition & initial site work	3% of SUBTOTAL
13.	NFWF management fee for LTMM	1% of LTMM
	TOTAL *for deposit into the Project Specific Sub-Account*	*$*

[1] All costs are best estimates as of summer 2010. Actual costs will be determined at the time of the transactions and may change the funding needed to implement the required mitigation obligation. Note: regardless of the estimates, the developer is responsible for providing adequate funding to implement the required mitigation (MOA V.I.).
[2] Generalized estimate taking into consideration a likely jump in land costs due to demand, and an 18-24 month window to acquire the land after agency decisions are made. If the agencies, developer, or 3rd party has better, credible information on land costs in the specific area where project-specific mitigation lands are likely to be purchased, that data overrides this general estimate. Note: regardless of the estimates, the developer is responsible for providing adequate funding to implement the required mitigation.
[3] For the purposes of determining costs, a parcel is 40 acres (based on input from the BLM California Desert District).
[4] Based on information from California Department of Fish and Game.
[5] Two transactions at $2500 each: landowner to 3rd party; 3rd party to agency. The transactions will likely be separated in time.
[6] Estimate for purposes of calculating general costs. The actual long term management and maintenance costs will be determined using a Property Assessment Report (PAR) tailored to the specific acquisition.
[7] Each renewable energy project will be a separate sub-account within the REAT-NFWF account, regardless of the number of required mitigation actions per project.
[8] If determined necessary by the REAT agencies if multiple 3rd parties have expressed interest; for transparency and objective selection of 3rd party to carryout acquisition.

US Army Corps
of Engineers
Los Angeles District

The effect of blowsand reduction on the abundance of the fringe-toed lizard (Uma inornata) in the Coachella Valley, California

October 1981

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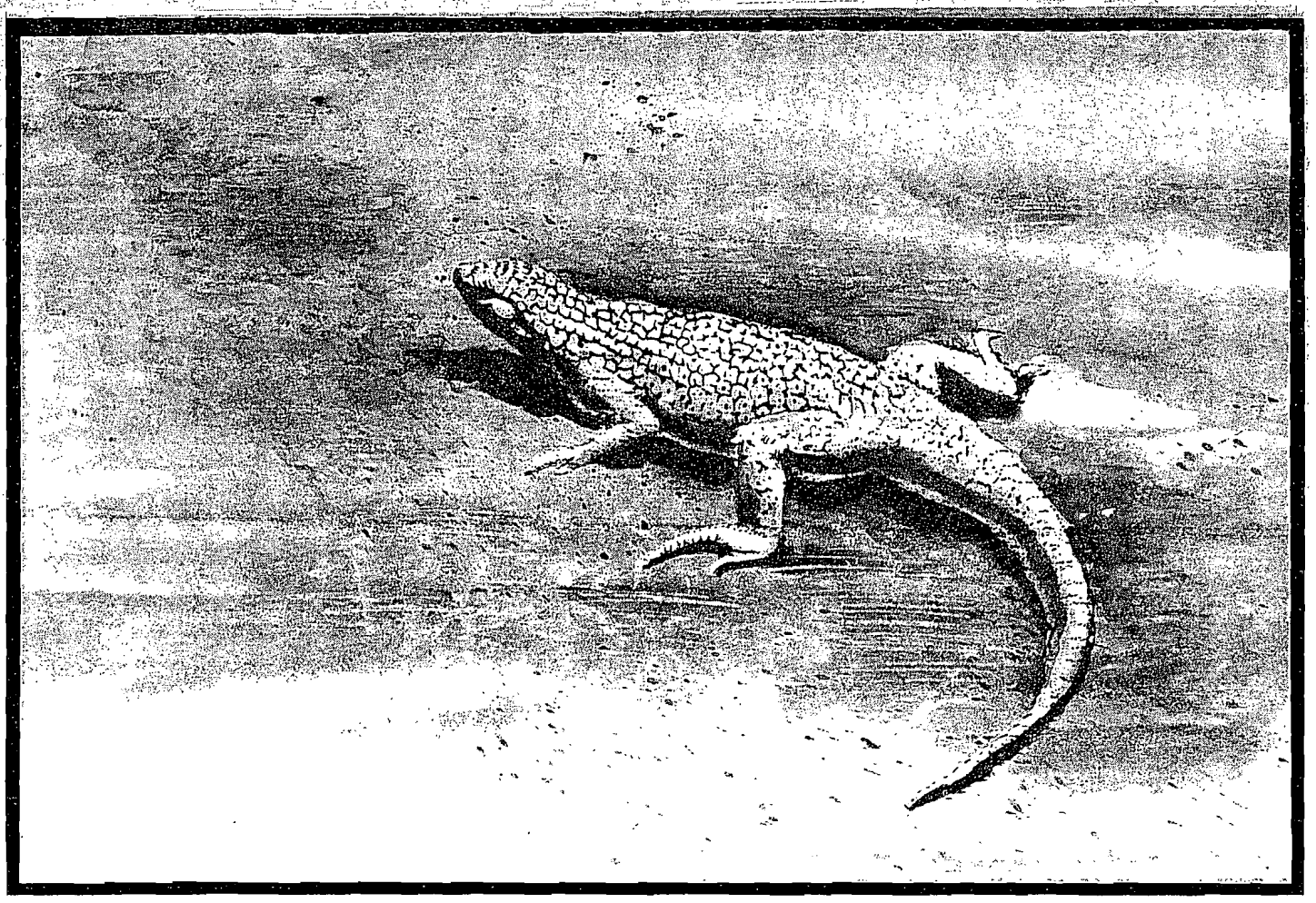

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PART II

Aeolian Sand Transport and Deposit Characteristics at Ten Sites in Coachella Valley, California

Donald C. Weaver, P.E.

Photography by

Jan G. Windhausen

Donald C. Weaver, P.E., Corp.

P.O. Box 5414

Riverside, California 92517

Abstract

Characteristics of aeolian sand transport and deposits at ten sites in the Coachella Valley were examined during mid-1980. Aeolian sands in the valley represent the sole habitat of the Coachella Valley Fringe-toed Lizard, *Uma inornata*, a potentially endangered species due to extensive development and other human actions. *Uma* abundance at the ten sites was determined concurrently by a team of biologists.

Six of the plots were in pairs, with one member of each pair located in a natural aeolian sand transport and deposit environment. The other, nearby member was shielded from the natural receipt of wind transported sands by a tamarisk tree row barrier, yet positioned sufficiently far from the trees to remain subject to natural wind velocities and, hence, to sand depletion and surface stabilization processes. The remaining four plots were in mesquite dune or sandy hummock areas.

Characteristics evaluated include natural and present rates of sand transport, number of years since receipt of new sand, penetrability, crustiness, size gradation and sorting coefficient of near-surface deposits, and coarseness of the surface layer of grains, all suspected of possibly influencing *Uma* behavior and abundance. Evaluations were made for

four microenvironments or microhabitats within each of the ten plots.

Dynamics of the basic aeolian sand transport system operating in the valley had previously been studied and quantified. Secondary, surficial deposit forms, superimposed upon the basic sand transport system environment, are classified here and changes which the various characteristics studied undergo in response to natural fluctuations in aeolian sand transport system dynamics and to human actions are discussed. Description of current and anticipated near-future conditions is also presented.

Data resulting from this study were analyzed in conjunction with the results of the companion biological study and reported in The Abundance of the Fringe-toed Lizard (*Uma inornata*) at 10 Sites in the Coachella Valley, California, by Turner, Weaver and Rorabaugh. Despite visually obvious overall differences between most of the plots in the field, differences in individual textural characteristics were quite subtle. In the companion study no significant correlations were found between individual characteristics and the observed *Uma* densities, although analyses involving combinations of characteristics elicited several highly significant relationships. Appropriate mathematical models for predicting *Uma* densities based upon certain combinations of aeolian sand transport and deposit characteristics are presented in the companion study

report.

Effects of shielding upon the characteristics studied and upon Uma abundance are discussed and evaluated herein. In time these effects extend to the downwind end of the valley and render the shielded area unsuitable as Uma habitat. Further research suggestions are offered.

Introduction

The transport of sand by wind occurs as a natural geologic process in Coachella Valley, Riverside County, California. The environment associated with this aeolian sand transport system, and particularly the deposits themselves, represent the sole habitat of the Coachella Valley Fringe-toed lizard, Uma inornata (Stebbins 1944, Norris 1958). Mosauer (1935), Mayhew (1965) and Pough (1970) further cite general relationships between the animal and various characteristics of its aeolian sand habitat.

England and Nelson (1976) indicate the historical range of the species to have been about 324 mi^2, which probably included some 200 mi^2 of suitable habitat. Aerial photographs taken in 1979, and ground survey conducted in 1975, indicate continuing agricultural and urban development of the valley to have directly resulted in the reduction of suitable habitat to some 99 mi^2 (Federal Register, 1980). As a result, in mid-1980 the species was being considered for listing as endangered by the State of California, and for declaration as threatened, with critical habitat determination, by the Department of Interior.

More insidious than the direct loss of habitat area to development, and of most recent concern, is the indirect effect of land development and other human actions on otherwise undisturbed habitat areas

downwind. Weaver (1979) indicates that areas shielded from the natural continuing receipt of windblown sand undergo changes in the form of sand depletion and surface stabilization and that, in time, these effects will extend to the downwind end of the region. Awareness of the general relationships between Uma and sand deposit characteristics has led biologists and others to believe that changes which occur in shielded areas are probably detrimental to the animal's habitat. Effects of existing land developments and other barriers to the natural sand transport process, together with anticipated continuing development activity and other project proposals, such as flood control measures which would result in 50% to 100% reductions in windblown sands entering the valley from the west (U.S. Army Corps of Engineers, 1979), emphasize the need for further definition of the relationship between Uma and its aeolian sand habitat and of the changes in habitat characteristics which occur in shielded areas.

Brief, companion studies of aeolian sand transport and deposit characteristics and of Uma abundance were planned during the early spring of 1980. Six sites (3 pairs) were selected, with one member of each pair shielded by an obstruction to the natural sand transport process. Pair members were located sufficiently close together to have been subjected to essentially the same sand transport conditions and to

have exhibited the same deposit characteristics and presumably the same Uma densities prior to the barrier's presence. Additionally studied were 4 sites representative of what England and Nelson (1976) classified as sandy hummock and mesquite dune types of habitat. The general locations of the ten study sites are shown on Exhibit 1, Area Map.

Purpose of the study described herein was to select and quantify aeolian sand transport and deposit characteristics affording reasonable possibilities of influencing Uma behavior and population density within each of the 10 study sites. Deposit characteristics were evaluated for 4 microenvironments: windward and lee hummock deposits, and typical intervening and coarsest intervening sandy deposits. Proportionate areas represented by each of the microenvironments were estimated visually. Three general types of deposit characteristics were examined: sand size gradation, surface penetrability and surface coarseness. Also evaluated were basic aeolian sand transport data, such as natural and present rates at which sand is received at the various sites and the number of years which several of the sites have been deprived of the receipt of new sand.

Data yielded by this study supplemented the parent biological study (Turner et al, 1980) which includes determination of Uma densities for the 10 study sites and correlation analyses of those observed

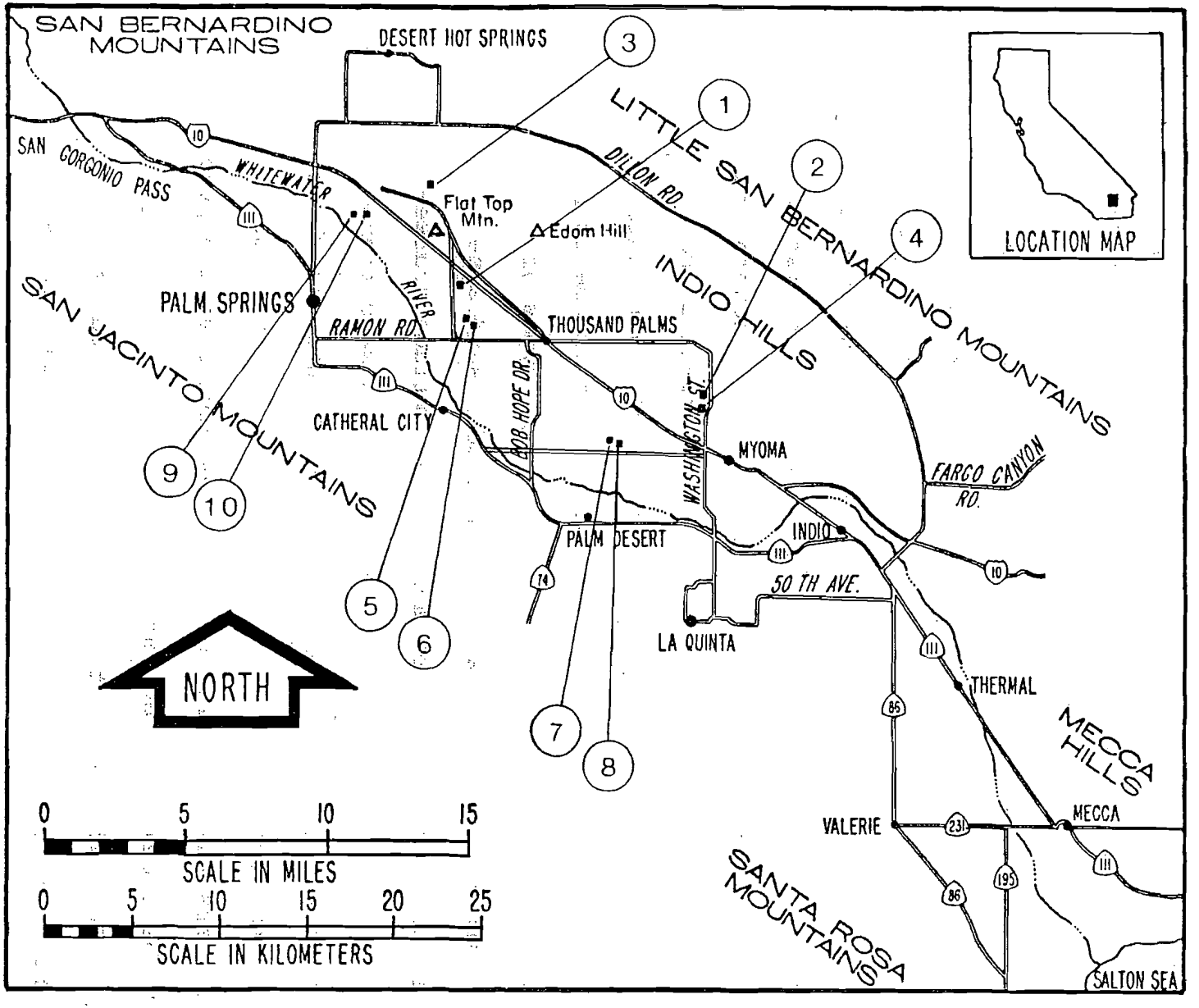

Exhibit 1. Area Map of Coachella Valley, California, showing locations of study sites.

densities with the habitat variables provided herein. We anticipated that the combined studies would clarify the effects of shielding on Uma abundance. It was less certain whether the relationships between Uma abundance and aeolian sand variables would permit reliable predictions of densities at other locations based upon aeolian sand characteristics.

Following review and analysis of the combined data, and realization of the dramatic effects of shielding upon Uma abundance, it was decided to incorporate additional information and discussion on shielding into this report as an aid to future studies.

Background

General relationships between *Uma inornata* and its aeolian sand environment are thoroughly discussed in Turner et al (1980). Weaver (1979) describes the geographics and dynamics of the basic regional aeolian sand transport system, a summary of which is appropriate here as background for subsequent discussion of surficial deposit forms.

The region of major aeolian sand transport activity covers an area of approximately 340 km^2, extending some 55 km from near Cabazon in the eastern San Gorgonio Pass to southerly of Indio. The region lies primarily between the San Jacinto Mountains and the Whitewater River channel on the southwest and the San Bernardino Mountains and the Indio Hills on the northeast, exhibiting a maximum width of about 18 km. It is situated entirely within the Whitewater River basin.

Sands supplied by floodwaters to the westerly and northerly portions of the region are transported to the southeast by a strong, unidirectional wind regime. Transporting winds emanate from the San Gorgonio Pass and occur most frequently and with greatest intensity during spring and early summer. Upon entering the valley, the winds tend to dissipate rapidly in the southeasterly direction, losing their capability of

transporting significant quantities of sand before reaching the Indio area.

The basic transport system can be conceived as a continuous sheet or stream of sand, intermittently flowing from northwest to southeast, resulting in a continuing, gradual decrease, or removal of sand from the occasionally replenished source areas and an increase, or accumulation in the downwind deposition area.

The alluvial plain of the Whitewater River extending between Windy Point and Indian Avenue, and the coalescing alluvial fans along the base of the Indio Hills constitute the primary source areas. The large accumulation or basic deposition area extends over the southerly and easterly portions of the region. Between the source areas and the basic deposition area lies an intermediate transport area across which sands tend to be expeditiously transported. This area exists as a result of the wind regime being capable of transporting more sand than is normally available to it over the long term. Thus, the basic tendency is for the area to be swept free of sand.

The upwind edge of the basic deposition area represents the location where the transport capability of the diminishing wind regime has been reduced to just equal the long term availability of sand. Beyond, extending to the southeast, continuing reduction in transport capability results in continuing deposition.

Note that water-laid alluvium constitutes the basic substrate in the source and intermediate transport areas, whereas the natural surface of the deposition area is comprised solely of wind deposited sand.

The pattern of sand movement is extremely stable, with transport being essentially unidirectional at any given location within the region. This results in a longitudinal division of the region into the Whitewater subregion, which receives its supply of sand from the Whitewater River and its upper basin tributaries, and the Indio Hills subregion, supplied by and through the Indio Hills. The regional boundary, the basic deposition area, sand movement pattern and the subregional dividing line are all indicated on Exhibit 2.

System dynamics, considered in terms of transport rates, source depletion rates, frequency of occurrence of transport conditions and size gradation of sands being transported, are most significantly influenced by fluctuations in the hydrologic provision of sand and in the transporting wind regime, and to a lesser extent by fluctuations in vegetative cover. Changes occurring in the basic system, in turn, effect changes in surface and near-surface textural characteristics of all aeolian deposits throughout the region. In simplest terms, greater availability of sand for transport tends to result in the surface sands in the basic deposition area becoming finer, stronger winds cause them to become coarser, and greater than normal

vegetation tends to subdue transport activity as a whole.

Superimposed upon the basic sand transport system environment described to this point, and of major importance to Uma habitat considerations, is a secondary system of surficial deposit forms. These can be classified as follows, after Beheiry (1967), who extensively describes their morphology:

a) hummocks (Beheiry's knob dunes)

b) mesquite dunes

c) sand drifts

e) sand veneers

f) sand undulations

g) wave and barchan-like dunes

All are dependent upon and are affected by changes in the basic transport system.

Hummocks, by far the most prevalent of the forms, are those deposits which accumulate in the wind shaded areas associated with individual vegetative shrubs. Normally a smaller upwind or windward deposit accompanies the major downwind, or lee deposit, with the combination generally being referred to as a single hummock. Size and shape are largely dependent upon the aeolian sand transport environment and the physical characteristics of the shrub. Hummocks commonly range in height from about 0.5 m to 2 m and tend to extend upwind from 1 m to 4 m and downwind from 2 m to more than 15 m.

Lee deposits, being formed largely by airborne grains moving into relatively dead air space and falling into place (rather than being propelled) generally are comprised of finer-textured sands, are less compacted and offer less resistance to penetration than their upwind counterparts. These lee deposits are generally favored by Uma for its submergence actions (Stebbins 1944, Norris 1958).

In response to changes in the basic sand transport system, hummocks tend to increase to maximum size when winds are laden to their capacity to transport sand and to diminish when winds are unladen. Thus, prolonged lack of sand available for transport can result in near total elimination of the deposits. Hummock depletion is generally evidenced by uncovered root structure of the involved shrub appearing above any remaining deposits. Total depletion leaves only slight mounds of coarse residual grains where the hummock once existed. The extent of ultimate depletion is further governed somewhat by the physical characteristics of the shrub and by location within the region.

Creosote, Larrea tridentata, is the primary shrub associated with hummock deposits, although saltbush, burrobush, cheesebush and other species also induce deposits of the same form. These types of vegetation occur throughout the valley, but trend from being more scarce in the west and north, where individual

shrubs are occasionally spaced more than 15 m apart (and in some areas are virtually non-existent), to being more profuse in the eastern and southern portions. Even under these conditions, shrub characteristics and spacing can result in extensive coalescing of the induced hummock deposits as far west as Palm Drive.

Substrates between hummocks range from water laid gravels and coarser alluvium, to fine wind blown sands, to caked silt and clay size particles. As noted by England and Nelson (1976), all combinations of hummock size and intervening substrate can be found in the valley. Hummocks in various states of luxuriance and depletion, together with a variety of intervening substrate conditions appear in several of the photographs referred to in the following section. Sandy hummock environments comprised 82% of the suitable Uma habitat identified by England and Nelson (1976). These included various combinations of hummocks and intervening surface conditions, some involving other surficial deposit forms.

Mesquite dunes exist primarily in an area northwest of Edom Hill, and more extensively, scattered throughout the easterly portion of the Indio Hills subregion. Lesser occurrences are to the north, in the Desert Hot Springs area, and to the southeast, toward the Salton Sea. Mesquite thickets, usually enhanced by the presence of other lesser shrubs,

impound and anchor wind blown sand in large, distinct formations. Individual dunes characteristically evolve as circular mounds, some of which approach 15 m in height and exceed 100 m in diameter. Less common, though covering more extensive areas, are large amorphous, billowy appearing masses, which can exhibit considerable internal vertical relief. England and Nelson (1976) noted 5 locations where these larger dune systems exist.

Mesquite shrubs, Prosopis glandulosa, are commonly known as water indicator Redo Plants associated with an abundance of available ground water, often at depths of several tens of meters. However, their presence in the aeolian sand transport environment appears also to be influenced by the rate at which sand is received. Physical characteristics of the shrub render it a highly efficient trap for intercepted sand. Consequently, to escape self-induced burial, the plant must be able to outgrow the rate at which the impounded accumulation increases in size. Within the region, mesquite dunes are found only in areas receiving a mean of less than about 2 cubic yards per foot-wide path of sand movement per year, as mapped by Weaver (1979). As the dune increases in size, the capability of the sand mass itself to absorb and make available additional moisture for plant growth is enhanced. These dunes often reside in an otherwise sandy hummock environment. However,

distinct individual hummocks seldom are found within the confines of the mesquite dune formations.

The mesquite dunes situated northwest of Edom Hill owe their existence to the combined presence of a high water table occurring along the Banning fault of the San Andreas fault system and minor localized transport of sand from the Mission and Morongo Creek washes to the west. These dunes are esentially unrelated to those farther to the east.

Under natural conditions mesquite dunes appear to have extensively covered the eastern portion of the Indio Hills subregion. The writings of Cowles (1977) recounting his studies during the 1930's, and comments offered by Dr. Wilbur W. Mayhew of the University of California, Riverside, and by Sid England (both pers. comm.), suggest this may have constituted the prime Uma habitat prior to the 1940's. Since then, virtually all of the area southerly of the Whitewater River channel, and much to the north, has succumbed to agricultural and urban development, obliterating all but minor, scattered evidence of the natural condition.

In an active aeolian sand transport environment, mesquite dunes tend to continue to increase in size. Beheiry (1967) discusses waning characteristics, including death of the bushes and loss of considerable mass, but concludes that whether rebuilding occurs or the dune vanishes completely is difficult to verify in the field. Changes in deposit characteristics

induced by changes in the sand transport process are considerably restrained in comparison with the other surficial deposit forms. This is due to the lower energy wind environment and the more uniform, finer deposits associated with the mesquite dunes. Certainly windward deposits reflect the characteristics of any recently received sands and become coarser during periods when little or no sand is available to winds capable of transport. Surface deposits within the formations themselves are normally well-protected by vegetative cover and probably undergo little change over even extended periods of time. When deprived of new sands indefinitely, the fate of these forms and the effects upon Uma habitat quality are unclear. However, if freshness of deposits is important to Uma, interminable lack of new sand must eventually be detrimental. When surveyed in 1975 by England and Nelson (1976), mesquite dunes comprised only 6% of the total habitat identified, no doubt considerably reduced from the natural condition.

Sand drifts are deposits which occur in the wind shadows of non-vegetative physical features and surface irregularities, and on insurmountable windward slopes. These deposits are associated largely with the more major physiographic features located in the westerly and northerly portions of the region, such as Windy Point, Garnet Hill, Flat Top Mountain and Edom Hill. Depressions, gullies, and the lee side of

cliffs and rock outcrops occurring in the surfaces of these features all tend to harbor drift deposits. In some locations in the intermediate transport area, large boulders and rock clusters are effectively responsible for drifts exhibiting hummock-like characteristics. Due to the impervious and relatively permanent nature of the physical features involved, the basic mass of these types of deposits is generally quite stable. However, the deposit surfaces themselves tend to be quite active, evidenced by their typically smooth, bare condition. Here also, surface deposits reflect the gradation of any recently received sands, whereas unladen winds cause their gradual coarsening as the finer, more susceptible grains are removed.

Extensive drift deposits exist in the lee of Flat Top Mountain and against the westerly and northwesterly flank of Edom Hill. Beheiry (1967) discusses these in detail, noting that a combination of rainfall, runoff, gravity and subsequent winds limits the size which they can achieve.

Where accompanied by hummocks, drift deposits serve as intervening sandy substrate. This combination is most extensive in the pass area between Flat Top Mountain and Edom Hill, noted by several biologists as being highly suitable habitat (Norris 1958, Mayhew 1965).

Sand veneers are relatively thin, smooth surfaced, surficial deposits which occur extensively within the source and intermediate transport areas. Aside from sand drifts, as described, veneers represent what sandy substrate is to be found in these areas. Invariably, these aeolian deposits are protected by a layer of coarse sand and pebbles, or a vegatative cover. Essentially, they are the product of sand being transported over small scale surface features and irregularities, and areas where relatively low-lying vegetation acts to impound and shield minor deposits of limited thickness. Rarely do these veneers exceed more than a few centimeters in depth, nor do they rise above the highest projections of the underlying alluvium or other non-aeolian substratum over any appreciable area. Veneers occurring in and near the source areas generally grade into alluvial surfaces, whereas those in the intermediate transport area grade into the large accumulation representing the basic deposition area. Similarly, those in the source area tend to be more transitory and subject to more radical and rapid changes than those nearer the basic deposition area.

Where and when veneers exist, they also grade into other surficial deposit forms which happen to be distributed among them. And, as with other surficial deposit forms in these areas, the near-surface textural characteristics of veneers are responsive to

changes in the relationship between wind transport capacity and actual sand transport.

Technically, veneers also occur within the basic deposition area, induced by low vegetative cover. There, however, it is simpler merely to consider all relatively smooth sandy substrate as the cumulative product of the basic aeolian sand transport system rather than as a superimposed surficial deposit form.

Surficial deposits which occur within the aeolian sand transport environment independently of fixed surface features range from small surface undulations of vertical relief of a few tenths of a meter and areal extent of a few m^2, up to wave and barchan-like dunes, some with active slip faces approaching 10 m in height. Undulations occur in the surface of the large sand accumulation and undergo essentially the same surface and near-surface textural responses to changes in the sand transport environment as described previously for that sandy substrate. Undulations are most common in the central portion of the basic deposition area, within the Whitewater subregion. England and Nelson (1976) included approximately the northwesterly two-thirds of these surface features within their sandy plains habitat classification. Overall, their sandy plains area extended southeast from the vicinity of Edom Hill and Flat Top Mountain to east of Bob Hope Drive, and comprised 12% of their identified suitable Uma habitat. Yet further to the

southeast, where vegetation becomes more plentiful, the sand undulations grade into either a series of vague sand mounds anchored by relatively dense vegetation or a small field of wave and barchan-like dunes. Both situations effectively mark the downwind termination of sand transport. Prior to partial destruction by urban development, the small dune field effectively graded into near-inactivity within itself and was truncated at its downwind end by the White-water River wash.

Two, likewise small wave and barchan-like dune formations presently exist in the Indio Hill sub-region; both roughly 1 to 2 km west of Washington Street, one about 2 km north and the other 1 km south of Interstate Highway 10. In total, the three areas comprise less than 2 km^2. Thus, although apparently constituting acceptable Uma habitat (Mosauer 1935, Cowles 1977) these most visually remarkable aeolian sand forms within the valley are of limited significance in terms of overall habitat. England and Nelson (1976) chose to include them within their sand hummocks and mesquite dunes classifications.

Sand hummocks, drifts, and veneers also occur quite extensively in a few isolated areas near Windy Point and extending westerly along State Highway 111 and the San Gorgonio River channel to the vicinity of Fingal Point. This latter location represents both the upwind limit, or beginning of the aeolian sand

transport region as well as the westerly extent of Uma habitat (Norris 1958). Since Uma ventures at most about 50 yd from the nearest windblown deposits (Norris 1958), fluctuations in the existence of such deposits on the floodplain extending between Windy Point and Indian Avenue occasionally isolate populations in these generally more consistent habitat areas near Windy Point and to the west from the main contiguous habitat. England and Nelson (1976) also found Uma present in several areas of localized deposits north and east of the primary aeolian sand transport region, representing minihabitats which may no longer or rarely afford transmigratory contact with the main habitat.

Sands involved in the aeolian transport system have been thoroughly examined and commented upon by Reed (1930), Sharp (1964) and Proctor (1968), among others. Essentially, sands supplied to both subregions are derived from similar parental rock formations. Feldspar is the most abundant constituent, with orthoclase more common than plagioclase. Quartz is next in abundance. Rarer minerals include green hornblende, muscovite, biotite, epidote, apatite, titanite, zircon and garnet. Biotite, due to the unusual aerodynamic property of its flakes, exists in greater abundance in finer deposits. Where found, finer deposits thus tend to be somewhat darker than the slightly grayish white appearance of the more

common, coarser sands present throughout most of the region. Viewed at a distance of a few meters, the more prevalent coarser deposits are slightly peppered in appearance. Closer, a slight pinkish tint emerges. Finally, inspection of the individual grains reveals a myriad of colors among the rarer minerals. Individual grains range from subangular to angular, with smaller grains tending to be slightly more angular than the larger ones. Only the softer biotite flakes exhibit notable wear due to aeolian transport. Thus, in summary, except for the sorting anomaly associated with the biotite flakes, aeolian sands deposited throughout the region are believed to exhibit no significant mineralogical differences.

How does the condition of the valley at present compare with the long-term average, and what might be expected in the near future? Of greatest significance is the fact that much of the region is presently developed or artificially shielded from the natural receipt of wind blown sand, the effects of which are discussed later. Next in importance is the overabundance of vegetation which prevails throughout the valley. This condition, resulting from abnormally high rainfall over several successive years, has effectively quelled the movement of sand within all but the upper portions of the region for the past 4 years. Extensive quantities of sand presently exist in both source areas. In the case of the Whitewater

subregion, continuing disturbance of surface conditions on the floodplain between Windy Point and Indian Avenue by Coachella Valley Water District percolation basin construction operations has further added to the availability and susceptibility of sands for transport. Transport across Indian Avenue as observed by the author, has been quite high in 1979 and 1980. Yet, aside from the sand which has been intercepted and stabilized by the Riverside County Road Department, Massey Sand and Rock Co., and the Southern Pacific Transportation Company, Redo the large volumes transported have been effectively absorbed by the overabundant vegetation, aided slightly by the limited trapping capacity of non-vegetative features within the intermediate transport area. The sand transport-inhibiting qualities of vegetative cover are well demonstrated in the area extending approximately 1.5 km immediately south of the railroad. Nonetheless, the sand transport process will prevail, in time, perhaps aided by a period of lesser rainfall and recession of the vegetative cover.

Major supplies of sand to the Indio Hills subregion tend to be more extensive, but generally owing their occurrence to desert thunderstorm activity, are delivered far less frequently than those to the Whitewater subregion. Here, massive quantities delivered during the past four years presently await wind transport, held in check to date primarily by extensive

surface vegetation. Likely, a new, major wave and barchan-like dune formation similar to that presently situated 2 to 3 km west of Washington Street and 1 to 2 km north of Interstate Highway 10 will evolve. How long this will take is uncertain. It may be several years before recognizable dune forms emerge. Extensive sand veneers and other surficial deposit forms will also be enhanced.

Thus, active transport conditions within the unshielded areas of both subregions appear well assured over the next several years.

Burrows of undetermined origin or present users are relatively abundant throughout the region and at all of the study sites. Aside from the occasional use of such burrows for escape or other periods of inactivity, Uma limits itself to activity on the surface and to submergence within the upper few centimeters of aeolian sand deposits (Stebbins 1944, Norris 1958). Submergence, the most common form of retreat from the surface, seldom exceeds 4 or 5 cm. As discussed with Sid England (pers comm), taking the height of the animal itself into account, activity thus appears limited to about 8 cm.

Lastly, the extensive rainfall in recent years has also contributed to the formation of a greater than normal, near-surface crust within most sand deposits and substrates throughout the region. Most prevalent are those formed in deposits where percola-

tion of rainfall is complete, with no evidence of flow along the surface. Finer sediments, silt and clay size particles and minor organic particles are filtered downward, creating an illuvial zone or layer which, when dried, is slightly cohesive. Also, deposits tend to be slightly calcareous, further contributing to the cementing process.

Where formed in wind deposited sands the crusts are generally between 0.5 cm and 2 cm thick and presently exist at or within a few centimeters of the surface. Invariably they are quite fragile, defying removal of pieces larger than a few cm^2. Generally, they disintegrate upon handling. Nonetheless, they quite evidently reduce the ease of penetration of the near-surface deposits on a physical scale probably commensurate with Uma submerging actions. Such conditions were present at all of the study sites.

Where surface runoff occurs, greater concentrations of finer sediments can result in considerably stronger crustal formations such as hardpan or caked orthogonal plates in low-lying areas, as were exhibited at some of the study locations.

Crustal formations induced by rainfall are not uncommon in arid lands (Fletcher and Martin, 1948). Normally, crusts of lesser thickness would exist from time to time at scattered locations throughout the valley. However, personal observations made during studies involving examination of deposits represent-

ing several centuries of accumulation at a number of regional locations indicate the present condition to be quite rare, probably not recurring but once in several centuries on the average.

While inhibiting Uma submergence activities at and near the surface, the present existence of crustal formations does enhance the creation and maintenance of underlying burrows.

Study Sites

Locations for the 10 study plots were established in early April 1980 following a field review of prospective sites by Fred Turner, Sid England, James Rorabaugh, Russell Duncan and Don Weaver. Final positioning of the 150 m square plots and grid staking at 25 m intervals was done by the biological field personnel engaged in the companion study. In general, the plots were well arrayed over the central portion of the valley, extending from near Garnet Hill, north of Palm Springs, to Washington Street, northwest of Indio, a distance of approximately 24 km. See Exhibit 2, Reference Map.

Plots 5 and 6, 7 and 8, and 9 and 10 were the paired plots. The first member of each pair was an undisturbed area presently subject to natural or near natural aeolian sand transport conditions and deposits, where it appeared that Uma would be present. The second member of each pair was downwind of the undisturbed plot at a location shielded for a known period of time from the natural sand transport process and receipt of sand by a tamarisk tree row obstruction. Each downwind plot was located far enough from the shielding barrier to be exposed to natural or near natural wind conditions. Plots 5 and 7 show on Exhibit 2 as being situated in areas destined for

stabilization. However, in each case the present shielding barrier is a considerable distance upwind, as compared with Plots 6, 8 and 10. This condition is discussed later.

Plots 1 through 4 were not a part of the experimental scheme, but were representative of England and Nelson's (1976) sandy hummocks (Plots 1 and 2) and mesquite dunes (Plots 3 and 4). Paired Plots 5 and 6, and 7 and 8 are located in areas representative of their sand Redo plains, with 9 and 10 being representative of sandy hummocks.

Basic plot information is presented in Table 1. Plot 1 is situated at the upwind edge of the basic deposition area and straddles a small swale occasionally subject to surface water flow. The occurrence of such a condition in recent months resulted in dried mudflats covering portions of the plot during the study period. Plates 1 and 2 present on-site and aerial views of the plot. The large, though essentially undeveloped subdivision immediately to the west is Palm Springs Panorama, which has remained basically unchanged since the early 1960's.

Plot 2 is situated in the intermediate transport area of the Indio Hills subregion, and is also subject to occasional surface waters, responsible for present dried clay surface areas. These and hummock deposits less extensive than in Plot 1 are pictured in Plate 3.

TABLE 1

Basic Data and Information

Plot	Direction of sand movement	Mean annual rate at which aeolian sand is received (CY per foot-wide path in the direction of movement)		Number of years since receipt of significant quantities of new sand	Mean annual rate of deposition (depth increase in base accumulation)		Sand supply source
		Under natural conditions	Under present conditions		Under natural conditions	Under present conditions	
1	S 49° E	11½	11½	4[a]	0-0.25mm	0-0.25mm	Whitewater R. floodplain
2	S 36° E	1-	1-	4[a]	0[b]	0	Indio Hills alluvial fans
3	S 60° E	2+	2+	0	0[b]	0	Mission and Morongo washes
4	S 36° E	1+	1+	4[a]	0[b]	0	Indio Hills alluvial fans
5	S 42° E	7	7	4[a]	1.1mm	1.1mm	Whitewater R. floodplain
6	S 40° E	6+	0	7	1.2mm	0	"
7	S 38° E	6+	6+	4[a]	2.7mm	2.7mm	"
8	S 38° E	6+	0	12	2.7mm	0	"
9	S 71° E	20	20	0	0[b]	0	"
10	S 66° E	20	0	17	0[b]	0	"

(a) due to overabundant vegetative cover

(b) deposits are essentially local, induced by vegetation or other obstacles, and overlying water-laid alluvium

Plate 1

Fig. 1. Plot 1. Viewed toward the northwest. Typical lee hummock deposit and responsible verdant creosote in foreground.

Fig. 2. Plot 1. Looking southeast in the direction of sand transport. Windward hummocks shown, with intervening sandy substratum and vegetation.

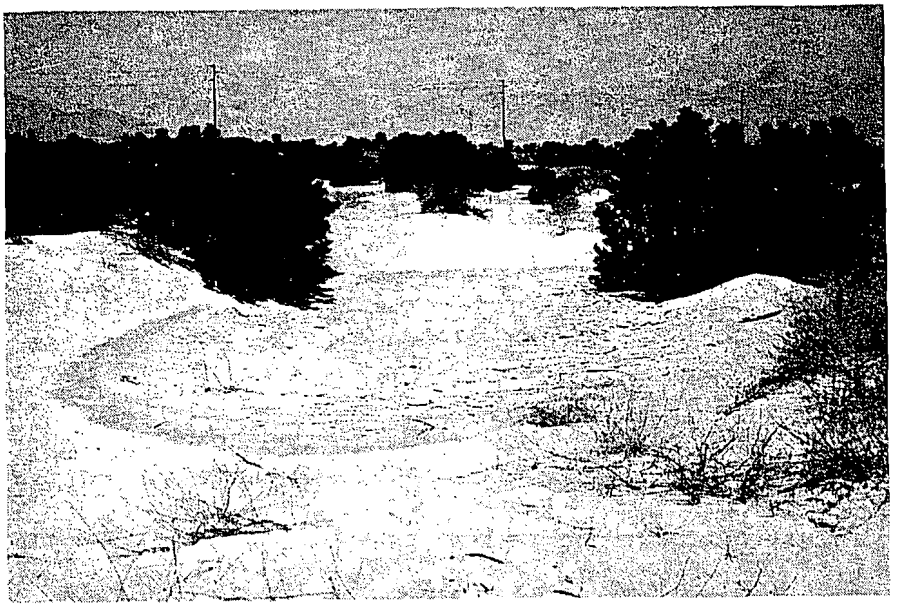

Fig. 1 . Plot 1. Typical mudflats, dried polygonal plates of fine silt and clay partially covered by blown sands.

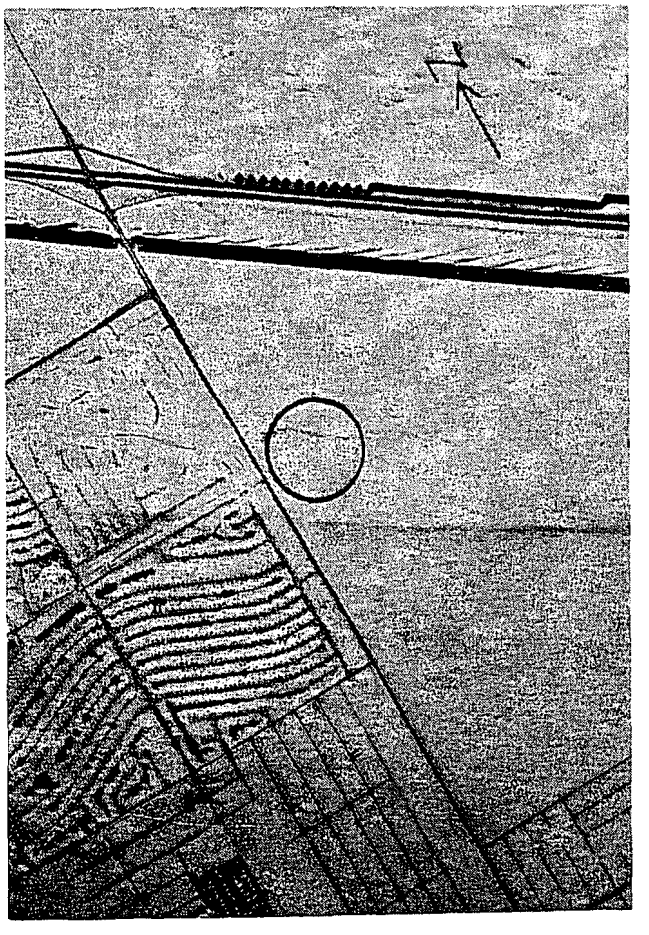

Fig. 2. Plot 1. Nov. 1974. Relationship of plot to surrounding terrain. This and all succeeding circles are approximately 350 m. diameter, 2+ times the 150 m. square plot centered within.

Plot 3, featured on Plates 4 and 5, and Plot 4, shown on Plates 6 and 7, differ from the remaining plots from the standpoints of greater abundance of vegetation and generally finer deposits. In addition, these two plots exhibit vertical relief of up to 10 m or more as compared to a maximum of less than 3 at any of the other study sites. These differences are largely due to the existence of the mesquite shrubs. In Plot 4 these shrubs may have been more extensive in the past than at present, as indicated by numerous dead remnants.

Plot 3 presently contains the most extensive vegetation-induced deposits. As noted, this plot is situated on the Banning Fault (of the San Andreas fault system), termed a "vegetation scarp" by Proctor (1968) in reference to near-surface fault-dammed ground water which has caused vegetation to grow in abundance along the fault trace. This appears most markedly on Exhibit 2 and on Plate 5, Figure 1. Plot 3 lies in a small, topographically isolated area commonly referred to as Seven Palms Valley, just outside the area of major aeolian sand transport activity as defined by Weaver (1979). A more or less continuous chain of aeolian deposits interconnect the areas.

Conditions associated with Plot 4, abundant vegetation, rolling mesquite dunes with vertical relief of some 10 m or more, and some dead mesquite,

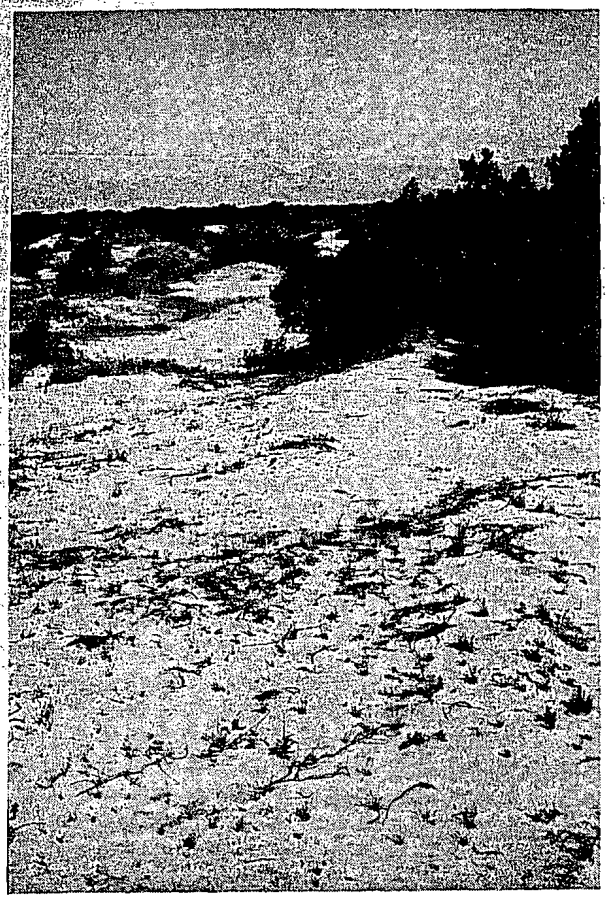

Fig. 1. Plot 2. Typical lee hummock deposits, viewed toward the northwest. Intervening sandy substratum and vegetation in foreground.

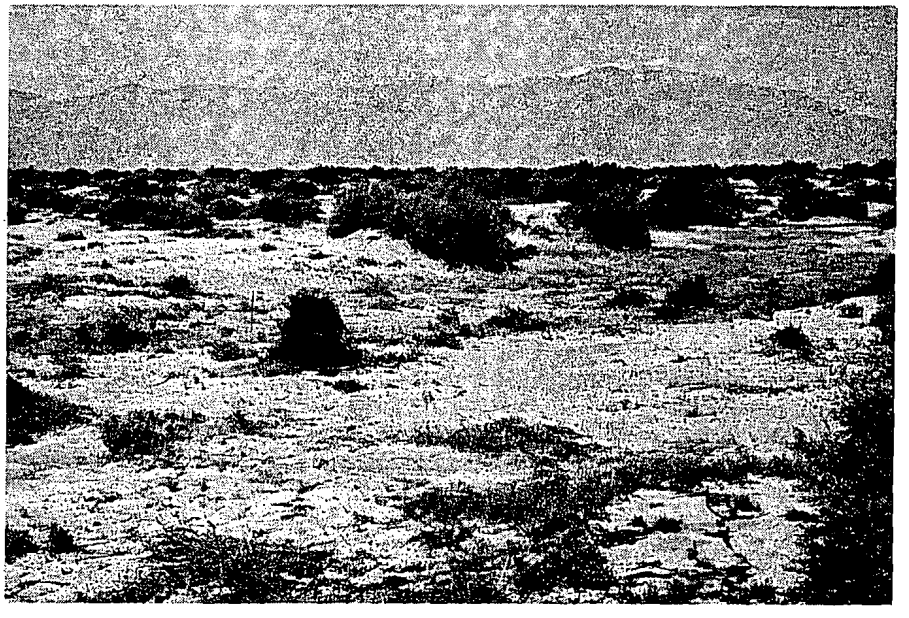

Fig. 2. Plot 2. Looking west. Intervening substratum partially overlain with water borne clayey sediments. Also see Plate 7, Fig. 1.

Fig. 1. Plot 3. Viewed toward the south. Mesquite and related deposits in foreground right, with vertical relief reflected in upper left.

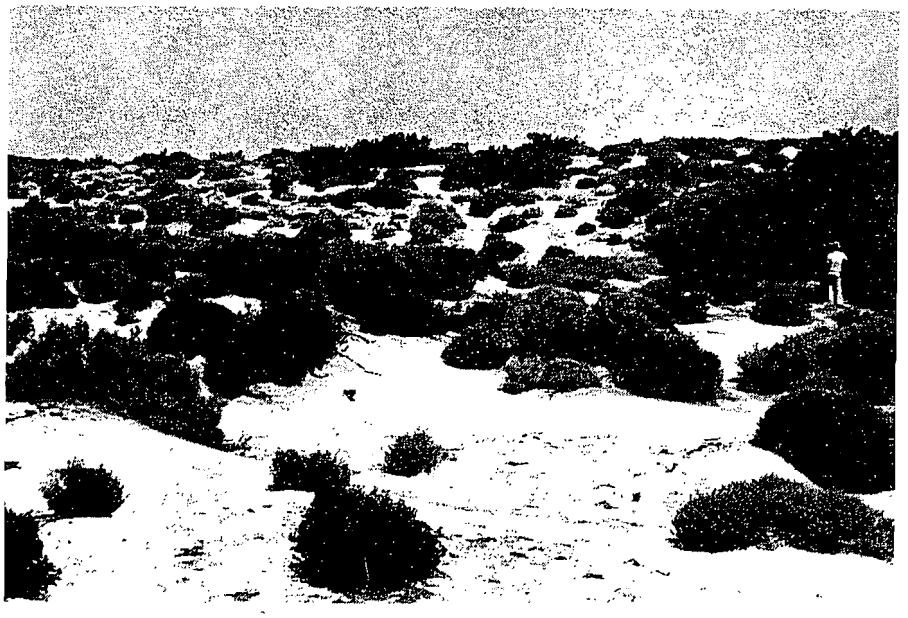

Fig. 2. Plot 3. Looking north. Relative abundance of vegetation.

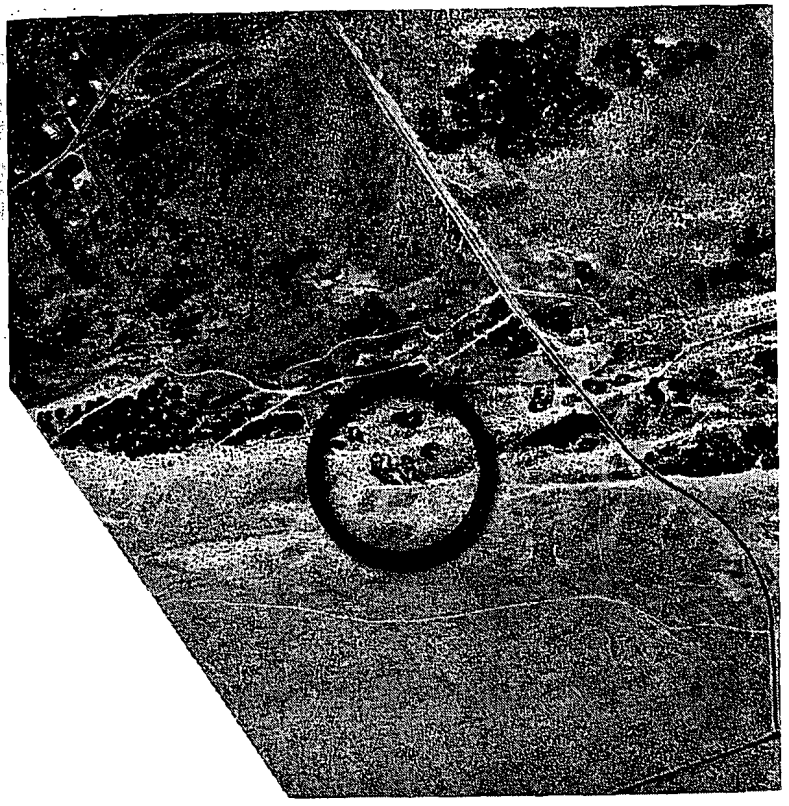

Fig. 1. Plot 3.
Aug. 1979. Relationship and vegetation comparison with surrounding terrain.

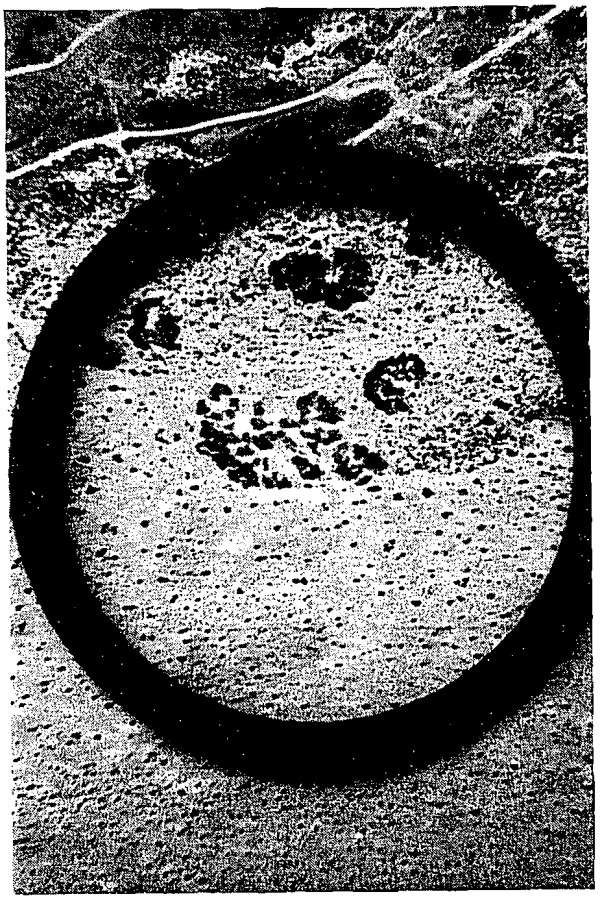

Fig. 2. Plot 3.
Enlargement of above.

Plate 6

Fig. 1. Plot 4. Relative abundance of vegetation and intervening sandy substratum, looking toward the northwest. Dead mesquite in foreground.

Fig. 2. Plot 4. Viewed toward the southeast. Russian thistle, dead mesquite, and windward type deposits.

Plate 7

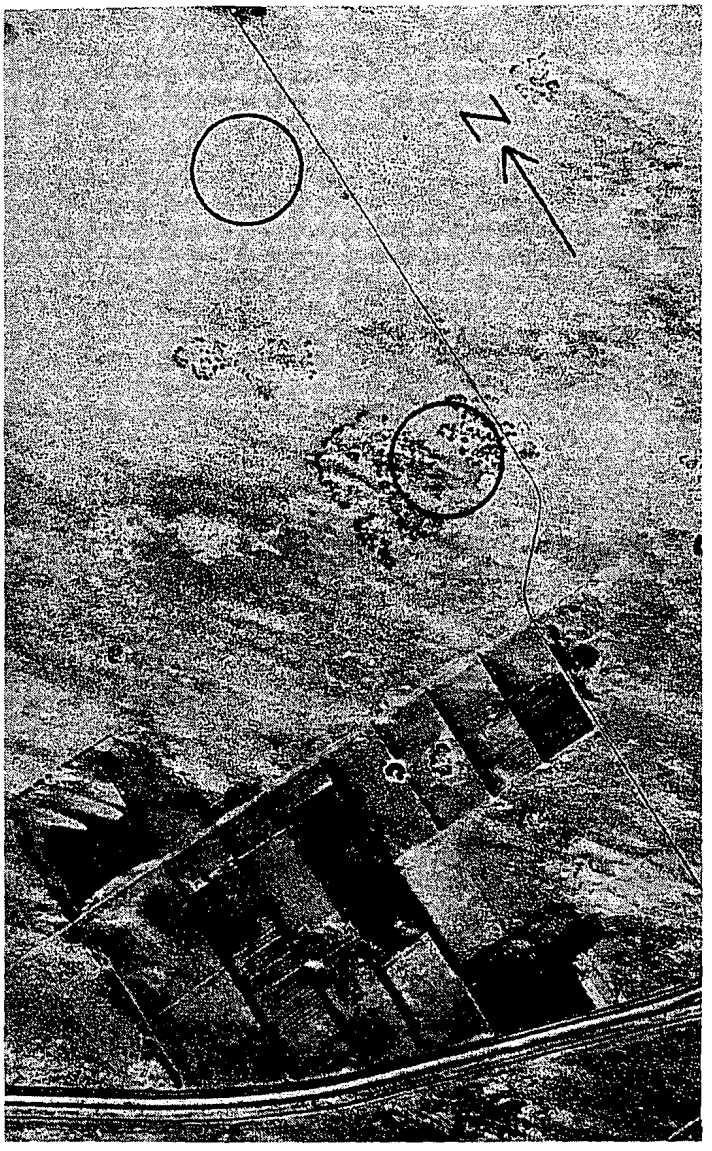

Fig. 1. Plots 4 and 2. March 1960. Relationships with surrounding terrain.

Fig. 2. Plot 4. Enlargement of above.

are pictured on Plate 6, Figures 1 and 2. This was the only plot containing Russian thistle (Salsola kali), but which is even more abundant in the more southeasterly portion of the valley. The general relationship of Plots 2 and 4 is depicted in Plate 7, Figure 1, with an enlargement of the Plot 4 area provided in Figure 2.

The apparent similarity of paired plots 5 and 6 with respect to biological and aeolian sand transport characteristics in 1950, prior to establishment of an intervening barrier is reflected in Plates 8 and 9, and again 10 years later in Plates 10 and 11. Despite not being readily discernable on 1979 aerial photos, Plate 12, marked visual differences now exist on the ground as exhibited by Plates 13 and 14.

Although not as evident as depicted in Plate 12, Figure 2, some minor ORV or other human disturbance was observed at all plots. None appeared to be recent or likely to have caused any significant change in Uma abundance or the sand characteristics studied.

Plate 15, Figure 1, is a panorama of the central portion of the valley showing the relative positions of Plots 1, 5 , and 6.

Surface and deposit conditions for Plots 7 and 8 are shown in Plates 16 and 17. Plates 18 and 19 reflect the general environmental similarity of the two paired plot locations prior to shielding of Plot 8.

Plate 8

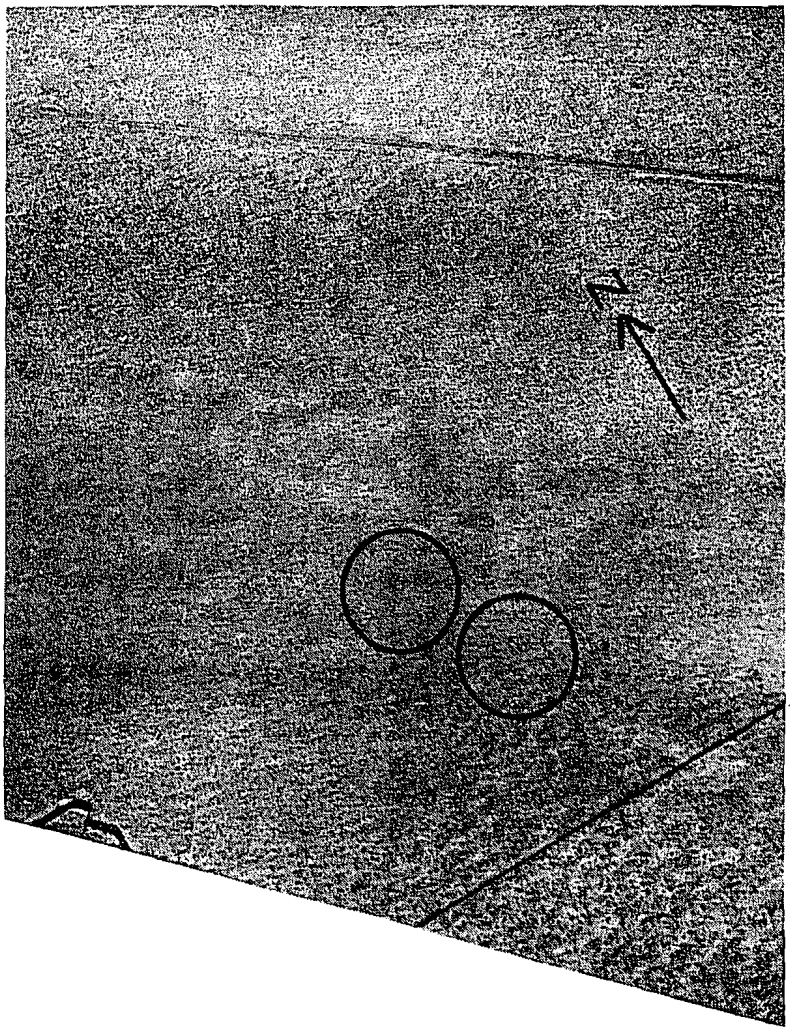

Fig. 1. Plots 5 and 6. December 1950.
Homogeneity of plots under natural conditions.

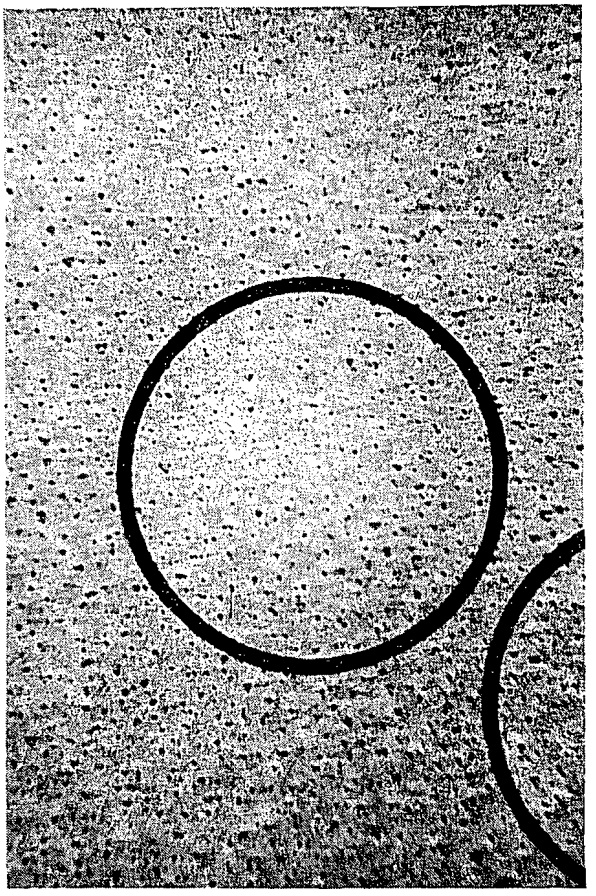

Fig. 1. Plot 5.
Enlargement of Plate 8,
Fig. 1.

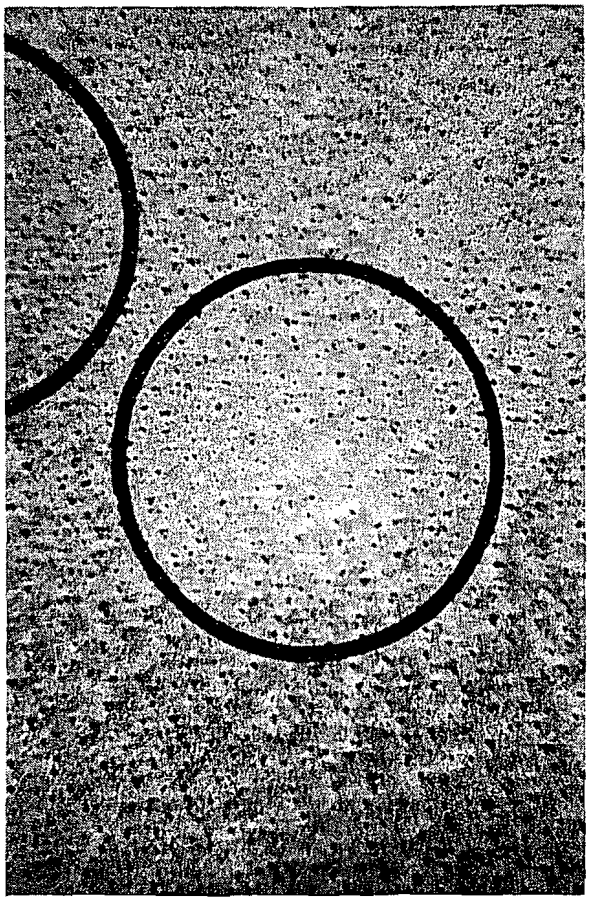

Fig. 2. Plot 6.
Enlargement of Plate 8,
Fig. 1.

Plate 10

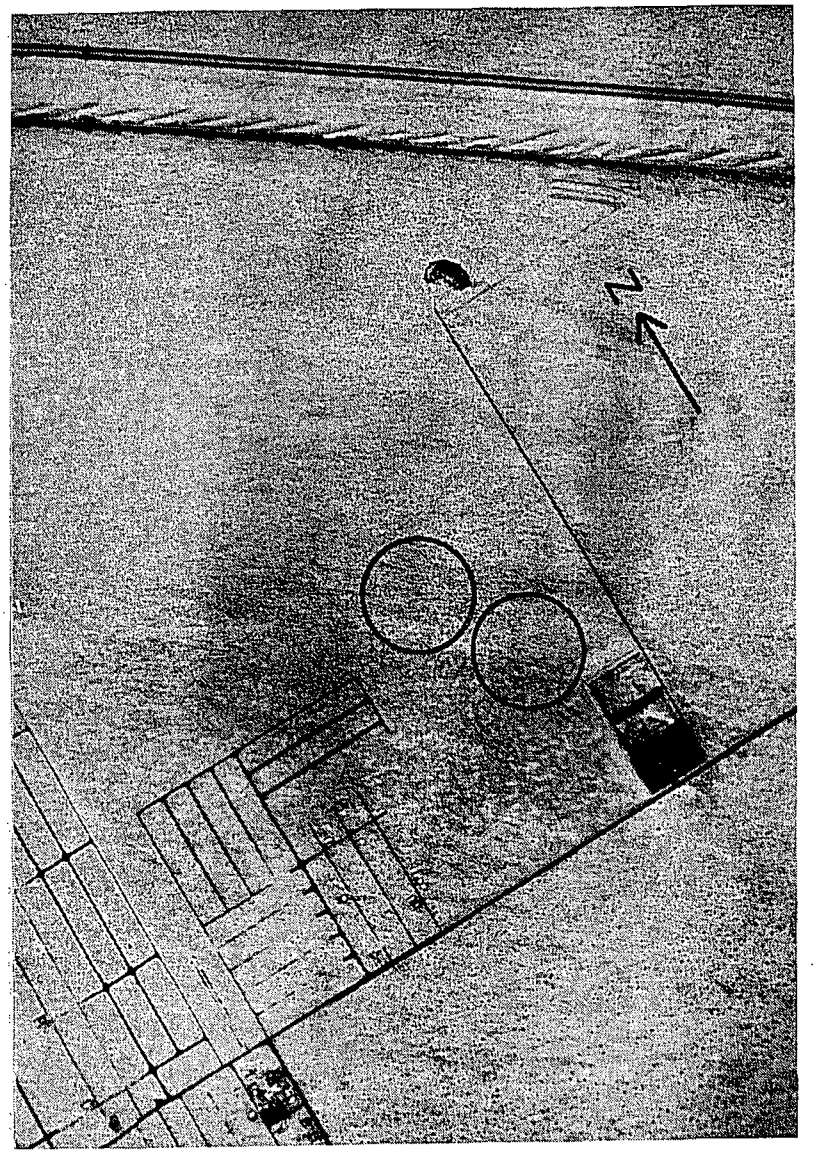

Fig. 1. Plots 5 and 6. March 1960.

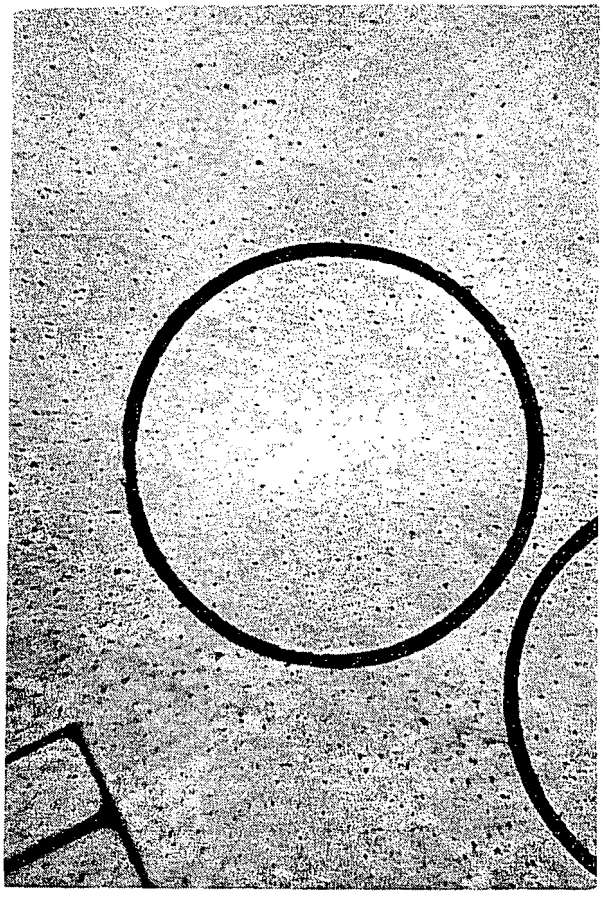

Fig. 1. Plot 5.
Enlargement of Plate 10,
Fig. 1.

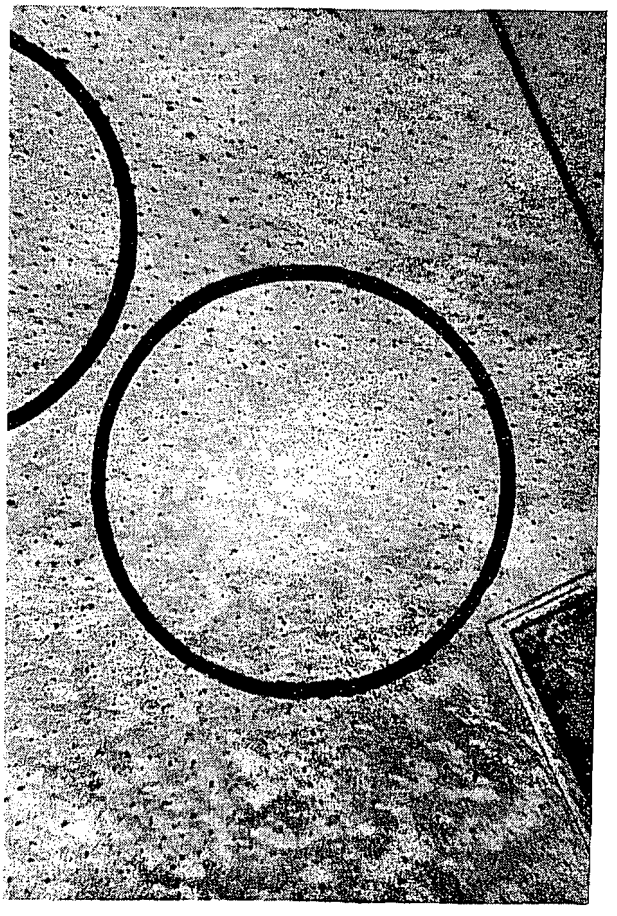

Fig. 2. Plot 6.
Enlargement of Plate 10,
Fig. 1.

Plate 12

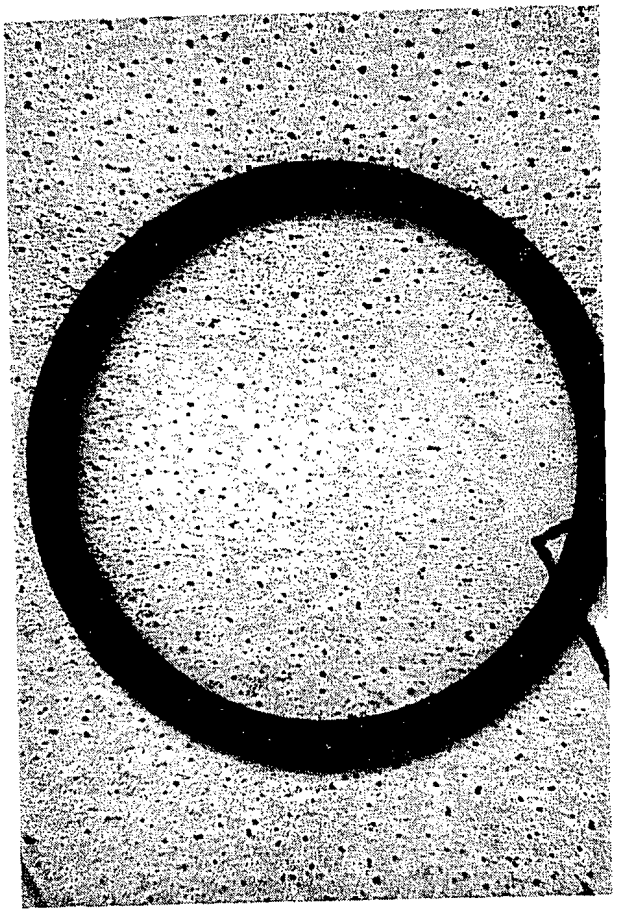

Fig. 1. Plot 5.
Aug. 1979.

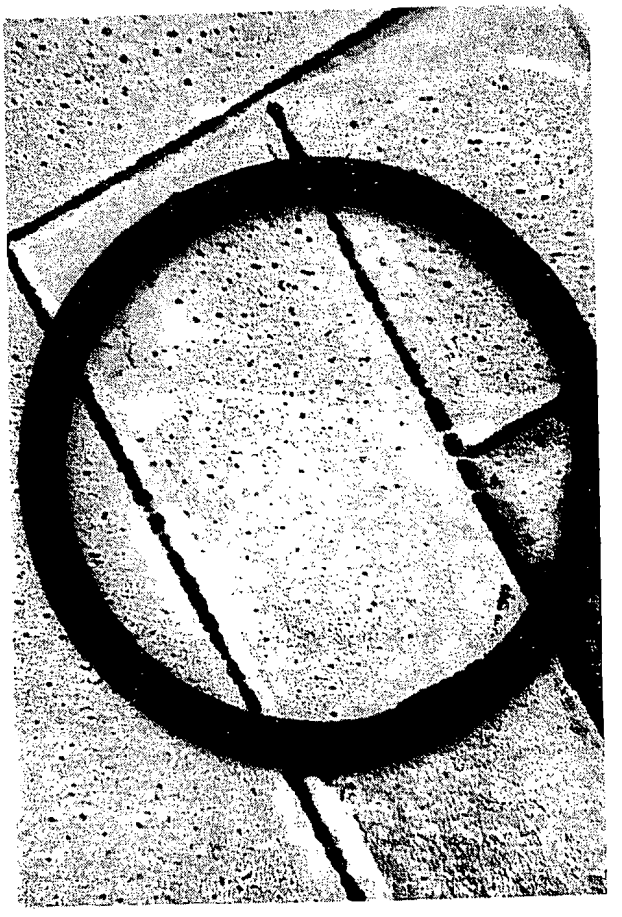

Fig. 2. Plot 6.
Aug. 1979.

Fig. 1. Plot 5. Viewed toward the northwest. Typical lee hummock deposit.

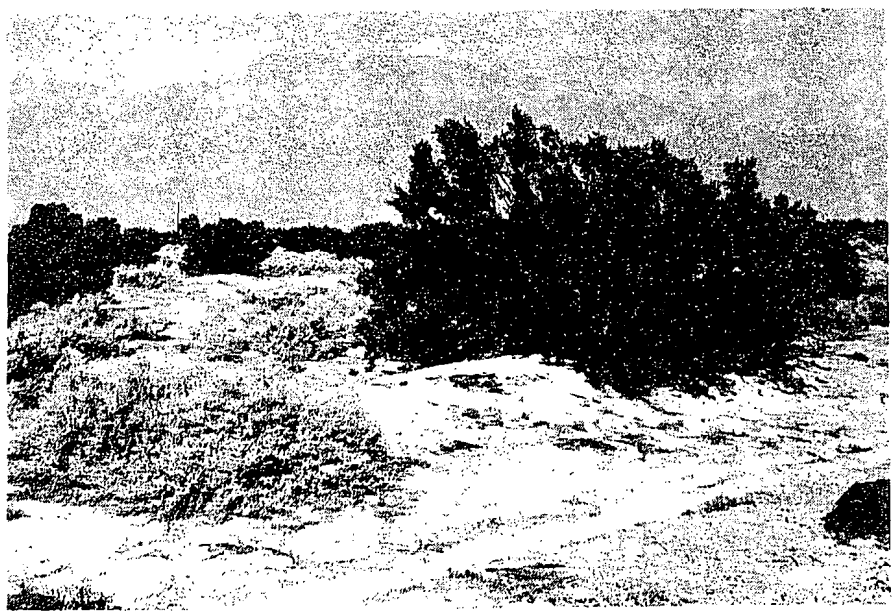

Fig. 2. Plot 5. Looking west at lee hummock deposit, intervening vegetation, and substratum. ORV tracks in foreground.

Fig. 1. Plot 6. Looking east from tamarisk tree induced sand deposit, elevated approximately 15 feet.

Fig. 2. Plot 6. Near total depletion of hummock deposit, the result of seven years without receipt of new sand.

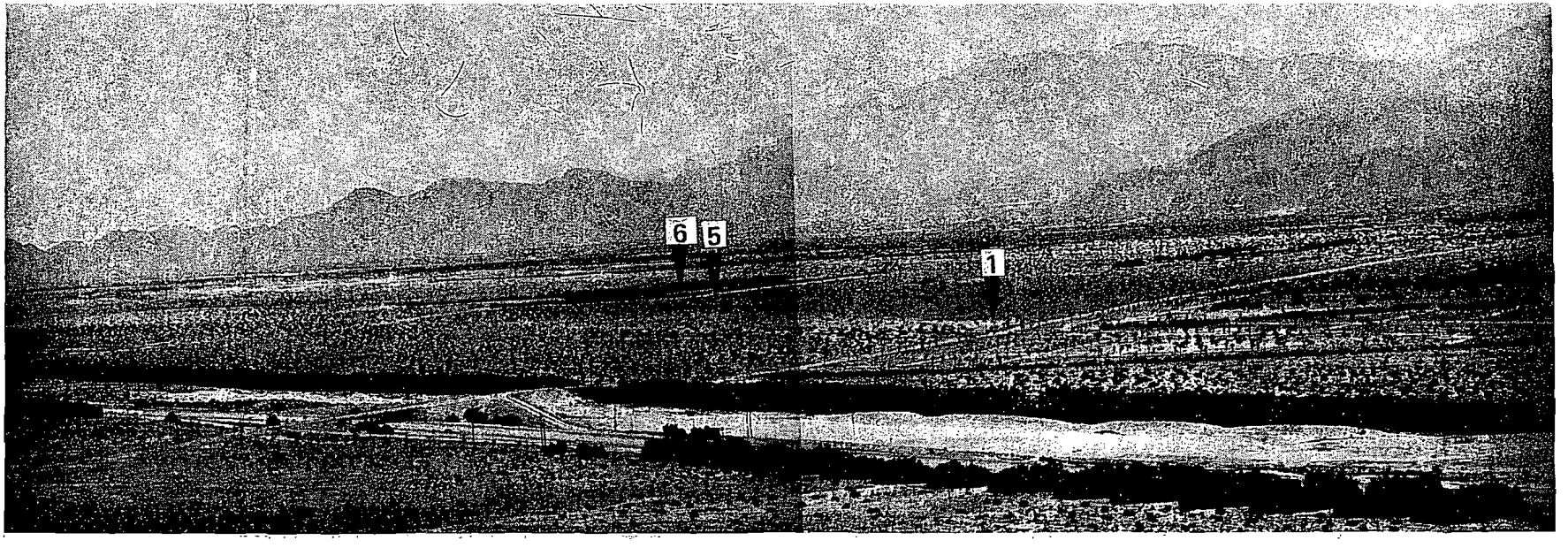

Fig. 1. Panorama of central portion of valley from Flat Top Mtn. Plots 1, 5 and 6 indicated. Dark Surface character due to over-abundance of vegetation and lack of sand transport activity in recent years.

Fig. 1. Plot 7. Typical lee hummock and intervening sandy substratum. Viewed toward the northwest.

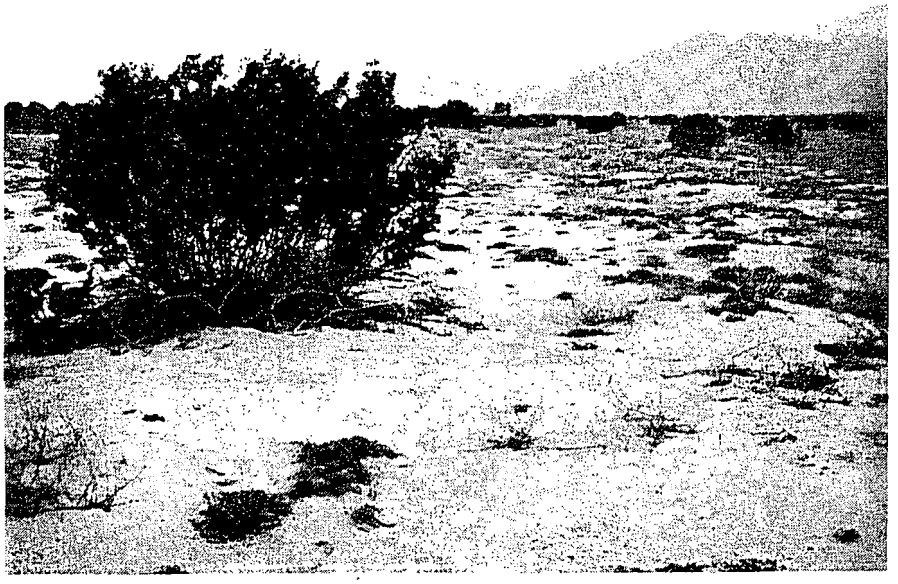

Fig. 2. Plot 7. Looking southeast. Windward view of same creosote centered in Fig. 1, above. Barren lower portion reflects prior existance of more extensive hummock deposit. Depletion here has resulted from approximately four years without receipt of new windblown sands.

Fig. 1. Plot 8. More extensive sand depletion than at Plot 7. Complete absence of windward deposit. Tree row in background is downwind of the plot.

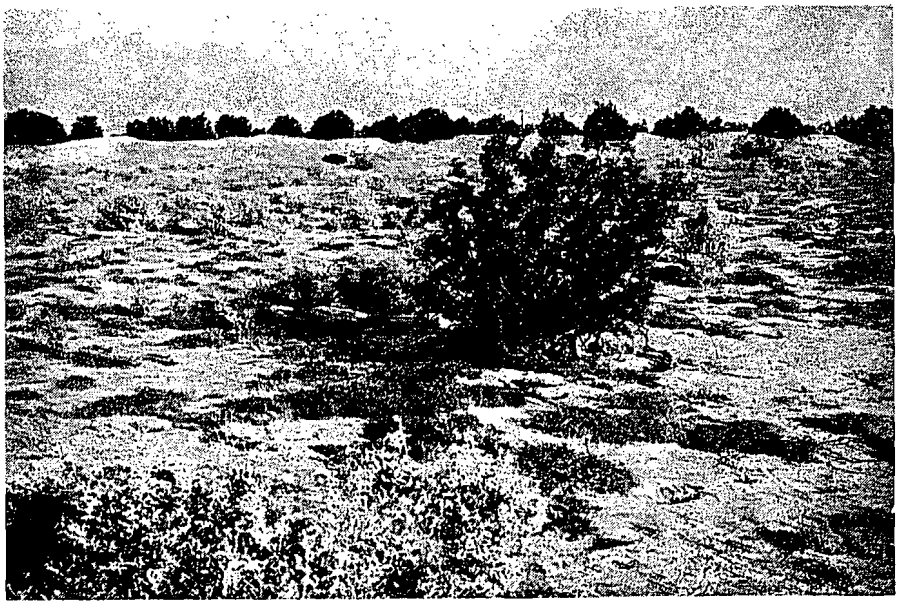

Fig. 2. Plot 8. View of same creosote from downwind. Extensive lizard tracks (not Uma) in foreground. Tamarisk tree row shielding this plot from receipt of new sand for approximately twelve years, with resulting deposits, in background.

Plate 18

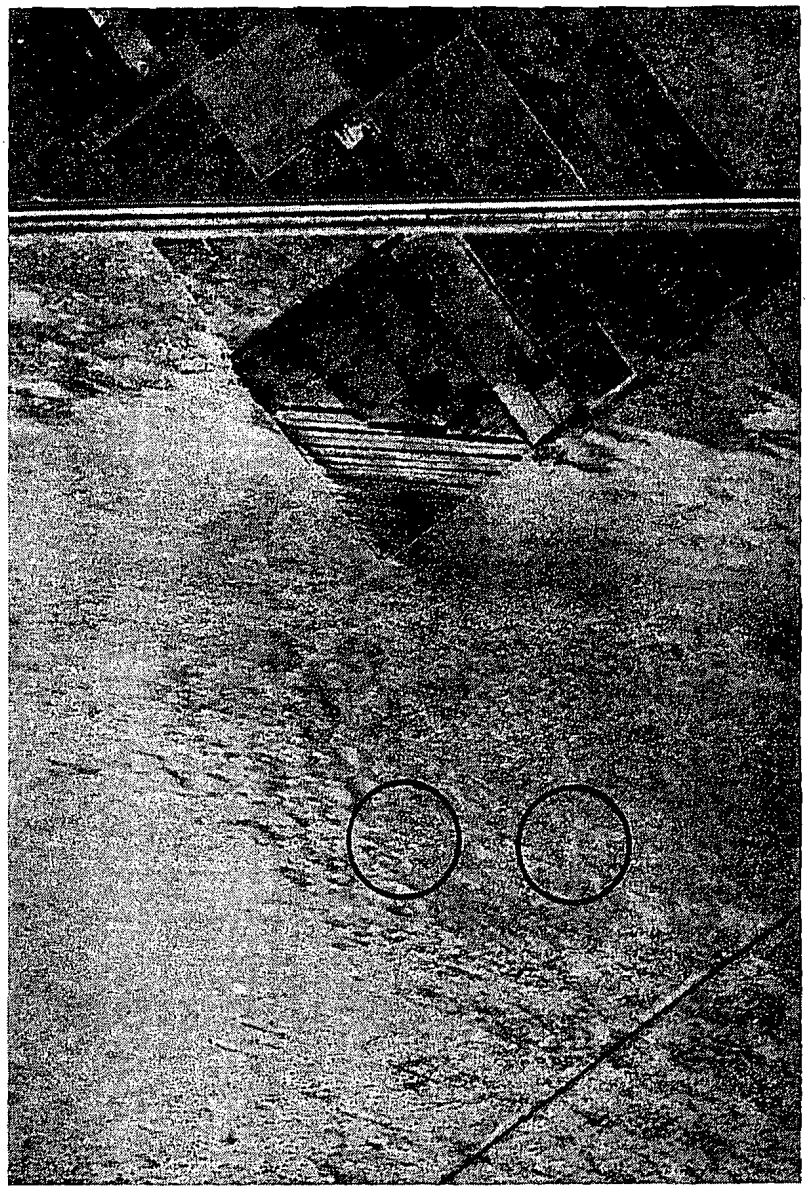

Fig. 1. Plots 7 and 8. March 1960. Similarity of aeolian sand and biological conditions prior to downwind site being shielded from natural receipt of new sand.

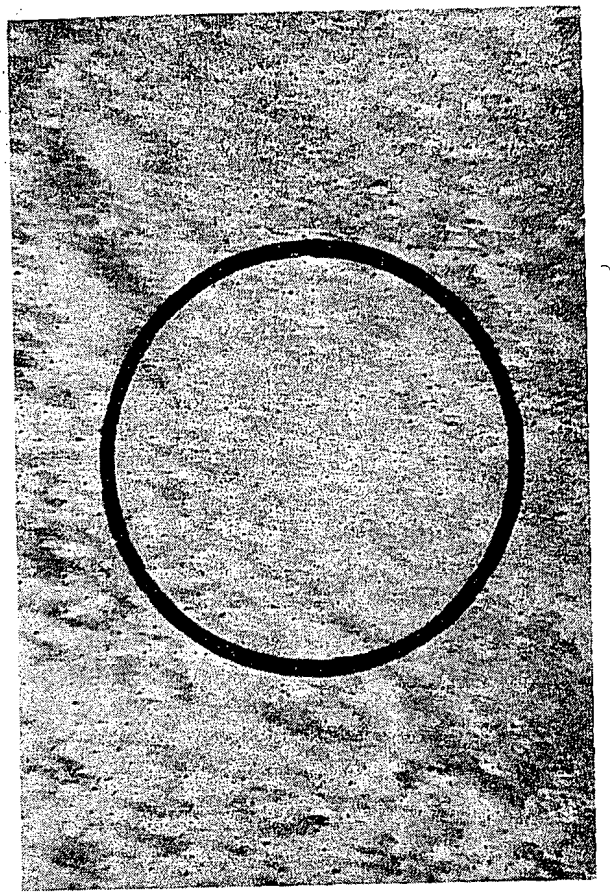

Fig. 1. Plot 7.
Enlargement of Plate 18,
Fig. 1.

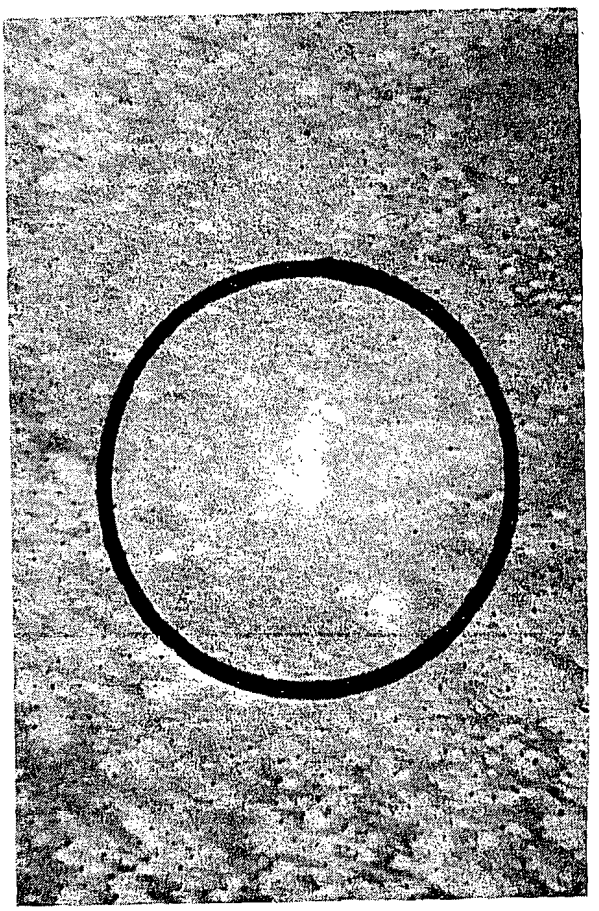

Fig. 2. Plot 8.
Enlargement of Plate 18,
Fig. 1.

Extensive hummocks of recently supplied sands in a sand veneer setting found at Plot 9 (Plate 20, Figures 1 and 2) were conspicuously absent at shielded Plot 10, as evidenced by Plates 21 through 23. Plot 10, under natural conditions without the presence of the upwind tamarisk tree barrier would have been subject to similar aeolian sand transport conditions and have displayed the same deposit characteristics. Average diameter of the pebbles comprising the surface shown in Plate 23, Figure 1 is approximately 6.5 mm, representing the upper limit of individual grains movable by the high energy wind regime at this location. The general relationship and similarity of these paired plots is shown in Plates 24 and 25.

Turner et al (1980) lists the more common plants found at each of the ten plots.

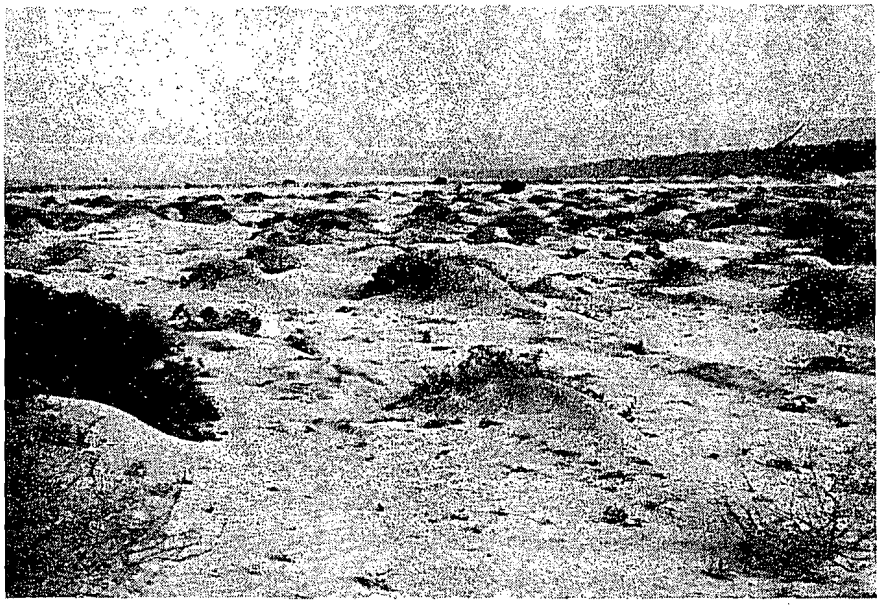

Fig. 1. Plot 9. Extensive, freshly supplied hummocks. SPRR tamarisk trees and Garnet Hill in background.

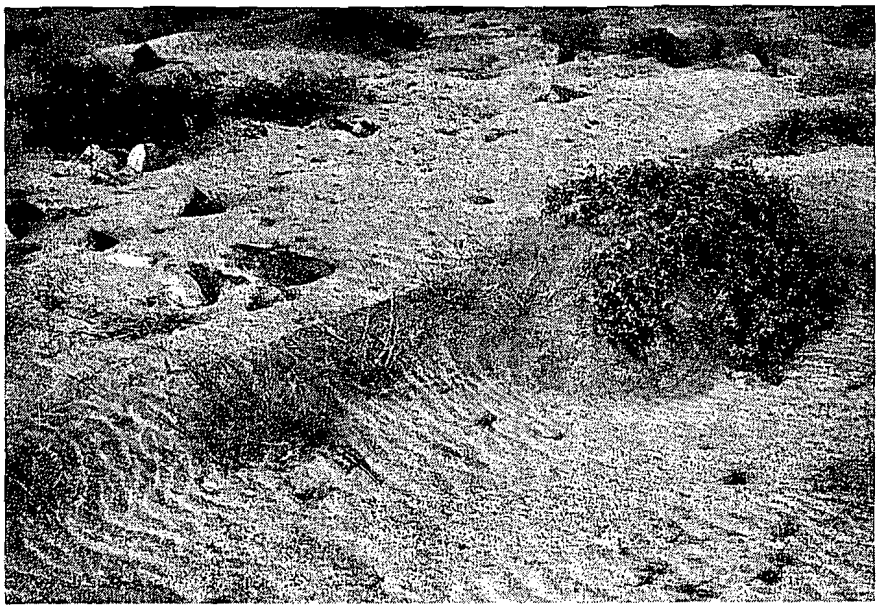

Fig. 2. Plot 9. Difference between finer hummock and coarser intervening deposits. Also, underlying alluvial substratum indicated by rocks.

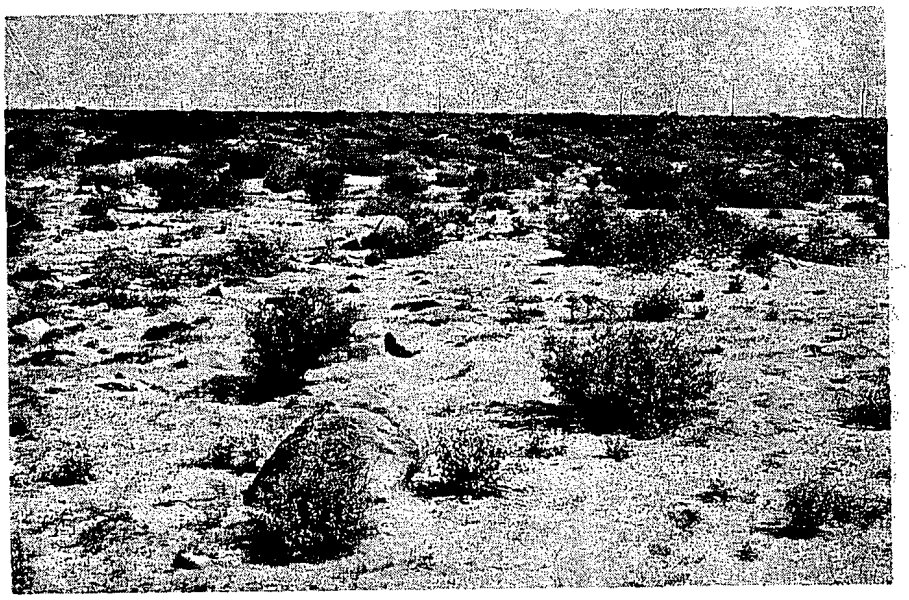

Fig. 1. Plot 10. Absence of hummock deposit, the result of seventeen years of depletion and surface stabilization without receipt of new sand.

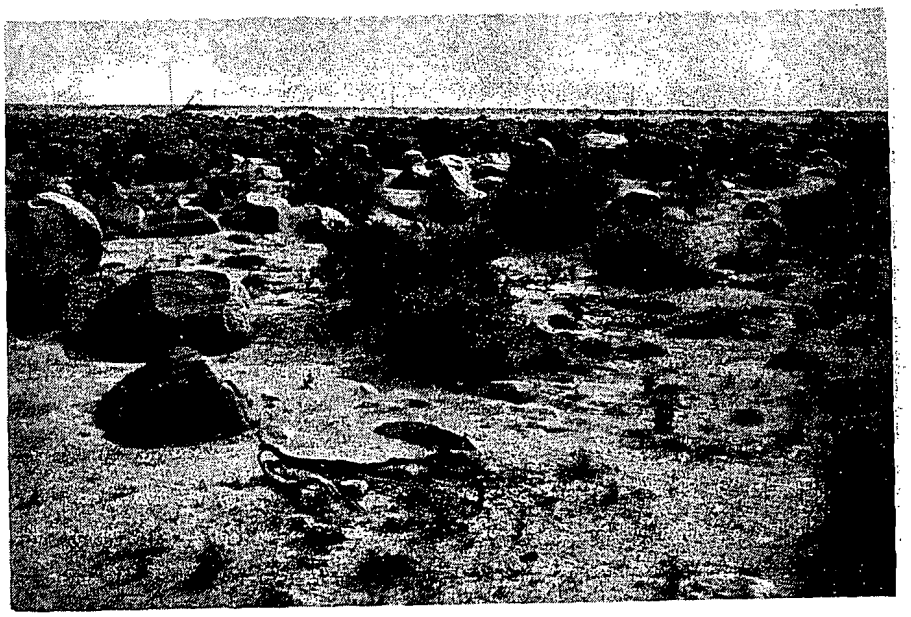

Fig. 2. Plot 10. Northeast portion of plot. Larger rocks, transported by floodwaters thousands of years ago and having remained stationary since, reflect extensive unidirectional sand abrasion.

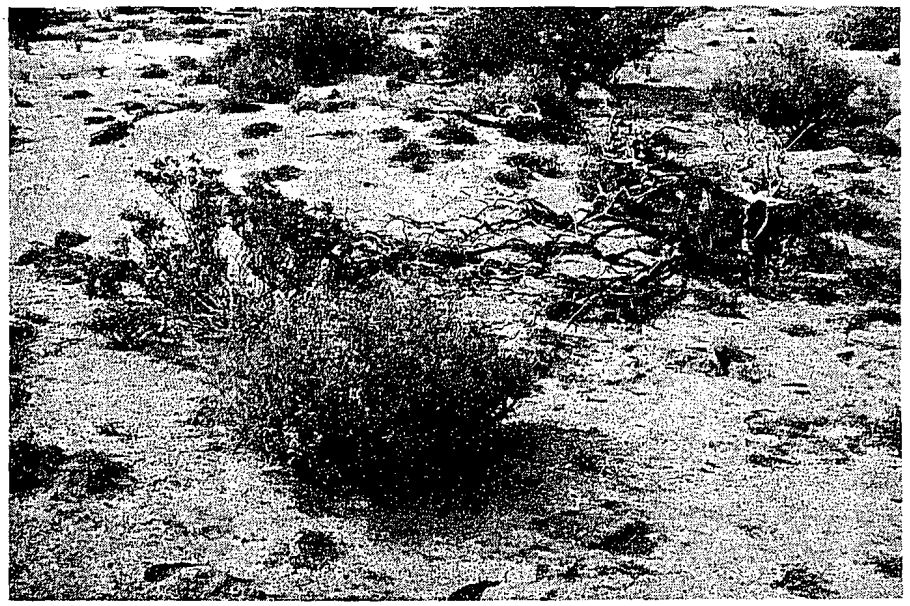

Fig. 1. Plot 10. Coarse, non-sandy substratum. Surface extremely stabilized.

Fig. 2. Plot 10. Miniature hummock deposit. Typical surface character.

Fig. 1. Plot 10. Closeup of uniform pebbly surface.

Fig. 2. Plot 10. Alluvial rock fragments and aeolian transported sediments comprise a highly stabilized surface. This and the above surface are predominant at Plot 10.

Plate 24

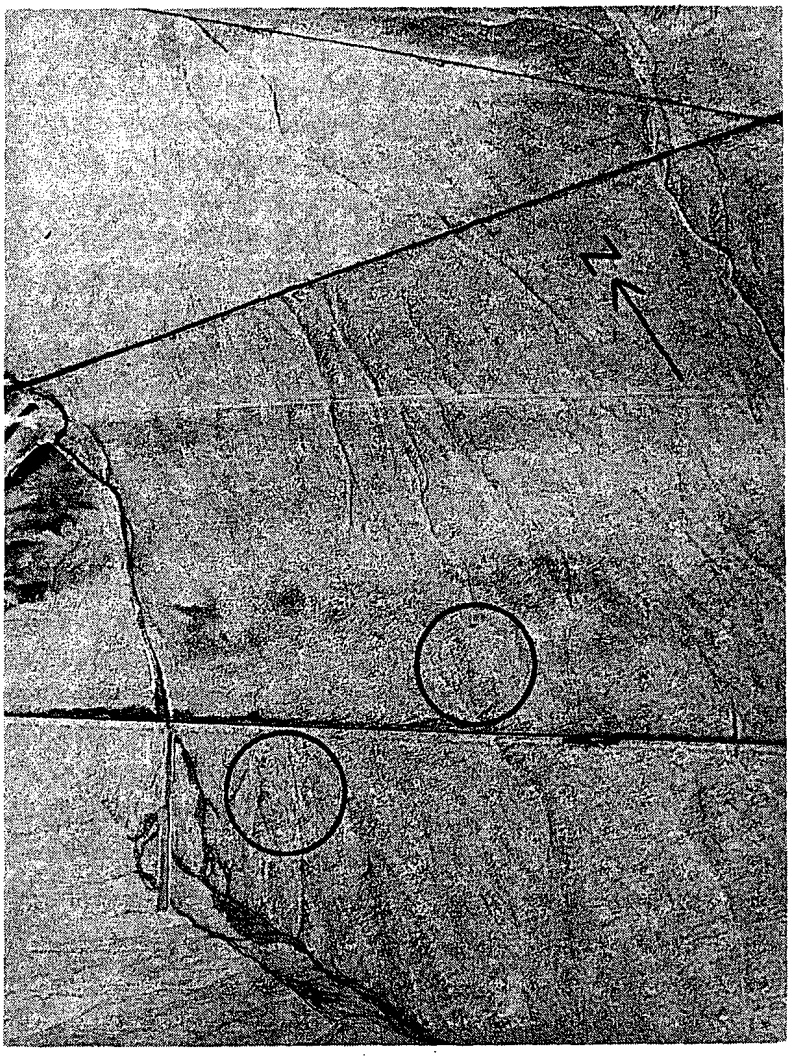

Fig. 1. Plots 9 and 10. Dec. 15, 1950. Basic alluvial character of plots. Apparent equality of aeolian sand transport and biological characteristics. Railroad, running between the plots, was laid in 1879. Comprised only of trackage on a slightly raised bed, it constituted no impediment to aeolian sand transport at the time of this photo.

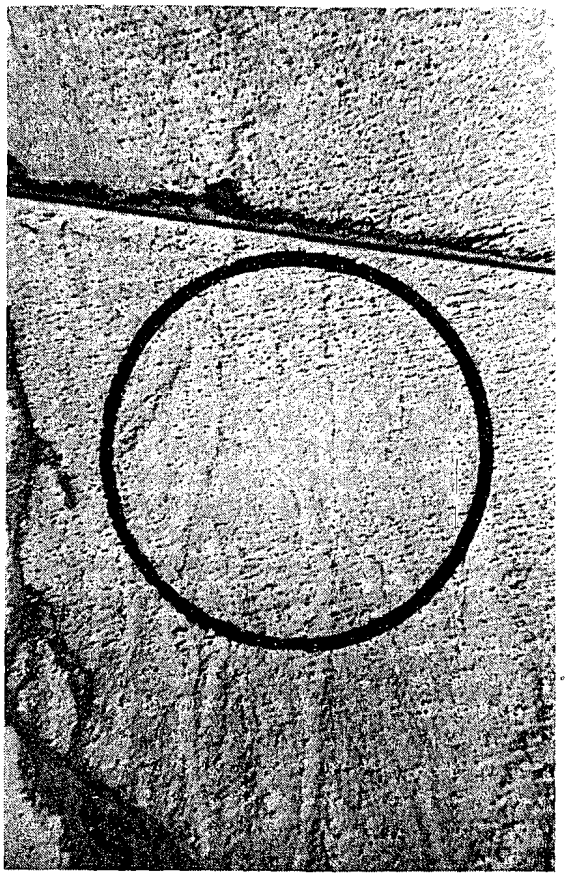

Fig. 1. Plot 9.
Enlargement of Plate 24,
Fig. 1.

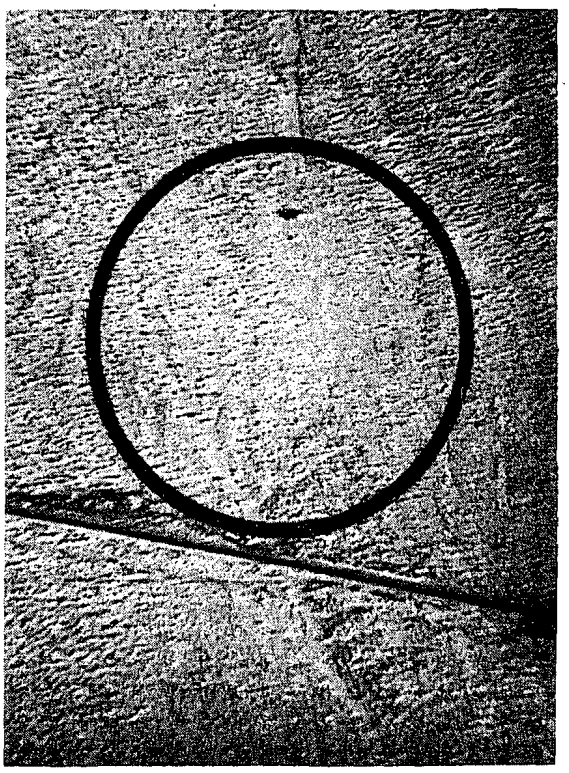

Fig 2. Plot 10.
Enlargement of Plate 24,
Fig. 1.

Tests and Procedures

Three basic textural characteristics of existing sand deposits were examined -- penetrability, size gradation and surface coarseness. Within each plot tests were conducted and samples taken at four locations selected as representative of (1) windward and (2) lee hummock or other vegetation induced deposits, and of (3) average, or most common, and (4) coarsest intervening sandy substrates. Semiquantitative visual estimates were made of the relative area within each plot represented by each of the four sampling locations, plus any non-sandy substrates.

Field work was performed during April and May 1980, with some photographs being taken in June. Climatic conditions were typical for the time of year. Daytime high temperatures ranged from approximately 27°C to above 49°C, with nighttime lows between 0°C and 16°C. No rain fell during the period. For purposes of this study, near-surface deposits could be considered essentially dry during the heat of the day when Uma are active, with little or no variation in moisture content throughout the region. Although occasional strong winds occurred, no significant sand transport took place.

Windward hummock test locations were selected directly upwind and approximately 1 m from the

vegetation responsible for the deposit. Lee locations were generally selected slightly to the south of center, within 1 to 2 m of the vegetation. Intervening sandy substrate locations were generally situated near the center of relatively open areas where deposition was least influenced by vegetation. Test locations tended to be centrally located within the plots.

Neither Plots 3 nor 10 contained typical windward hummock deposits which could be considered comparable to the remaining plots. Substitute microenvironments were evaluated, as noted in the results.

Penetration tests consisted of releasing a standard 16 oz surveyors' plumb bob* from heights of 30.5 cm (1 ft) and 0 cm (the point just touching the surface before release). Three drops, each into an area not previously disturbed, were made from both heights at each test location. Drops resulting in the plumb bob being tilted more than approximately 20° from vertical were rerun, as were those that occasionally penetrated into theretofore undiscovered burrows. Penetration depths were measured to the nearest 0.1 cm from the tip, along the side of the plumb bob.

Samples were extracted with a closed-end, 6.35 cm diameter cylinder, which was depressed vertically

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* A. Lietz Co., manufacturer; made of brass, with a steel point slightly rounded to a radius of approximately 1 mm, and having a maximum diameter of 3.8 cm located 10.2 cm from the tip.

to a depth of 8 cm. Sand was then scooped away from the side, and the bottom of the cylinder covered with a flat hand-shovel before extraction. At each location, four such samples were taken and combined, providing a total sample weight of approximately 1.5 kg.

The coarsest intervening sandy substratum surfaces were sampled using 3.8 cm wide Scotch clear plastic tape placed over a rectangular, 2.5 cm by 8 cm opening cut in a thin sheet metal plate. Upon being pressed firmly to the surface, the plate was lifted and the tape, with all contacted grains intact, peeled away and transferred to a small card.

Visual estimation of the representative areas within each plot was aided by the 25 m staked grid.

Laboratory and office procedures included penetration tests on the extracted samples, grain size analysis, and measurement of the surface samples. Penetration tests were performed in an attempt to elicit some measure of the influence of the near-surface crust on the field penetration test results. For each sample, any crustal deposits which happened to have survived being extracted and transported were broken up by hand. The sample was then poured slowly into a cylindrical container, 19.5 cm high and 7.75 cm in diameter, the top surface gently leveled, and the sand volume determined by measuring from the top down to the surface to the nearest 0.1 cm. A penetration test was then made from the 30.5 cm

height and the result recorded, as in the field. Some consolidation of the sample was then induced by slightly pounding the container down on a hard surface, a determination made of the new reduced volume and another penetration test performed. Yet additional consolidation was induced and the process repeated until a minimum of 4 data sets were obtained. The sample was then transferred to another container and repoured slowly into the test cylinder, and the measurement - test process repeated a minimum of 4 times for the 0 cm drop. The ratios of the consolidated volumes to the loose poured volume were later calculated and these relative volumes plotted against the penetration test results for each of the two drop heights. Curves were drawn through the two sets of points and the penetrations associated with 0.90 relative volume noted. The corresponding field penetration reading was then subtracted from this value and the result recorded as the crustiness index. The relative volume of 0.90 (representing a 10% reduction in volume due to consolidation) was arbitrarily selected as the maximum consolidation that might reasonably be expected to occur under natural conditions in the field. Thus, it was believed that comparison of the field penetrations with those into the same sand at 0.90 relative volume might yield some indication as to the degree of influence the near-surface crust presently in existence has upon the field

penetration test results at each location.

Grain size (granulometric) analysis was performed on all 40 samples. Samples, unwashed, were split and sieved in accordance with current American Society for Testing Materials (ASTM) procedures, with U.S. Standard Sieve Sizes of 1/2", 3/8", 1/4", #4, #8, #12, #16, #30, #40, #50, #80, #100 and #200 being used. Results were plotted and cumulative gradation curves drawn using arithmetic scale for percentage finer by weight and log scale for size in mm. More refined analysis involving the use of additional sieves and probability scale in lieu of arithmetic scale, as encouraged by Folk (1966) and others, was viewed as unnecessary for the purpose of this study.

Mean grain size diameter was determined for each sample using the McCammon (1962) formula

$$\underline{d}_{mean} = \frac{\phi_{10} + \phi_{30} + \phi_{50} + \phi_{70} + \phi_{90}}{5}$$

$$\text{with } \phi_p = -\log_2 \underline{d}_p$$

where $\underline{d}_p$ is the grain size in mm at percentile p, as originally proposed by Krumbein (1934).

For comparison with Norris (1958) and Beheiry (1967) data, median grain diameter, or $\underline{d}_{50}$ (being that which has one half the grains, by weight, finer, and one half coarser) was noted directly from the cumulative curve for each sample.

Subsequent anaylses made in conjunction with the

companion study solicited examination of diameters associated with other percentiles, with $\underline{d}_{75}$ for the lee deposits eventually found to have significant correlative value (Turner et al. 1980).

Despite more sophisticated techniques now available, for comparison with earlier studies, sorting coefficient, a measure of dispersion around central tendency, was calculated as

$$S_o = \sqrt{\frac{\underline{d}_{75}}{\underline{d}_{25}}}$$

long used as the sorting parameter for sediments (Folk 1966).

Percentages finer than 0.1 mm and coarser than 1.0 mm, noted by Norris (1958), Pough (1970) and England and Nelson (1976) as having correlation with Uma behavior, were taken directly from the gradation curves.

Surface coarseness values were determined as the average of the apparent diameter of the 5 largest grains displayed in each surface coarseness sample. This was accomplished by measuring the apparent length and width of the 8 largest individual grains, as viewed through the clear plastic tape. Measurements were made to the nearest 0.2 mm. aided by 8X magnification. The average of the length and width was considered as the apparent diameter of the grain, with the average of the 5 largest provided as a

measure of surface coarseness. Such a measure has precedents with Pettijohn (1957), Schlee (1957), Pelletier (1958) and Towe (1963) using variations in the size of largest pebbles (or averages of several largest) for determining direction and distance of transport of deposited sediments. The maximum size of deposited surface grains bears relationships with the energy of the transporting medium and the depositional environment. When considered in conjunction with underlying average or long-term deposits, it is believed by this researcher to be an indicator of the degree of surface stabilization which has occurred since discontinuance of the normal supply of sand to the transporting winds. The process of surface stabilization has not received sufficient study to suggest a "best" indicator. Nonetheless, for purposes here, a surface stabilization index for each plot was calculated as being the ratio of the apparent diameter of the coarsest surface grains to the average of the mean grain size diameters of the typical and coarsest intervening substrate deposit samples, the average being weighted according to the relative plot area represented.

Lastly, weighted averages were calculated for each plot based upon the relative area represented by each of the 4 microenvironments for all of the test results except the surface coarseness and surface stabilization measures.

Results and Discussion

Basic aeolian sand transport data and information for each of the plots, and area percentages of plots represented by each of the microenvironments are provided in Tables 1 and 2. Tables 3 through 13 present data derived from the various field and laboratory studies described in the previous section. As noted, these data were developed primarily for analysis with the results of the companion biological field study, which are presented here, for convenience, in Table 14 (Turner et al 1980). Clearly, the most important outcome of the combined studies was the difference in *Uma* densities observed in the paired plots, as reflected in Table 14. The significance of these findings is discussed in Turner et al (1980) and further under Shielding in this report.

Overall, data developed in this study are quite consistent with comparable data from earlier reports. Median grain size values (Table 8) compare favorably with those of Norris (1958) and Beheiry (1967). Norris shows diameters of 0.285 mm and 0.120 mm for the finest sands at two locations, the first situated closest to our Plot 5, and the second, with mesquite cited as the predominant vegetation, most closely associated with our Plot 4. Plots 5 and 4 reflect median diameters of 0.22 and 0.14 mm, respectively.

TABLE 2

Area Percentage of Plots by Deposit and Substrate Types

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum
	Windward	Lee	Typical	Coarse	
1	15	30	15	10	30
2	15	10	45	10	20
3	20[a]	45	20	15	--
4	20	40	25	10	5
5	10	20	50	20	--
6	5	10	70	15	--
7	8	17	60	15	--
8	2	8	80	10	--
9	15	30	35	15	5
10	2[b]	1[c]	5	2	90

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 3

Penetrability — 1' Drop Field Test Penetration in Centimeters

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Penetrability #2 -- (cm) (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	7.63	9.07	7.00	5.47	--	7.80	70%
2	5.40	5.23	6.00	5.43	--	5.72	80%
3	7.33[a]	7.70	7.37	6.90	--	7.44	100%
4	5.70	6.97	5.83	5.43	--	6.24	95%
5	7.33	6.43	5.97	6.53	--	6.31	100%
6	7.07	6.93	7.10	5.83	--	6.89	100%
7	5.70	8.80	6.33	7.20	--	6.83	100%
8	7.27	5.70	7.00	6.40	--	6.84	100%
9	5.83	7.07	6.30	5.57	--	6.35	95%
10	5.85[b]	5.63[c]	3.93	5.13	--	4.73	10%

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 4

Penetrability — 0' Drop Field Test Penetration in Centimeters

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Penetrability #1 -- (cm) (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	4.37	4.47	4.07	2.80	--	4.12	70%
2	2.67	2.13	2.47	3.10	--	2.54	80%
3	4.93[a]	4.23	4.37	4.27	--	4.40	100%
4	2.40	4.47	2.50	2.60	--	3.32	95%
5	3.00	4.17	2.77	4.83	--	3.49	100%
6	2.80	3.60	3.47	2.63	--	3.32	100%
7	2.53	4.10	2.23	3.90	--	2.82	100%
8	3.60	3.87	3.87	2.87	--	3.76	100%
9	3.83	4.47	3.70	3.23	--	3.89	95%
10	1.27[b]	1.10[c]	2.07	2.67	--	1.93	10%

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 5

Crustiness Index — Derived From 1' Drop Penetration Tests

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Crustiness Index #2 (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	-1.33	-3.07	-0.70	0.53	--	-1.632	70%
2	0.90	1.07	0.30	0.97	--	0.593	80%
3	-0.33[a]	-1.70	-1.57	-1.00	--	-1.295	100%
4	0.30	0.13	0.37	0.67	--	0.286	95%
5	-0.73	-0.43	0.33	-0.53	--	-0.100	100%
6	-1.47	-1.33	-1.00	0.67	--	-0.806	100%
7	0.50	-2.60	-0.03	-0.90	--	-0.555	100%
8	-0.87	1.20	-0.40	-0.40	--	-0.281	100%
9	0.77	-0.67	-0.20	0.43	--	-0.096	95%
10	-0.15[b]	1.77[c]	2.77	0.47	--	1.622	10%

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 6

Crustiness Index — Derived From 0' Drop Penetration Tests

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Crustiness Index #1 (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	0.53	0.63	1.03	1.60	--	0.833	70%
2	2.13	3.17	2.63	1.70	--	2.488	80%
3	1.27[a]	0.67	0.33	0.33	--	0.671	100%
4	2.40	1.23	2.60	3.10	--	2.034	95%
5	1.80	0.23	2.33	-0.33	--	1.325	100%
6	1.80	0.80	0.73	1.87	--	0.962	100%
7	2.67	0.90	2.67	1.10	--	2.134	100%
8	1.60	1.13	1.23	1.63	--	1.269	100%
9	1.37	-0.07	0.80	1.17	--	0.674	95%
10	3.43[b]	3.80[c]	2.03	1.73	--	2.427	10%

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 7

Mean Grain Size Diameter (mm)

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Mean Diameter (mm) (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	0.26	0.31	0.34	0.49	--	0.33	70%
2	0.30	0.29	0.29	0.30	--	0.29	80%
3	0.19[a]	0.26	0.36	0.38	--	0.28	100%
4	0.18	0.14	0.22	0.20	--	0.18	95%
5	0.39	0.26	0.42	0.37	--	0.38	100%
6	0.28	0.29	0.28	0.36	--	0.29	100%
7	0.26	0.29	0.33	0.33	--	0.32	100%
8	0.24	0.47	0.29	0.40	--	0.31	100%
9	0.31	0.22	0.33	0.54	--	0.32	95%
10	0.37[b]	0.20[c]	0.13	0.67	--	0.29	10%

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 8

Median Grain Size Diameter (mm)

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Median Diameter (mm) (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	0.26	0.37	0.42	0.60	--	0.39	70%
2	0.39	0.35	0.32	0.37	--	0.34	80%
3	0.23[a]	0.27	0.43	0.45	--	0.32	100%
4	0.18	0.14	0.23	0.24	--	0.18	95%
5	0.47	0.22	0.72	0.35	--	0.52	100%
6	0.27	0.31	0.28	0.37	--	0.30	100%
7	0.25	0.32	0.45	0.44	--	0.41	100%
8	0.24	0.63	0.32	0.62	--	0.37	100%
9	0.34	0.22	0.39	0.56	--	0.36	95%
10	0.33[b]	0.17[c]	0.11	0.99	--	0.34	10%

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 9

Sorting Coefficient

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Sorting Coefficient (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	1.46	1.70	1.83	2.05	--	1.44	70%
2	2.11	1.82	1.88	1.87	--	1.91	80%
3	1.39[a]	1.73	1.64	1.62	--	1.63	100%
4	1.61	1.22	1.65	1.46	--	1.44	95%
5	2.54	1.96	2.58	2.54	--	2.45	100%
6	2.07	2.22	2.18	2.61	--	2.24	100%
7	1.69	1.66	1.98	2.08	--	1.92	100%
8	1.67	1.21	2.07	2.21	--	2.01	100%
9	1.83	1.48	2.00	2.78	--	1.93	95%
10	2.89[b]	1.86[c]	1.62	3.37	--	2.25	10%

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 10

% (by weight) Finer than 0.1 mm Diameter

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	% Finer than 0.1mm Diameter (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	6	9	8	5	--	7.6	70%
2	13	10	10	10	--	10.6	80%
3	14[a]	7	9	6	--	8.6	100%
4	16	14	12	12	--	13.7	95%
5	10	10	14	10	--	12.0	100%
6	13	14	14	10	--	13.4	100%
7	9	8	10	10	--	9.6	100%
8	11	6	13	12	--	12.3	100%
9	8	8	12	7	--	9.3	95%
10	13[b]	18[c]	31	12	--	22.3	10%

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 11

% (by weight) Coarser than 1.0 mm Diameter

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	% Coarser than 1.0mm Diameter (Weighted average)	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1	1	3	3	28	--	6.1	70%
2	2	2	1	1	--	1.3	80%
3	0 (a)	1	3	6	--	2.0	100%
4	0	0	0	0	--	0	95%
5	23	4	24	24	--	19.9	100%
6	5	3	7	24	--	9.0	100%
7	2	3	3	4	--	3.1	100%
8	2	3	3	9	--	3.6	100%
9	6	0	9	40	--	10.6	95%
10	29 (b)	6 (c)	6	50	--	19.4	10%

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 12

Surface Coarseness -- Apparent Diameter of Coarsest Surface Grains (mm)

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Portion of total plot represented
	Windward	Lee	Typical	Coarse		
1	--	--	--	3.00	--	10%
2	--	--	--	1.66	--	10%
3	--	--	--	3.26	--	15%
4	--	--	--	1.36	--	10%
5	--	--	--	3.10	--	20%
6	--	--	--	3.18	--	15%
7	--	--	--	2.08	--	15%
8	--	--	--	2.18	--	10%
9	--	--	--	2.86	--	15%
10	--	--	--	8.00	--	2%

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 13

Surface Stabilization Index

Plot	Typical hummock or other vegetative induced deposits		Intervening sandy substrates		Non-sandy substratum	Surface Stabilization Index	Portion of total plot represented
	Windward	Lee	Typical	Coarse			
1						7.50	
2						5.69	
3						8.84	
4						6.35	
5						7.64	
6						10.81	
7						6.30	
8						7.21	
9						7.28	
10						28.14	

(a) Beneath mesquite

(b) Hummock lee - coarse

(c) Hummock lee - fine

TABLE 14

Observed *Uma inornata* Densities[a]

Plot	Density estimate ($n \cdot ha^{-1}$)
1	17.2
2	16.8
3	8.8
4	45.5
5	4.4
6	0
7	43.0
8	0.4
9	45.0
10	0

(a) source: Turner et al (1980)

Beheiry sampled four locations (his Sites 2, 5, 8 and 11) displaying median diameters of 0.35 mm, 0.40 mm, 0.20 mm and 0.38 mm, by description comparable to our typical intervening sandy substrates which exhibit an overall average median diameter of 0.37 mm. His comparable lee deposits (Sites 1, 4, 7, 10 and 12) ranged from 0.11 mm to 0.27 mm, ours from 0.14 mm to 0.37 mm (excluding Plot 8 which was 0.63 mm). Here, in making such grain size comparisons, it is important to note that the present data probably reflects a greater recent stabilization, deposit coarsening process than the earlier measurements, particularly in the shielded plots.

Sorting coefficients, shown in Table 9, likewise agree closely with Norris (1958), 1.94 and 1.37 for his locations cited previously, as compared with the present 1.96 and 1.22. The same is true for Beheiry's lee and intervening substrate deposits which for the Sites noted averaged 1.63 and 2.26 versus our 1.69 and 1.94.

Deposit characteristics varied widely within each plot, to the extent that for every characteristic measured at the four microenvironments within each of the plots, a range existed which was common to all plots. For example, mean grain diameter (Table 7) ranged overall from 0.13 mm to 0.67 mm at various of the microenvironments within the plots. However, all plots contained some deposits displaying a mean

diameter in the range of 0.22 mm to 0.29 mm (either as measured directly, or as inferred through measurements both above and below this range). The same is true for Penetrability, for the 1' drop (Table 3) between 5.85 cm and 6.90 cm, and the 0' drop (Table 4) between 2.67 cm and 4.23 cm; for the Crustiness Index, 1' drop (Table 5) between -0.33 cm and 0.30 cm, and 0' drop (Table 6) between 1.27 cm and 1.73 cm; for Median grain diameter (Table 8) between 0.24 mm and 0.32 mm; for Sorting Coefficient (Table 9) between 1.65 and 2.07; and % Finer than 0.1 mm Diameter and % Coarser than 1.0 mm Diameter (Tables 10 and 11) between 9% and 12%, and 0% and 6%, respectively.

Thus, despite visually obvious overall differences between most of the plots in the field, differences in individual textural characteristics of the deposits are quite subtle. In fact, if one were to assume that normal conditions existed at each of the plots, and taking plot locations within the region into account, inconsistencies abound relative to every characteristic studied, particularly among data relating to vegetative induced deposits. Under normal conditions, windward hummock deposits would consistently be less penetrable and comprised of a coarser distribution of grains than lee deposits. However, data in Tables 3, 4, 7, 8, 10 and 11 do not conform. Similarly, deposits nearer the northwestern, source end of the region would normally be coarser than those extending progressively to the

southeast. In other words, Plot 9 should exhibit coarser deposits than Plot 5, and Plot 5 coarser than Plot 7. Again, data in Tables 7, 8, 10, 11 and 12 do not bear this out. Likewise, under natural conditions paired plots should exhibit essentially the same characteristics. Previously described effects of reduced or discontinued receipt of new sand for varying time periods offer a plausible explanation for the values in characteristics found.

In Turner et al (1980) no significant correlations were found between individual aeolian sand transport and deposit characteristics and the observed Uma densities. However, more detailed analyses, involving combinations of characteristics, elicited several highly significant relationships. Specific lee deposit characteristics, coarseness of intervening sandy substrate surfaces and years of stabilization, in combination, appear to most significantly influence Uma abundance. Appropriate mathematical models for predicting Uma densities based upon these variables are presented in the companion study.

Shielding

Shielding, as used here, describes the condition which prevails once the natural transport of sand into an area is discontinued by the artificial emplacement of a barrier to the natural transport process. Although similar to the effects of gradual depletion of source supplies previously described, the effects of shielding on near-surface deposit characteristics beyond the area shaded from wind by the barrier itself occur more rapidly and are more pronounced due to the relatively abrupt discontinuance of sand being fed into the area.

Weaver (1979) indicates that the shielding effects of any substantial barrier to the natural transport of sand will, in time, extend to the downwind end of the region because of the extreme unidirectional nature of the sand movement pattern. A substantial barrier is intended to imply one which extends a few hundred meters or more laterally across the path of movement and has the capability of dealing with the quantities of sand intercepted over a reasonably long period of time.

Effects upon near-surface deposit characteristics are essentially those resulting from winds, unladen with sand, scouring existing surfaces until all susceptible wind-transportable particles have been

redistributed sufficiently far downwind that they are no longer susceptible to further movement by the diminishing wind regime. Effectively, within intermediate transport areas, this leads to eventual elimination of virtually all sand deposits and, within the basic deposition area, to the eventual near complete depletion of hummock deposits and stabilization of intervening sandy substrate surfaces.

How rapidly does this sand depletion - surface stabilization process occur? And what are the effects upon the quality of Uma habitat? Prior to the present study, little data was available to aid in answering these questions. Based upon extremely meager data, Weaver (1979), at the request of the Corps of Engineers, suggested downwind progression rates of 3/4 mile per year between Indian Avenue and Vista Chino and 1/4 mile per year beyond Vista Chino to Ramon Road. Further, these rates were intended to reflect the near complete elimination of sand transport and may or may not be representative of the effects upon Uma habitat or abundance.

In general, sand depletion and surface stabilization occur more rapidly under the more intensive wind regime in the upper portion of the valley. Likewise, the process occurs more rapidly immediately beyond the wind-shaded area behind a given barrier than it does farther downwind. Within the area shielded from wind by barriers of a vertical nature (that area situated

immediately behind the barrier and extending approximately 10 times the height of the barrier in the downwind direction), the sand depletion process is retarded. Thus, surface stabilization is essentially complete once the barrier is in place.

Insofar as possible, shielded members of the paired plots (Plots 6, 8 and 10) were purposely located just beyond the wind-shaded areas, to test the most rigorous effects of the sand depletion-surface stabilization process associated with the related barriers. The number of years since emplacement of the barrier was 7, 12 and 17, respectively for the 3 plots, as indicated in Table 1.

Natural and shielded states of the surficial deposit forms can readily be noted in the field, particularly in such contrast as exhibited by the paired study sites.

Clearly, the effects of shielding are detrimental to the existence of Uma, as reflected by the results of the biological field counts shown in Table 14. In all three plots the effected changes in aeolian sand characteristics, and possibly in related biological variables, have effectively rendered the area unsuitable as Uma habitat. These findings strongly suggest that Uma population will eventually be extinguished in all areas shielded from the natural receipt of windblown sand.

To preliminarily assess the importance of this

condition it was decided late in the study to map the presently developed or shielded areas, which are indicated in Exhibit 2. Excluding the source areas west of Indian Avenue and along the base of the Indio Hills, approximately 80% of the region is presently either developed or shielded. Area determinations show this condition to apply to 24 km^2, or 49% of the intermediate transport area and 91 km^2, or 95% of the basic deposition area within the Whitewater subregion, and to 17 km^2, or 60% of the intermediate transport area and 78 km^2, or 97% of the basic deposition area within the Indio Hills subregion.

It can be noted that Plots 1, 2, 5 and 7, all of which support Uma populations, are also located within shielded areas. This was not taken into account in the present studies due to the distances from the shielding barriers involved and the seemingly more important influence of 4 years of surface stabilization induced by the recent overabundance of vegetative cover. Similarly, observations by England and Nelson (1976) indicated at least some presence of Uma in shielded areas, including locations more than 8 km south of Indio, deprived of any significant new deposits for many years. They did not, however, detect presence southerly of State Highway 231, the extent previously recorded.

Of final note regarding shielding is that elimination of a barrier, either through removal or its being

impounded to capacity, renews the natural sandflow into the previously shielded area, eventually resulting in restoration of the natural sand transport environment.

Concluding Remarks

Results of the present studies considered in light of anticipated sand transport activity in areas which remain subject to the natural aeolian sand transport process suggest the favorable continuation, and possible enhancement of *Uma* habitat quality over the next several years. Conversely, the now verified effects of shielding project a discouraging picture for those shielded areas still supporting significant *Uma* population, as well as for areas destined for shielding by anticipated continuing land development. From the standpoint of preserving the species, emphasis should be placed upon preserving areas in an unshielded state.

Models presented in the companion study will now permit, with minimal field work, prediction of *Uma* densities at other sites within the region, facilitating population estimates over selected areas.

Pointed out is the need for further studies into the effects of shielding and the habitat degradation and population declination processes, in terms of time, proximity and location within the valley. This will allow more definitive assessments of future habitat and population changes within presently shielded areas, of the potential effects of proposed shielding-oriented projects, and of habitat enhancing

concepts.

Appropriate biological field studies should be integral to all such efforts. Also included should be examination of other biological variables, which were essentially excluded from the present studies.

England and Nelson (1976) performed extensive areal analyses of the Redo overall Uma habitat situation in view of the then existing and anticipated future development the valley. Results of the present study strongly urge an updating of their work, with the now verified effects of shielding taken into account.

It is indeed a pleasure to engage in studies which so closely link the biological and physical sciences.

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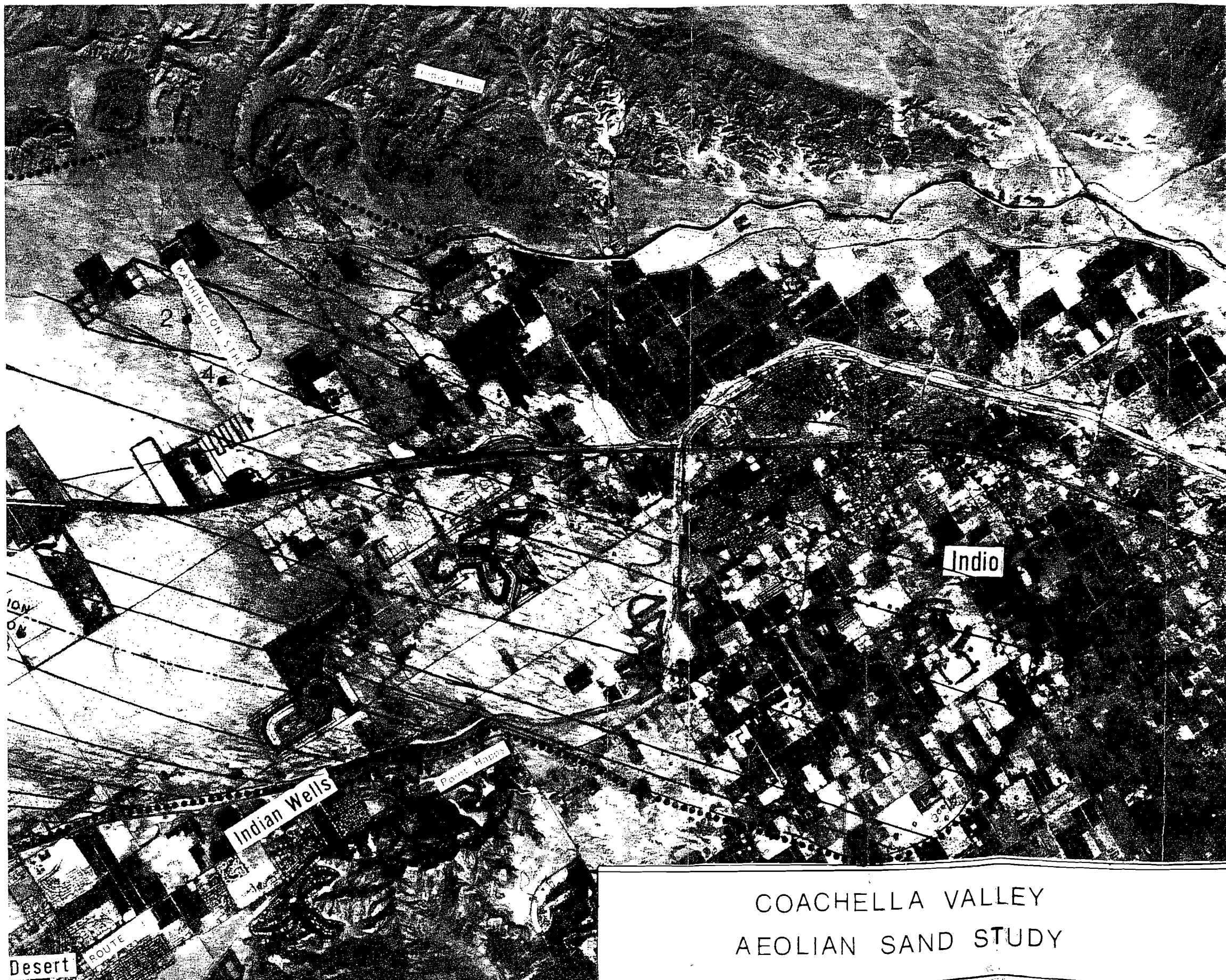


REFERENCE MAP

LEGEND

5■ STUDY SITES

→ SAND MOVEMENT DIRECTION

— — DEPOSITION AREA BOUNDARY

AEOLIAN SAND TRANSPORT REGIONAL BOUNDARY

AREAS PRESENTLY DEVELOPED, STABILIZED OR DESTINED FOR STABILIZATION

0 1 2 3

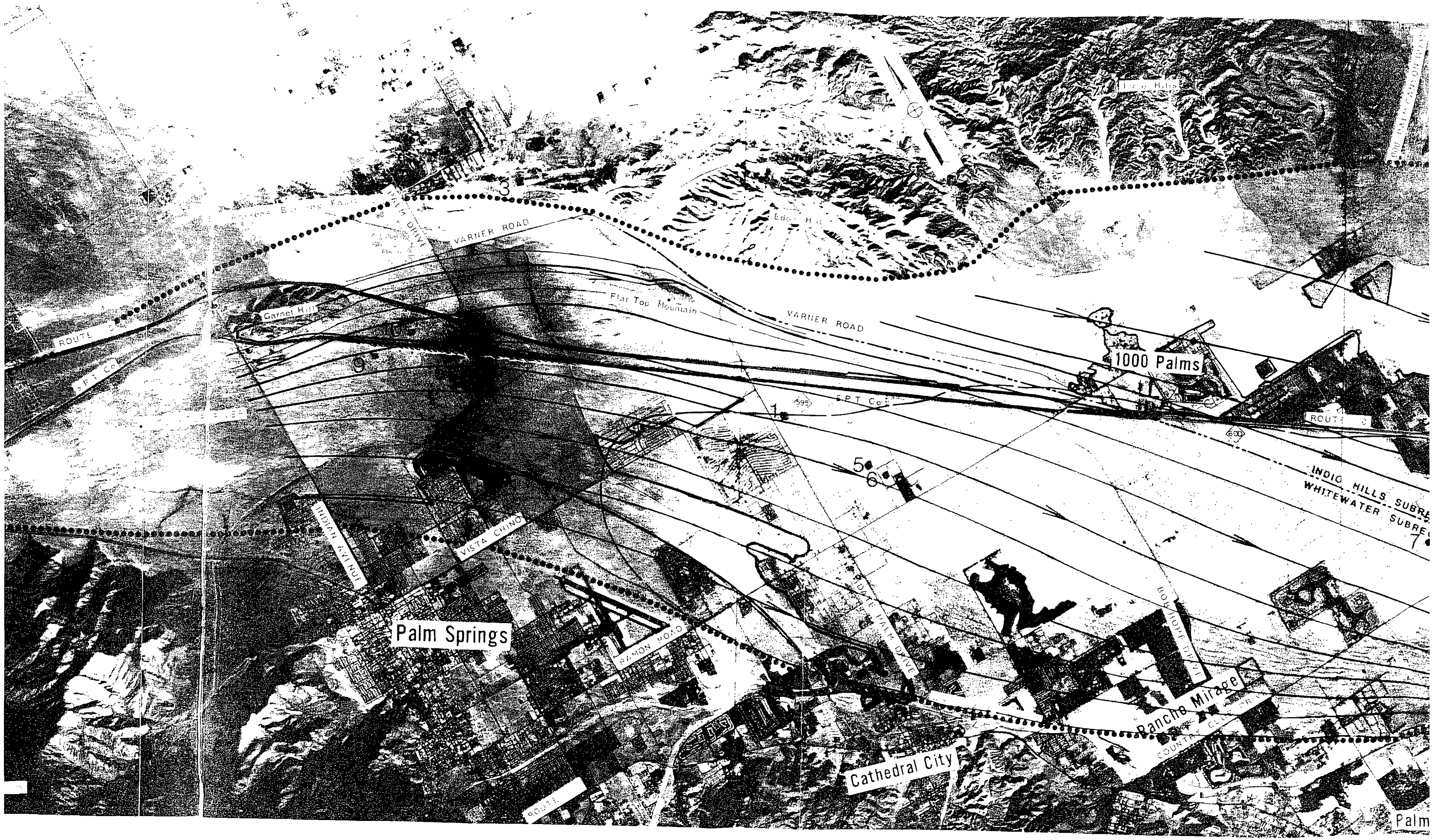
SCALE IN MILES

COACHELLA VALLEY
AEOLIAN SAND STUDY

FLIGHT DATE: NOV 26, 1974

SEPTEMBER 1980

EXHIBIT 2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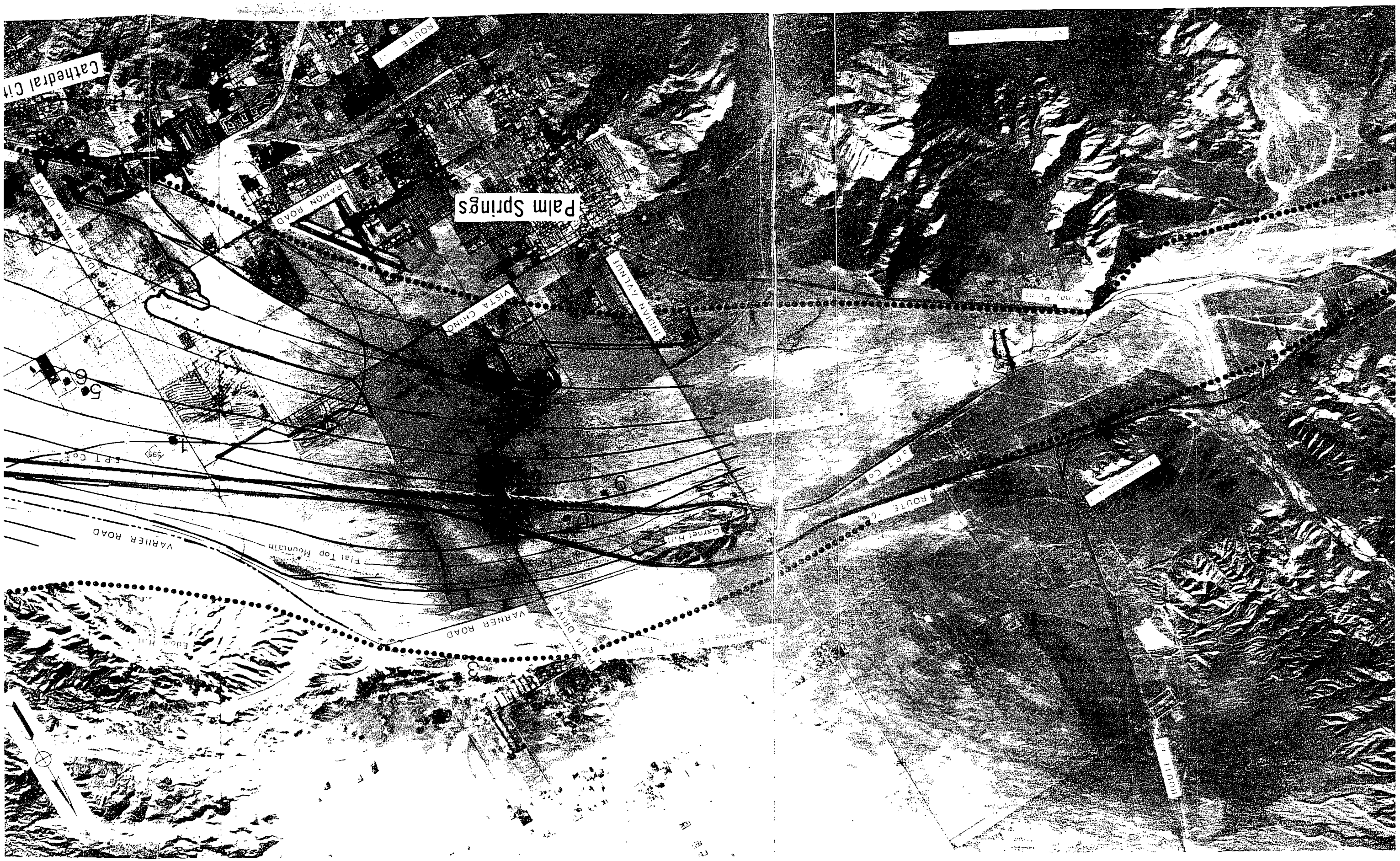
Garnet Hill
Flat Top Mountain
VARNER ROAD
1000 Palms
INDIO HILLS SUBRE
WHITEWATER SUBRE
VISTA CHINO
INDIAN AVENUE
Palm Springs
RAMON ROAD
DATE PALM DRIVE
BOGART LANE
Rancho Mirage
Cathedral City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Eagle Hill
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Research Notes

An Ecological Model for the Protection of a Dune Ecosystem

CAMERON W. BARROWS*

The Nature Conservancy, P.O. Box 188, Thousand Palms, CA 92276, U.S.A.

Introduction

A once common inhabitant of a 500-km^2 sand dune system near Palm Springs, California (U.S.A.), the Coachella Valley fringe-toed lizard (*Uma inornata*), is restricted to the loose, aeolian sand habitat of that region (Stebbins 1944). Human development that began in the 1950s and accelerated through the next three decades created barriers to sand movement that have altered the habitat. As a result, the lizard was listed as threatened by the federal government in 1980. The lizard's listing as a threatened species set in motion a series of actions that resulted in the creation of the Coachella Valley Preserve System in 1986. One of those actions was the development of an ecological model to guide the design of the preserve system.

The ecological model, which became the basis of the Coachella Valley Habitat Conservation Plan, was used to delineate which lands would be preserved and which would be available for development. The focus was on protecting the natural processes that create and maintain the dune ecosystem, not on the lizard alone. Although not oblivious to ownership and political patterns, designers of the preserve system emphasized the dynamic nature of the sand dune ecosystem and developed a protection plan to incorporate large-scale patterns. Protected lands were designed to encompass ecosystem processes, including wind and sand corridors, as well as the sand dune habitat.

The Coachella Valley Preserve system was among the first habitat conservation plans (HCP) created under the Endangered Species Act. HCPs have been heralded as a means to reconcile the disparate interests of human development and the habitat needs of endangered species (Bean et al., 1991). The Coachella Valley fringe-toed lizard HCP has been held up as a model for resolving conservation conflicts to the satisfaction of all parties (Bean et al., 1991; Beatley 1994).

The most vocal critics of the Coachella HCP (Webster 1987) decried the large acreage left available for development compared to the relatively small area protected (about 5% of the total available). The ecological model was used to identify habitat with long-term viability within the range of the lizard, as well as those habitats deemed nonviable because their sand source and/or wind corridor were blocked by previous developments. These assumptions were supported by research (Turner et al. 1984). This meant the vast majority of the lizard's range was no longer suitable for long-term protection and was therefore available for human development. Based on the tenets of the model, all of the viable habitats were designated for protection. Without the ecological model to focus conservation efforts on viable habitats, cooperation from affected parties would have been more difficult and the acquisition and management of conserved lands would have been considerably more expensive, frustrating, and ultimately unsuccessful.

Concern about catastrophic events, potential epizootics, and natural habitat dynamics argued for protection of multiple and separate sand dune ecosystem sites; ultimately, three areas were established for protection. Of the three sites, the one near the town of Thousand Palms was by far the largest and most complex in design. It therefore received the most intensive examination and modeling to determine its boundaries. The following is an ecological model specific to that site, though the generalities could apply to all three sites.

The Ecological Model

The Coachella Valley fringe-toed lizard HCP included an ecological model that was both qualitative (Fig. 1) and, to the extent deemed feasible at the time, quantitative. Qualitatively, the model identified two primary sand sources for the Thousand Palms site: Thousand Palms Canyon and the western Indio Hills (Weaver 1981).

Address correspondence to: 53277 Avenida Diaz, La Quinta, CA 92253, U.S.A.
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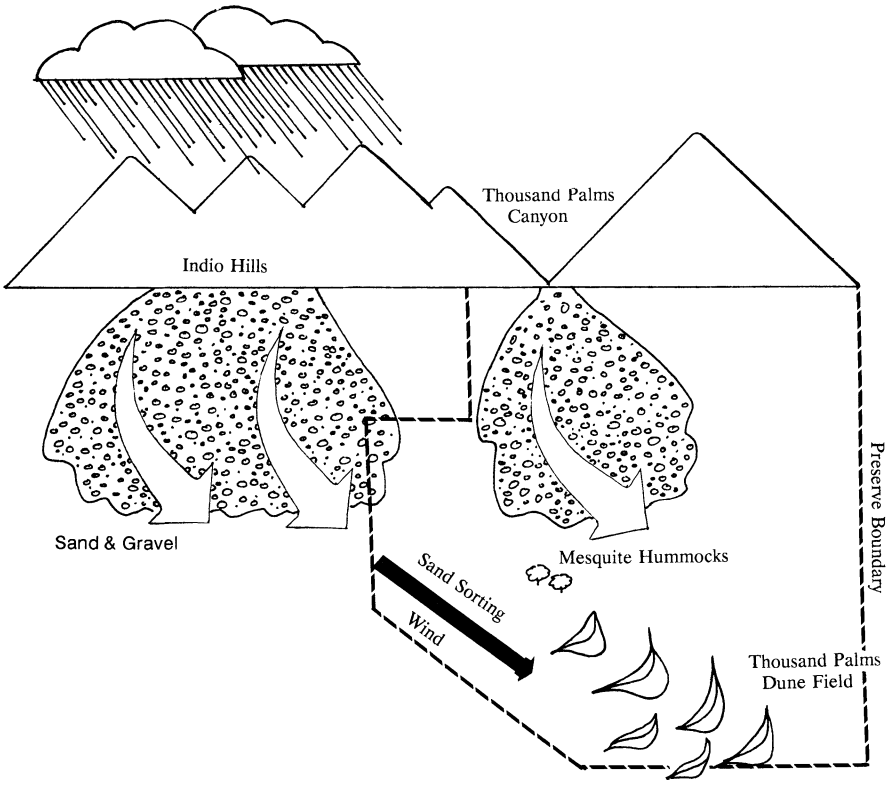

Figure 1. A graphic depiction of the ecological model of sand transport for the Thousand Palms preserve (not to scale).

Those two sources release sand during heavy rains; the sand is deposited on alluvial fans through flood events. Strong winds from the northwest then transport and sort these sediments, ultimately forming dunes that continue to move in a southeasterly direction. Blocking any stage of this process curtails dune development; existing dunes either stabilize or continue to "march" off of any protected parcels of land.

Experts in aeolian sediment transport estimated that the two identified sand sources each contributed about 50% of the total sand delivered to the Thousand Palms dune field. The Thousand Palms Canyon sand source was largely in a single ownership and would be a relatively simple acquisition. The western Indio Hills sand source and transport corridor was made up of hundreds of small parcels, each with separate ownership. The acquisition of this sand source would be difficult and extremely costly. This situation posed a dilemma to the architects of the HCP and the preserve system. Without quantitative data there was no way to determine whether protecting just one of the sand sources would be sufficient. Nevertheless, a decision was required; the architects of the HCP decided to protect just the Thousand Palms Canyon sand source through direct acquisition. Protection of the western Indio Hills sand source would be accomplished, at least in part, through zoning restrictions to limit development densities.

In 1993 the managers of the Coachella Valley Preserve system, a committee including the U.S. Fish and Wildlife Service, the Bureau of Land Management, the California State Parks Department, the California Department of Fish and Game, and The Nature Conservancy, faced doubts that they and others had raised about the sufficiency of the existing ecological model; they contracted to have it reexamined by two separate consultants. The goals were to confirm the relative importance of the two identified sand sources for the Thousand Palms site and to make some estimate of the frequency of flood events delivering sand for aeolian sorting and inclusion into the dunes.

The two consultants, Norman Meek of the California State University, San Bernardino, and Nicholas Lancaster of the University of Nevada, Reno, came to the same general conclusion: The western Indio Hills sand source is by far the largest contributor of sand to the dune field, accounting for perhaps as much as 95%. Thousand Palms Canyon contributes much less, with much of its sand not forming dunes until it reaches areas outside the protected boundary of the preserve. Through an aerial photo sequence dating from 1939 to the present, Lancaster was able to determine, by extrapolation of the movement of dune masses, that there had been two major inputs of sand to the dune field from the Indio Hills sand source. One of those occurred about 1890 and the other about 1938. Both roughly corresponded to major rainfall events.

This new information significantly refined the ecological model for the Thousand Palms preserve site. The

most important sand source had been clearly identified but had not been sufficiently protected within the preserve boundary. Significant flooding events bringing sand to the dune field may have occurred only twice in the past 100 years. The rate of dune movement indicated that, without an additional input of sand, much of the existing dune field would migrate outside the preserve boundary. There was also a suggestion that mesquite hummocks present in the earliest photos may have played an important role in dune formation. Those mesquite hummocks are all but gone today, presumably because of the substantial drop in ground-water levels as water has been used to hydrate the surrounding developments.

This refined model indicates the need for new actions to protect this dune ecosystem, focusing on the western Indio Hills sand source. Zoning limits housing density but does not prevent the construction of wind breaks. Even at relatively low densities, wind breaks would block sand flow onto the preserve. Fortunately, at this time no such construction has occurred within the sand corridor. Also, the effects of major flood events need to be preserved. The Army Corps of Engineers is currently studying how to maintain flood effects for the dune field and to protect the property of nearby residents.

Because of the falling water table, mesquite hummocks may never be restored to the wind and sand corridor. Alternatives such as snow and sand fencing could suffice as dune accretion sites. The U.S. Fish and Wildlife Service is restoring an abandoned vineyard within the preserve back to a dune field habitat. It is located in an area that should capture sands originating from Thousand Palms Canyon, sands currently lost to the preserve's habitat. The restoration effort will test the efficacy of fencing for the creation of sand dune habitat. If successful, such fences will be placed strategically throughout the preserve to enhance dune development.

Examination of the other two dune preserves in the Coachella Valley has not raised questions about their integrity and viability. Though much smaller, their sand sources appear secure.

Conclusion

The use of an ecological model was critical in the design of the Coachella Valley sand dune preserve system. It enabled planning efforts to focus on only those areas that possessed the components necessary for long-term viability. Ten years after the habitat conservation plan was implemented, there are still hundreds of acres of undeveloped and unprotected sand fields in the valley. They are shielded from natural sand and wind movement by wind breaks, golf courses, and housing developments up-wind. Few fringe-toed lizards still occur there, and in some areas they are absent altogether. Even when present, they are far less abundant than on the preserve sites (personal observation). Substantial effort and money was saved by not investing in protecting those shielded sand fields.

Fringe-toed lizard populations have been monitored within the three preserve sites every year since 1986 (Barrows et al., 1995). The results of these surveys indicate that the lizard populations fluctuate with the availability of resources such as food and loose sand. This apparently natural fluctuation over a much longer time span should indicate that the preserve design is sufficient to protect the lizard. But this conclusion could be in error. If the viability of the processes that maintain the sand dunes is not monitored, those processes could be irreparably altered years before a decline in the lizards would be detected. If that happened, monitoring the lizards as they decline to extinction would be an academic exercise, with no options for remedial protection efforts. Those options are available today.

The creation of multiple preserve sites in the Coachella Valley has provided assurances for the long-term protection of the lizard. The three sites have separate sand sources and appear to have very different rates of sand deposition and movement. The three sites assure that some fraction of the original viability and stochasticity of this valley's dune ecosystem will be maintained. Losing even one of the sites weakens that assurance.

The Coachella Valley HCP provides an important model for future conservation efforts. It employs an ecological model emphasizing natural processes within the context of protecting habitat for individual species. Monitoring is not limited to species; it includes an evaluation of the viability of large-scale natural processes. The Coachella HCP was successful at removing an impasse between economic concerns and implementation of the Endangered Species Act; since the HCP process was initiated and implemented, no development proposals have had to be stalled to protect fringe-toed lizard habitat.

Responding to improved knowledge of how natural processes shape the landscape will increase the likelihood of successful conservation of the Coachella Valley fringe-toed lizard. Without a mechanism and the inclination to respond to defensible scientific information that indicates the need for additional conservation measures, the Coachella habitat conservation plan will ultimately be crippled.

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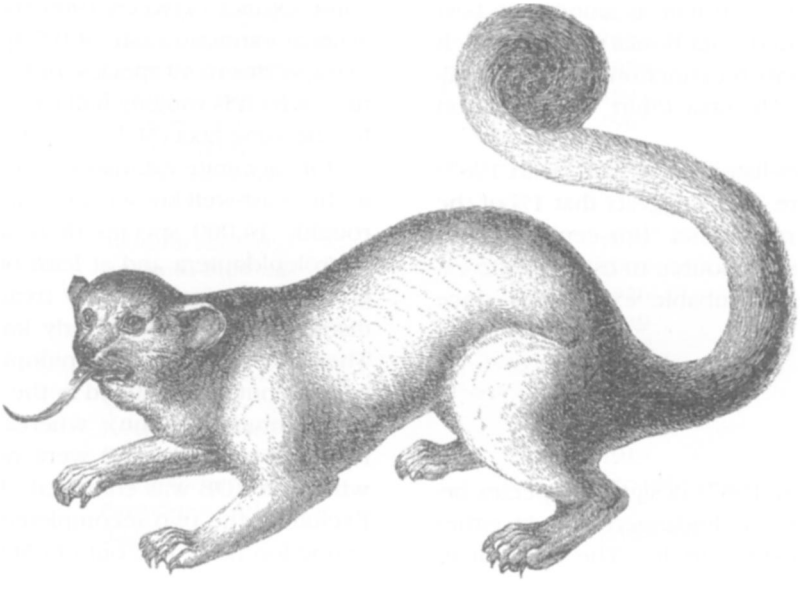

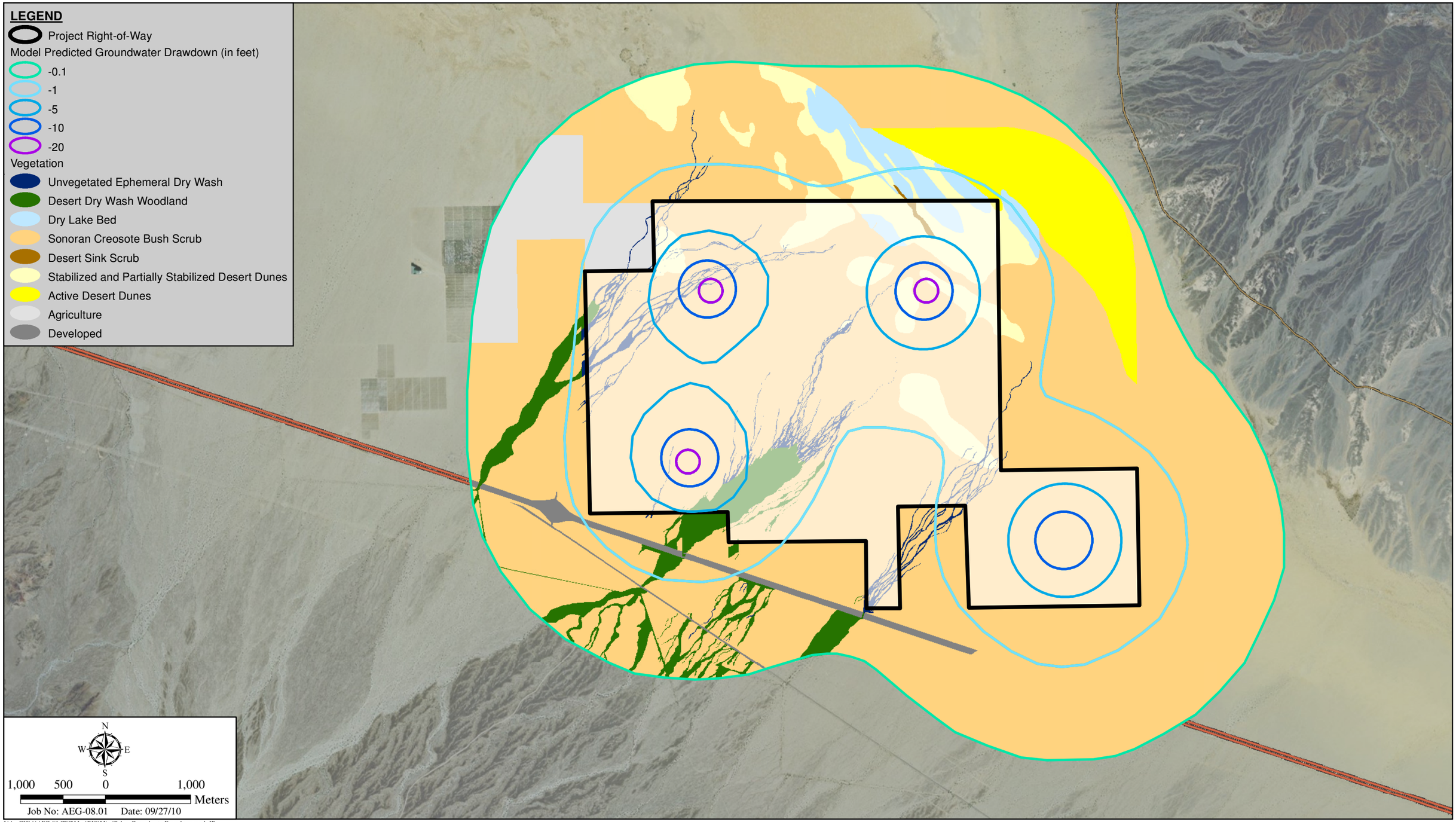

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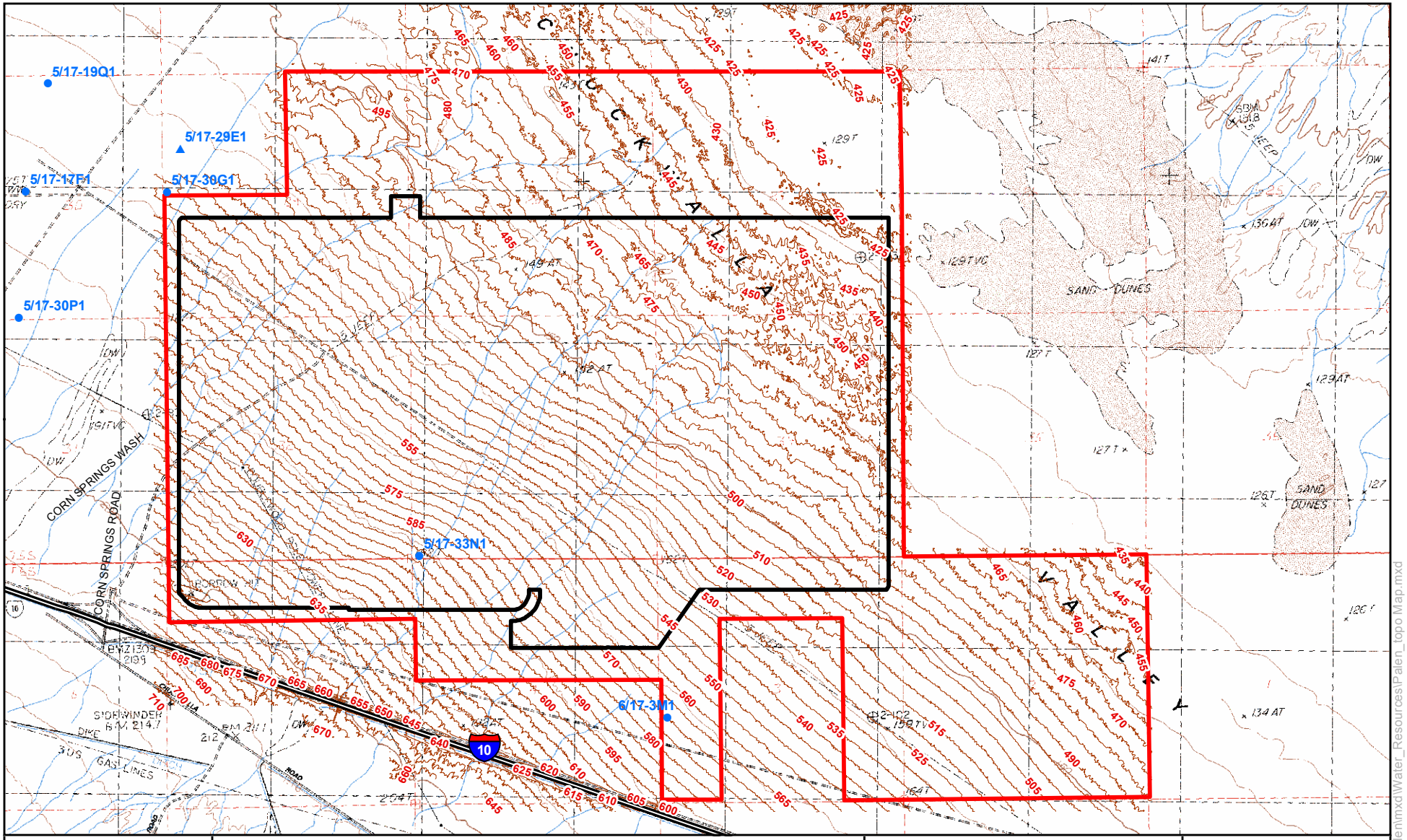
Groundwater Drawdown and Vegetation Communities

PALEN

HELIX



Map Location

Legend

- Project Right-of-Way
- Facility Footprint
- Freeway
- 540 Topographic Contour (5-ft interval) feet msl
- Groundwater Well Location based on Latitude and Longitude in USGS Database
- Groundwater Well Location based on the State Well Number (approximate)

Data Sources:
Topographic Contours from Towill 2009

USGS 7.5 Minute Quadrangle,
Sidewinder Well, California-Riverside Co. 1983

0 3,000 6,000 Feet

Palen Solar Power Project

Figure 5.17-2
Site Topography Map

Solar Millennium

AECOM

Project: 12944-001
Date: August 2009

J:\GIS\Projects\SolarMillinneum\Palen\mxd\Water_Resources\Palen_topo Map.mxd

Collison

Palen Solar Power Plant Application Hearing

California Energy Commission

October 27th 2010

ESA PWA

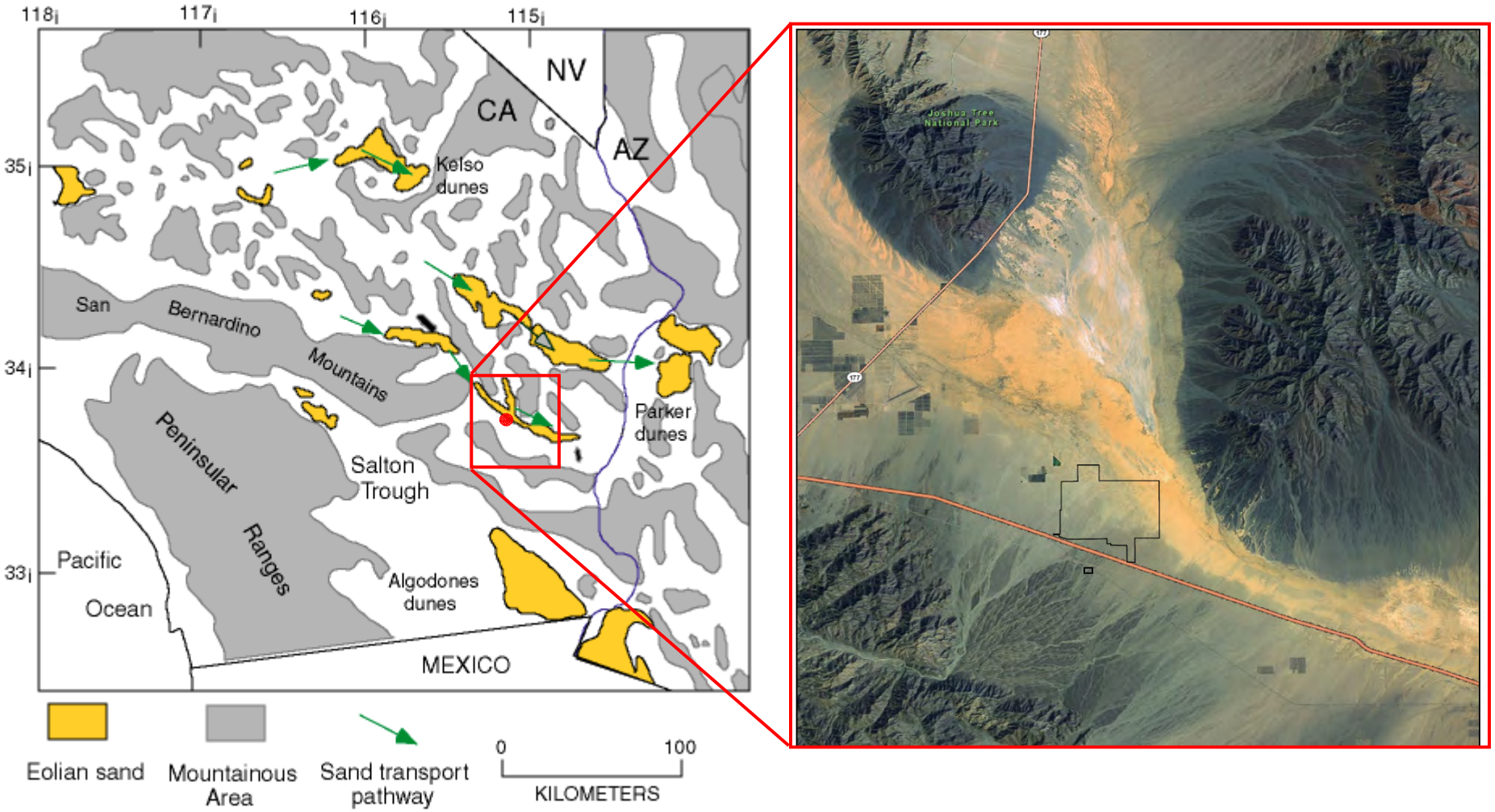
Mojave Fringe Toed Lizards Require Wind Blown Sand

Figure 1. Mojave Fringe Toed Lizard showing its preferred habitat of fine, loose sand. Source: Southwest Images.

Figure 2. Good MFTL habitat showing 'plump', vegetated dunes connected by relatively deep, loose sand sheets.

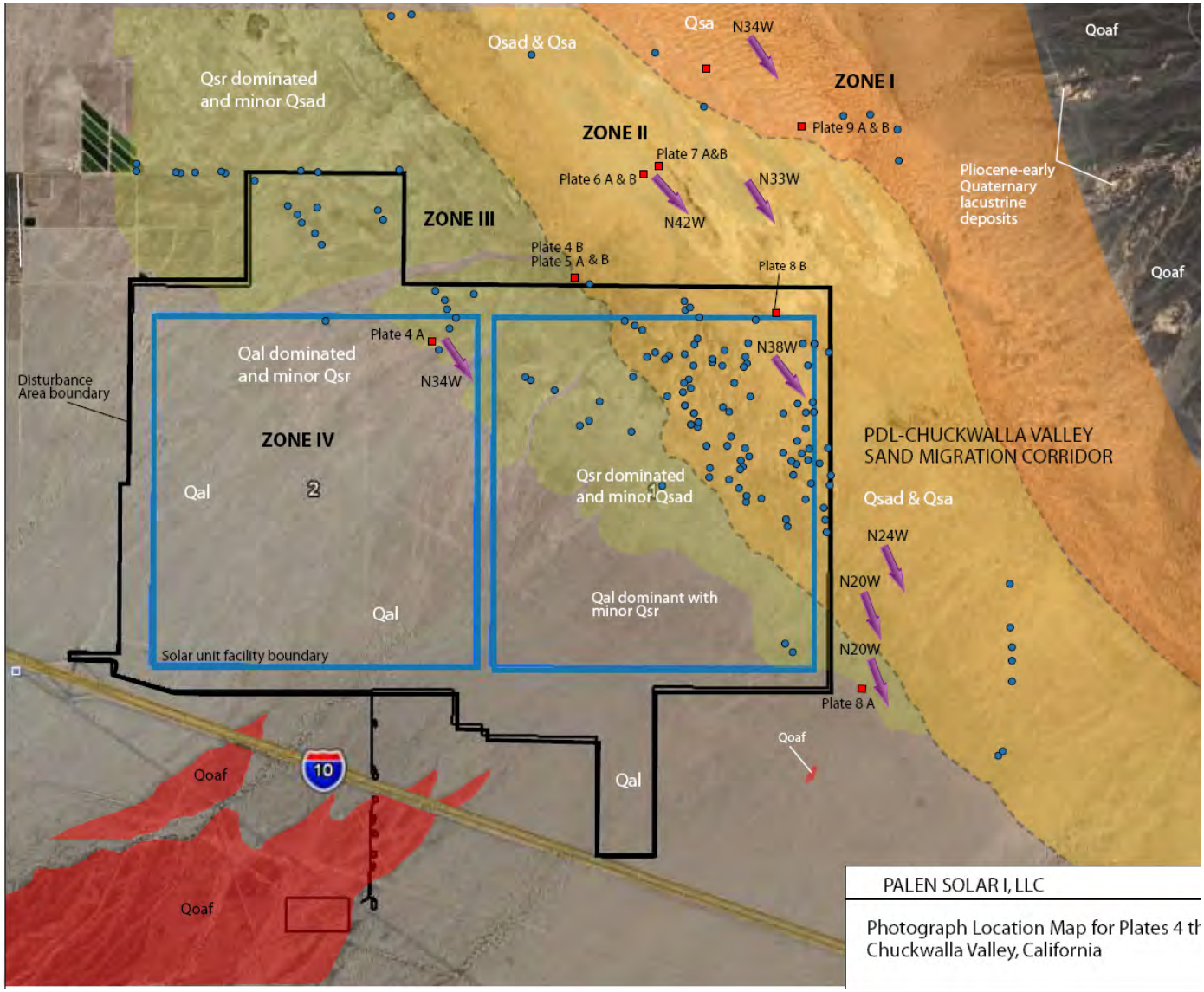
Figure 3. Deflated former vegetated dune showing remnants of eroding dune under creosote bushes surrounded by an armored lag of coarse gravel and shallow, compacted sand. This habitat does not support MFTL.

Wind Blown Sand Follows Defined Corridors That Pass Through the Proposed Project Site



Muhs et. al. 2003

Sand Corridors Are Associated With Mojave Fringe Toed Lizards

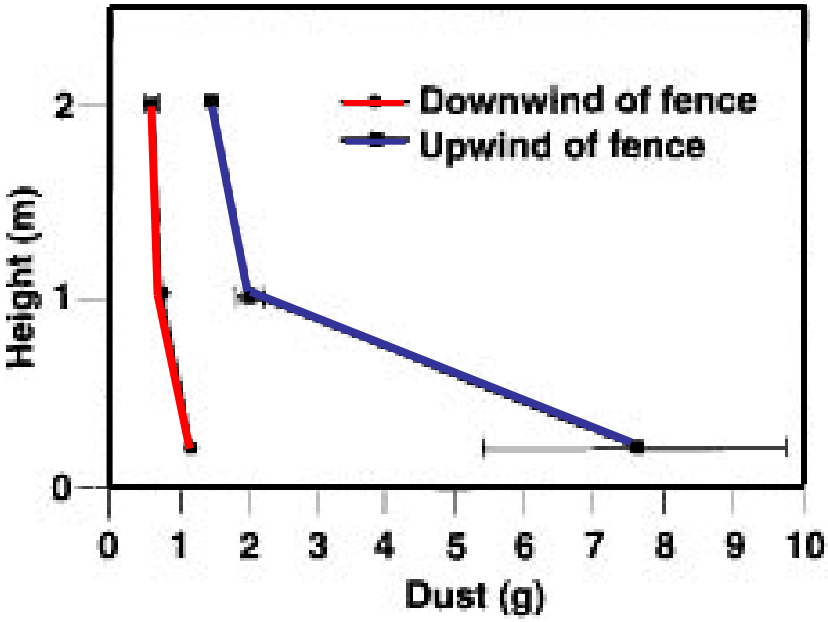


From Revised Staff Assessment

Fences and other obstructions trap wind blown sand, depleting areas downwind to create a ‘sand shadow’

Wind fences provided effective control of blowing fugitive dust in areas with over-blown sand that resisted revegetation efforts.

Grantz et. al 1998



Wind fences in Antelope Valley, Western Mojave Desert, reduced dust transport by 80% close to the ground level. Note that due to its greater mass, sand is more effectively trapped by obstructions than dust

When upwind sand supply is disrupted, MFTL supporting dunes rapidly erode and lose habitat value

Long-Term Sand Supply to Coachella Valley Fringe-Toed Lizard (*Uma inornata*) Habitat in the Northern Coachella Valley, California

By Peter G. Griffiths, Robert H. Webb, Nicholas Lancaster, Charles A. Kaehler, and Scott C. Lundstrom

It is also likely that the eolian-transport rates are less than used in this analysis, because they are reduced by the presence of vegetation in the transport corridors. As a result, the depletion times in table 16 should be regarded as minimum values. In general, however, the eolian removal of expected annual sediment yields in approximately one year – both before and after development – is consistent with the presence of persistent sand dunes in the Coachella Valley.

Table 16. Eolian depletion rates of fluvial sediment deposited in depositional areas upwind of the Coachella Valley reserves.

Depositional area	MONTHS TO REMOVE ALL SAND		MONTHS TO REMOVE "UMA SAND"	
	Renard (1972) equation	Flood-frequency method	Renard (1972) equation	Flood-frequency method
		Historic record		
San Gorgonio/ Whitewater	12.9	25.3	2.5	4.9
Mission/Morongo	8.0	17.6	1.7	3.8
Long Canyon	3.6	7.4	0.8	1.7
		Modern record		
San Gorgonio/ Whitewater	15.7	30.3	4.1	8.1
Mission/Morongo	8.0	17.6	1.7	3.8
Long Canyon	7.8	17.3	2.0	4.4

Copeia, 1984(2), pp. 370–378

Effects of Reduction in Windblown Sand on the Abundance of the Fringe-Toed Lizard (*Uma inornata*) in the Coachella Valley, California

Frederick B. Turner, Donald C. Weaver and James C. Rorabaugh

"Data from the six experimental plots show that obstructions to sand flow and ensuing sand depletion and surface stabilization definitely affect the occurrence of Uma inornata. The three plots down- wind of obstructions (2, 4, 6) have been subjected to these processes for 7, 12 and 17 years, respectively. In all three situations changes in aeolian sand characteristics, and possibly in related biological variables, have rendered the areas unsuitable as Uma habitat. The continuing reception of new sand appears, then, to be an indispensable ecological process insofar as the survival of fringe-toed lizards is concerned. The importance of rates of sand passage is less clear. The three plots exhibiting highest densities of Uma (3, 5 and 9) sustain, respectively, passages of 15, 50 and 2.5 m3 per meter-wide path per year. These observations suggest that some active passage of sand is necessary, with the rate of sand transport less important."

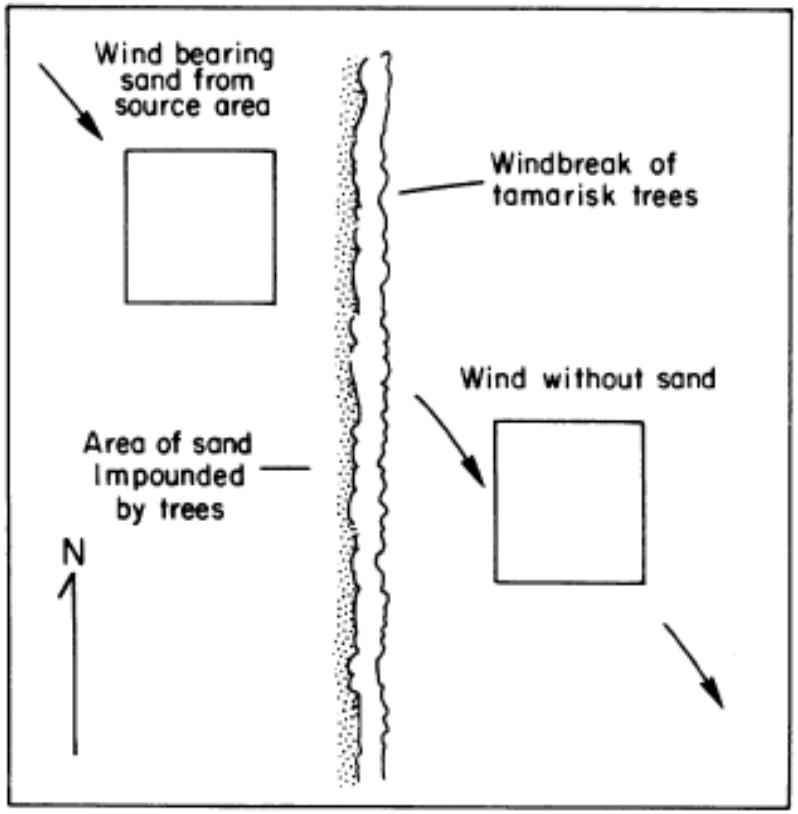
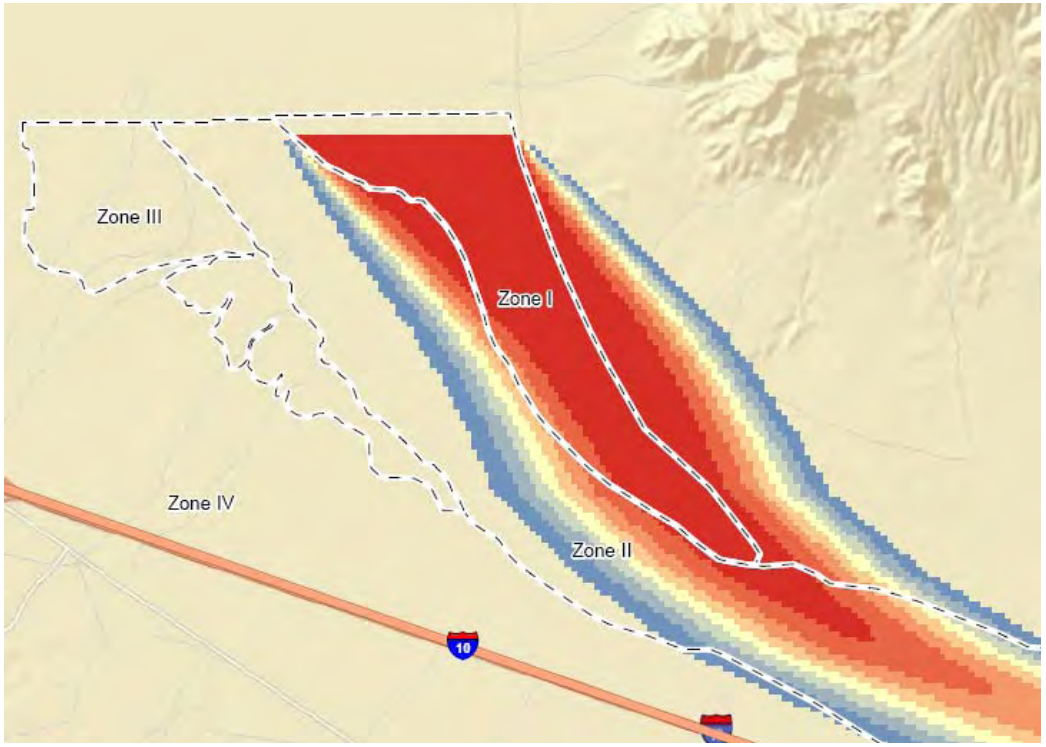


Fig. 1. Generalized plan for disposition of paired sampling sites. Plot in upper left is exposed to normal flow of wind bearing sand particles from source area. Plot in lower right is shielded by windbreak and receives little or no windblown sand.

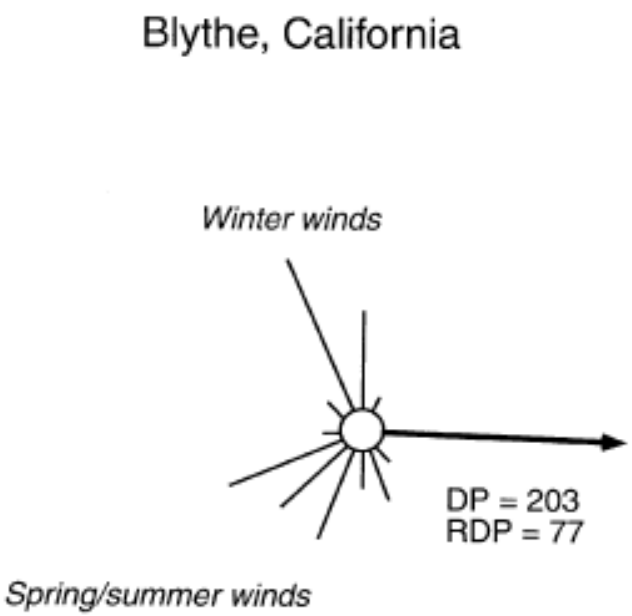
Calculating the area of indirect impact due to sand transport obstruction

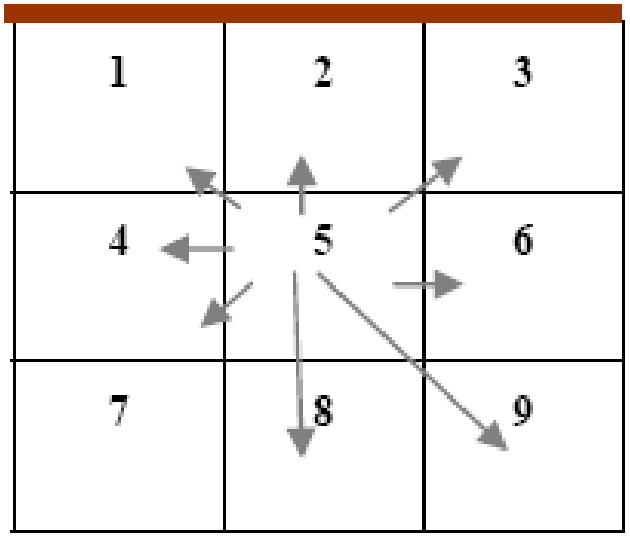


We developed a model of wind transport for sand based on applicant's data on prevailing sand transport direction and published wind distribution data

Prevailing sand transport direction is based on sand dunes mapped by applicant

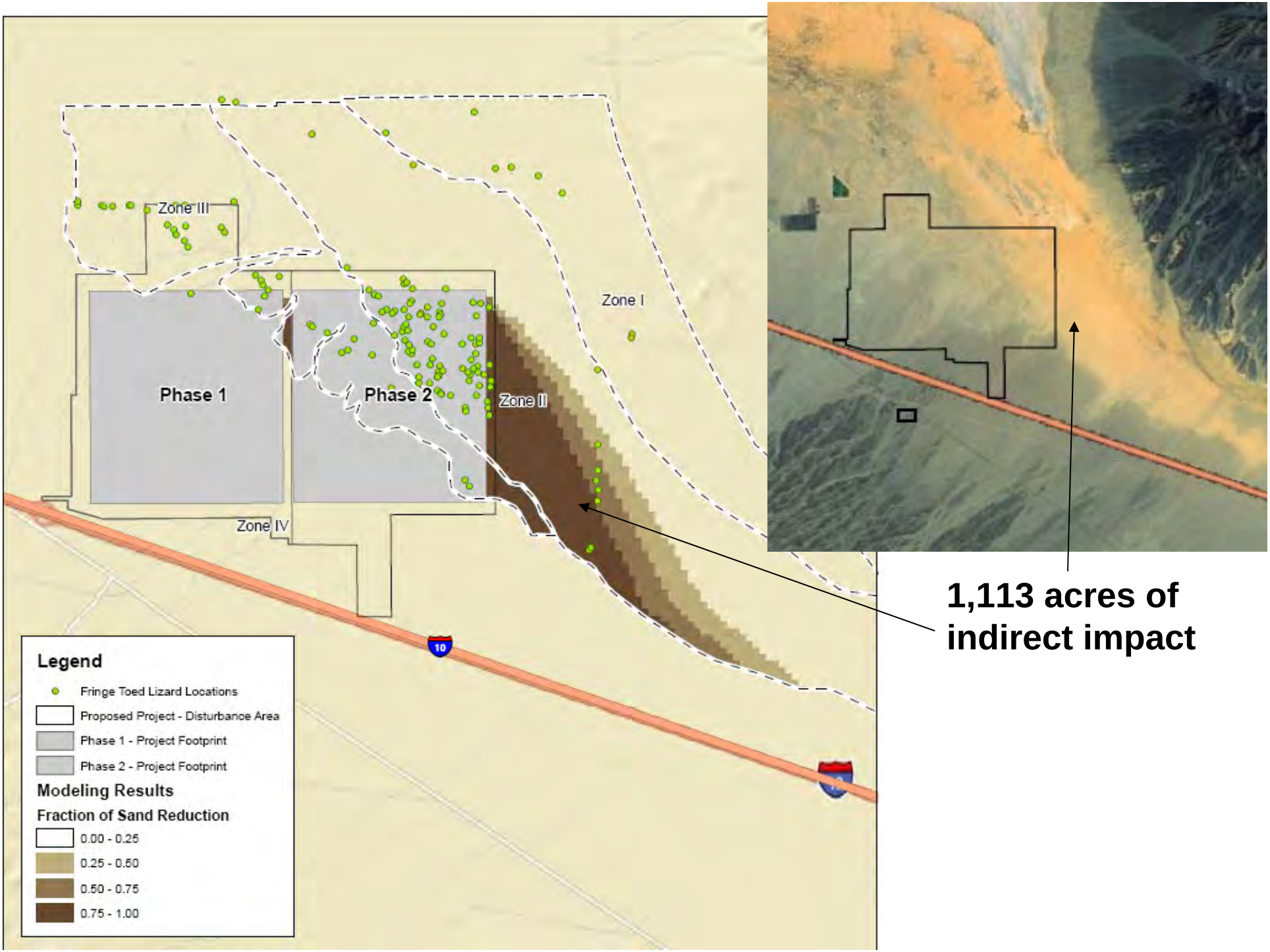
We developed a model of wind transport for sand based on applicant's data on prevailing sand transport direction and published wind distribution data

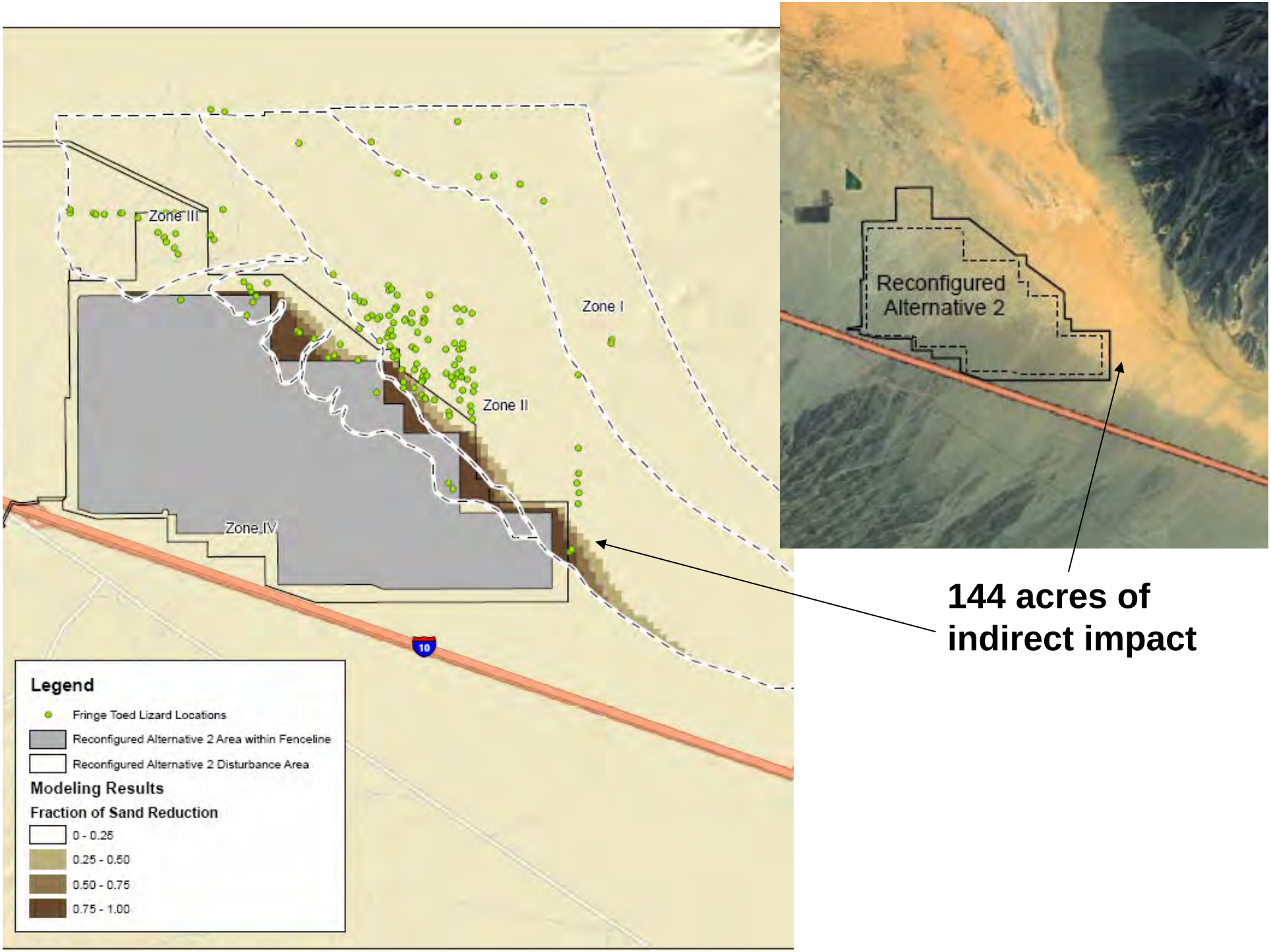


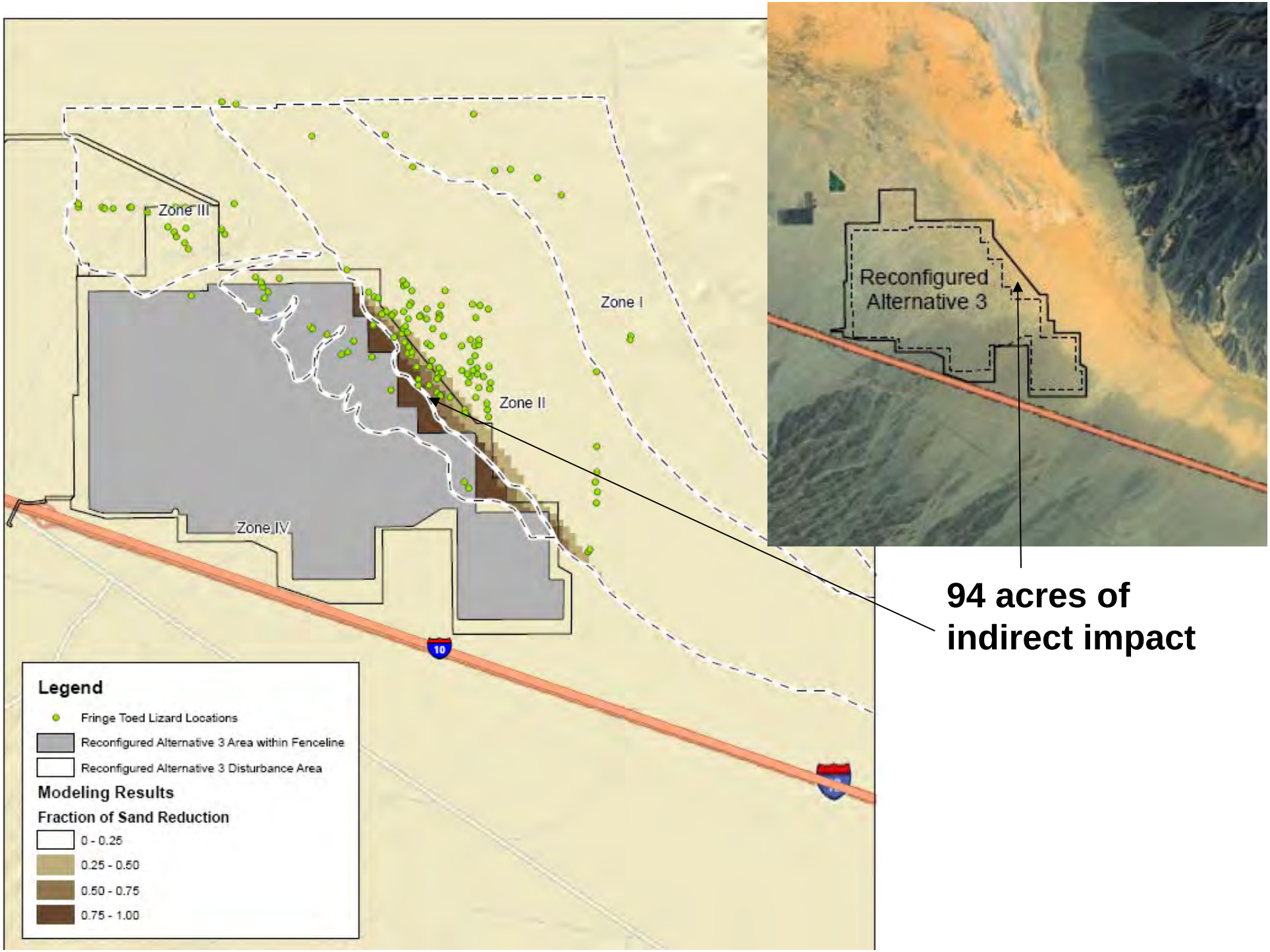


5%	5%	5%
5%	0%	10%
5%	16%	49%

Distribution around prevailing direction is based on Blythe airport wind record


Zone III
Zone I
Phase 1
Phase 2
Zone II
Zone IV
10
Legend
Fringe Toed Lizard Locations
Proposed Project - Disturbance Area
Phase 1 - Project Footprint
Phase 2 - Project Footprint
Modeling Results
Fraction of Sand Reduction
0.00 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
1,113 acres of indirect impact


Zone III
Zone I
Zone II
Zone IV
10
Legend
Fringe Toed Lizard Locations
Reconfigured Alternative 2 Area within Fenceline
Reconfigured Alternative 2 Disturbance Area
Modeling Results
Fraction of Sand Reduction
0 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
Reconfigured Alternative 2
144 acres of indirect impact


Zone III
Zone I
Zone II
Zone IV
10
Legend
Fringe Toed Lizard Locations
Reconfigured Alternative 3 Area within Fenceline
Reconfigured Alternative 3 Disturbance Area
Modeling Results
Fraction of Sand Reduction
0 - 0.25
0.25 - 0.50
0.50 - 0.75
0.75 - 1.00
Reconfigured Alternative 3
94 acres of indirect impact

Discussion of indirect impacts from solar arrays only (assuming boundary fence is removed)

Grantz, D.A., Vaughn, D.L., Farber, R.J., Kim, B., VanCuren, T. and Campbell, R. 1998. Wind barriers offer short-term solution to fugitive dust, California Agriculture, Volume 52, No. 4

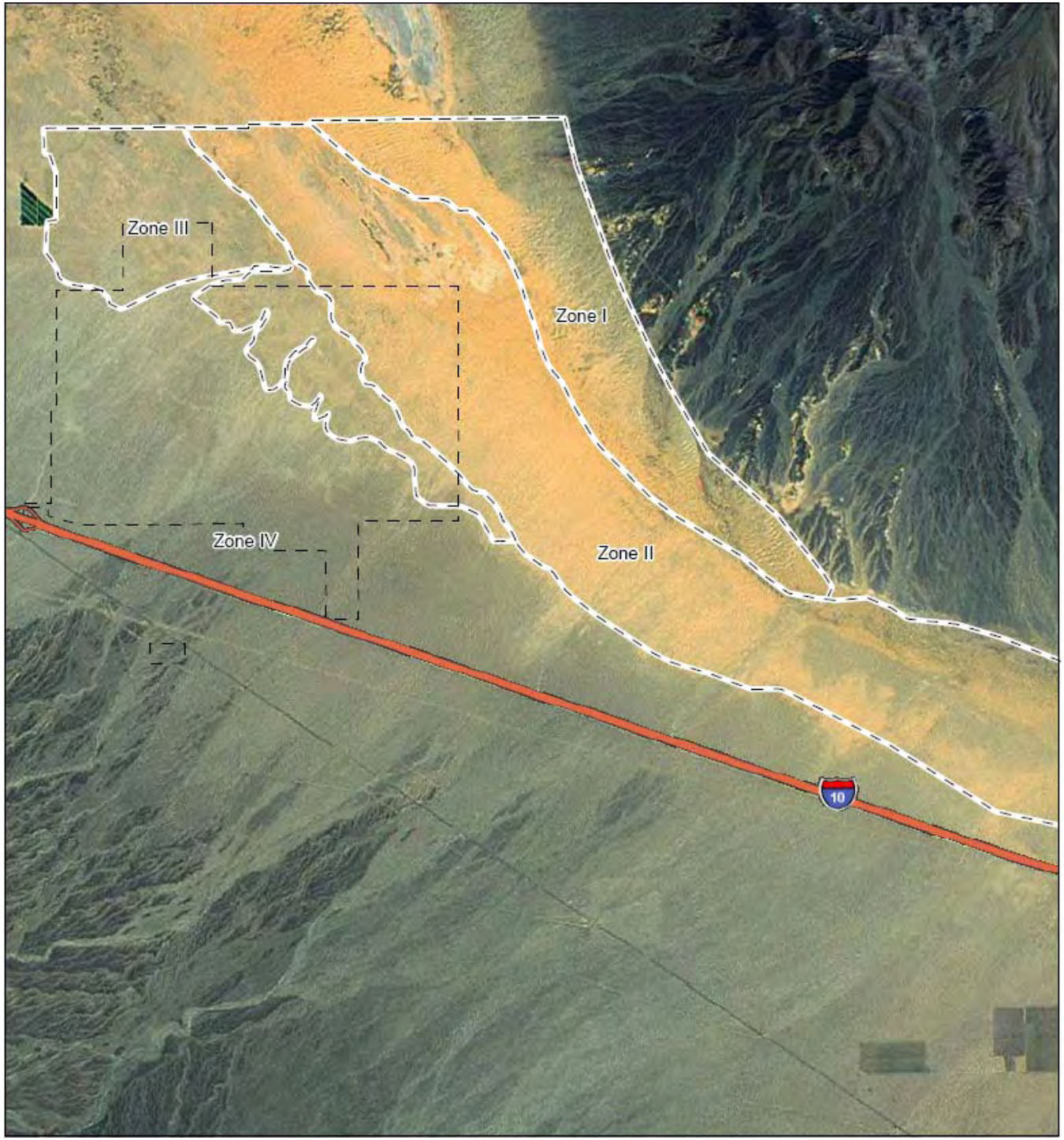
Adding 24 inch plastic cones to bare ground in the Mojave Desert reduced dust transport by 40-64% within 3 feet of the ground.

(Solar array shown for comparison)

Grantz, D.A., Vaughn, D.L., Farber, R.J., Kim, B., VanCuren, T. and Campbell, R. 1998. Wind barriers offer short-term solution to fugitive dust, California Agriculture, Volume 52, No. 4

TABLE 1. Control of fugitive dust by various types of wind barriers

Year	No. of weekly samples	Barrier type	Mean wind speed		Maximum wind gust		Sampler height	Average control
			m/s	*mph*	*m/s*	*mph*	*m*	%
1992	3	Wind fence	3.3	7.4	20.5	45.9	0.2	71
	3		3.3	7.4	20.5	45.9	1.0	67
	3		3.3	7.4	20.5	45.9	2.0	54
1994	8		5.6	12.5	24.2	54.1	1.0	63
1995	16		4.0	8.9	25.2	56.4	1.0	69
1995	3	Furrows	3.6	8.1	19.6	43.8	0.20	93
	3		3.6	8.1	19.6	43.8	0.37	76
	3		3.6	8.1	19.6	43.8	0.67	66
	6		4.4	9.8	25.2	56.4	1.0	56
	3		3.6	8.1	19.6	43.8	1.16	24
	3		3.6	8.1	19.6	43.8	2.00	33
1996	10	Roughness elements	4.8	10.7	22.8	51.0	0.20	64
	10		4.8	10.7	22.8	51.0	0.37	66
	10		4.8	10.7	22.8	51.0	0.67	40
	10		4.8	10.7	22.8	51.0	1.16	25
	10		4.8	10.7	22.8	51.0	2.00	15


Zone III
Zone I
Zone IV
Zone II
10

BUILDING A WORLD OF DIFFERENCE®

BLACK & VEATCH

LTPP Solar PV Performance and Cost Estimates

Ryan Pletka, PE

June 18, 2010

PV Performance Estimates

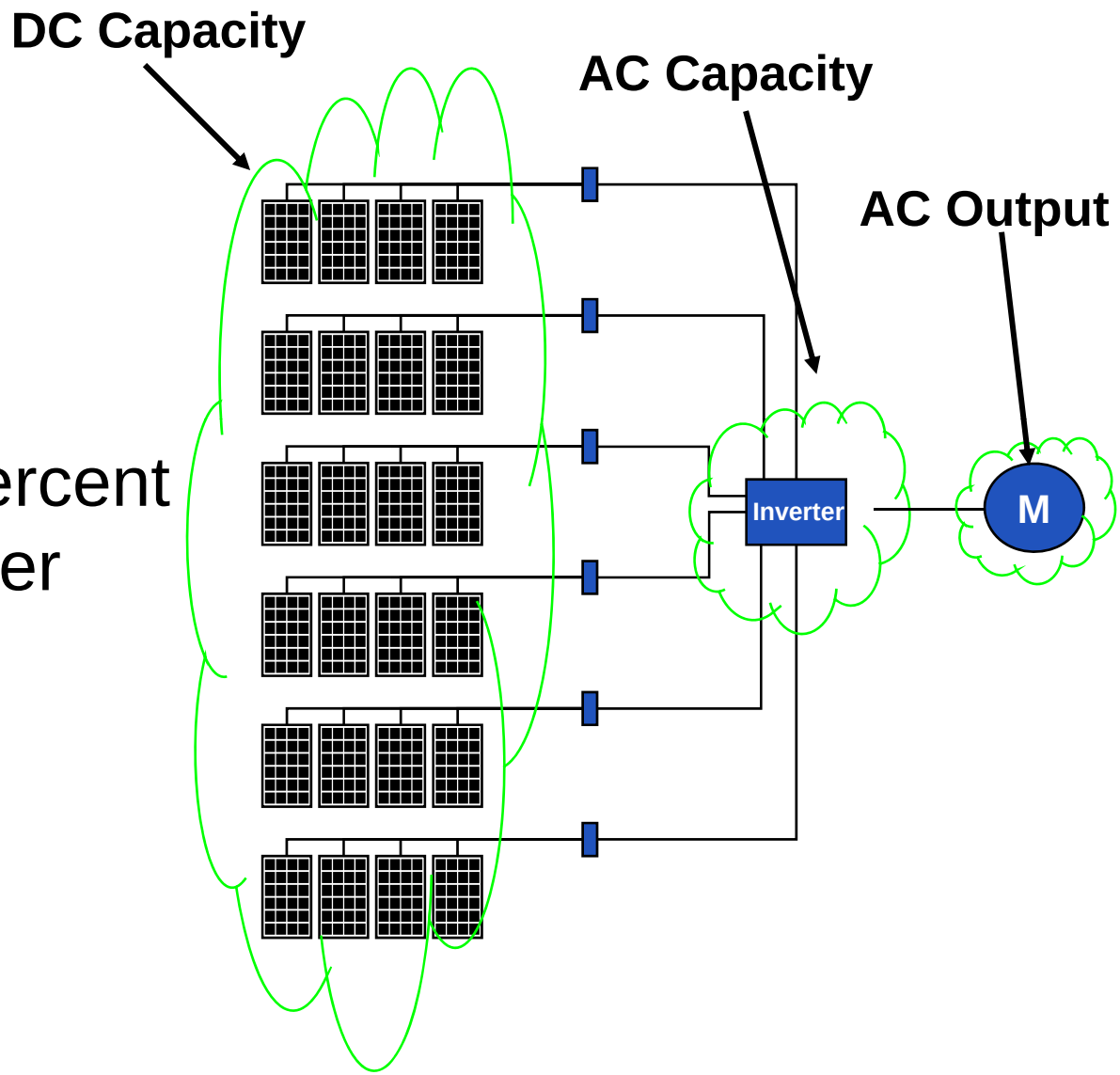
Definitions

- **DC Capacity**

  Sum of *module* nameplate rating. Modeled as 20 percent higher than inverter nameplate rating.

- **AC Capacity** –

  Sum of *inverter* nameplate rating.



Definitions Continued

- **AC Annual Energy Output**

  The total energy output on an annual basis at the energy meter. This number includes dc and ac wiring losses.

- **AC Capacity Factor**

  = AC Annual Energy Output [kWh] /

  (AC Capacity [kW] * 8760 [hours per year])

- **DC Capacity Factor**

  = AC Annual Energy Output [kWh] /

  (DC Capacity [kWp] * 8760 [hours per year])

Overview of Performance Estimate Methodology

- System definition
  - Chose 4 representative locations and 4 system configurations
  - Developed high-level conceptual design
- Gathered solar resource data (TMY – Typical Meteorological Year)
- Modeled system performance in PVSYST
- Similar methodology as that used by B&V's Solar Performance Group for more than 100 operating and proposed PV projects, most in California

System Definitions

Size and Locations

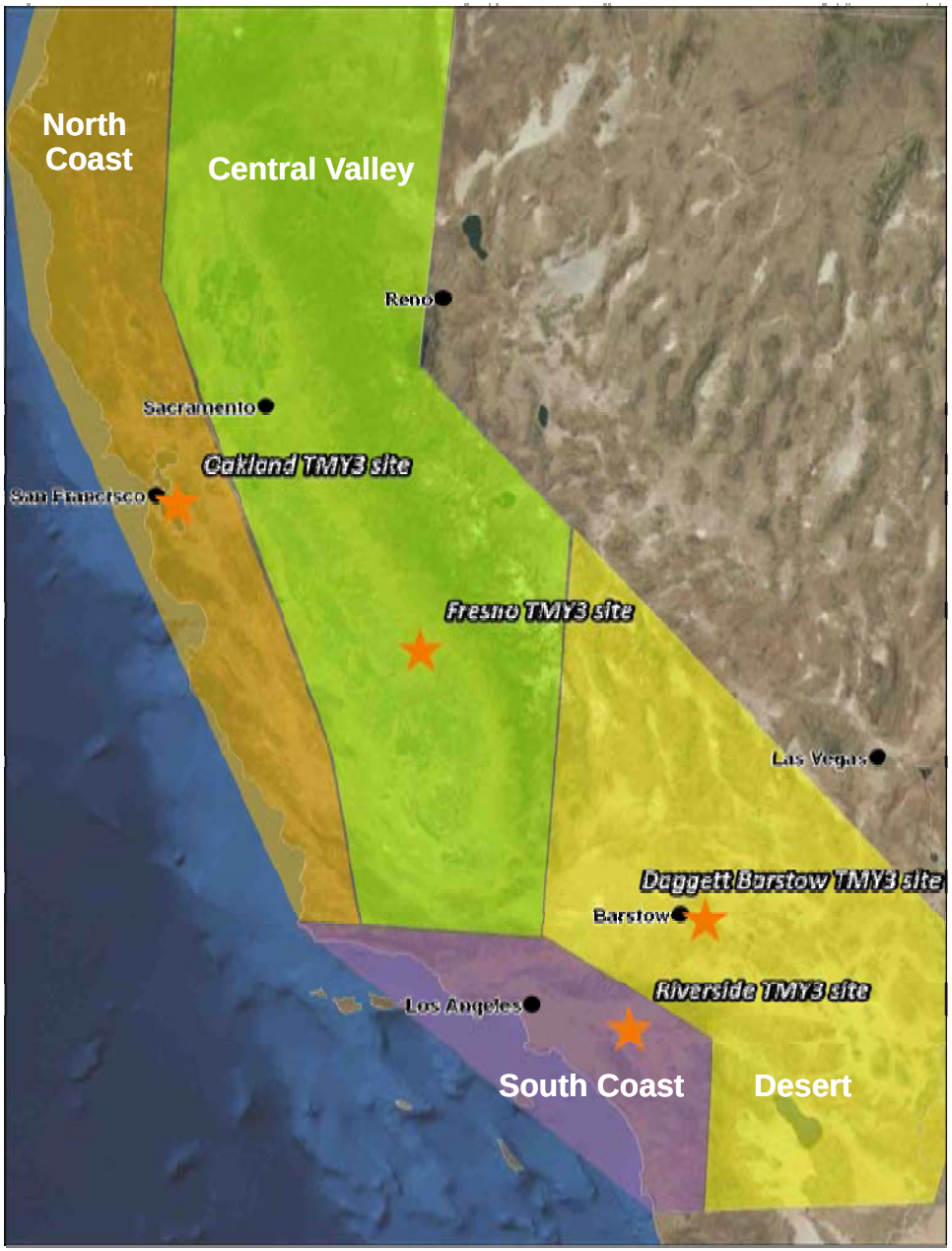
	0.5 – 2 MW Rooftop	0.5 – 2 MW Ground	2 – 5 MW Ground	5 – 20 MW Ground
North Coast				
Central Valley				
South Coast				
Desert				

Conceptual Design Basis

System Type	Rooftop	Single Axis Tracking	Fixed Tilt
Size	1 MW	1 MW	5 MW, 20 MW
Module Tilt	15 degrees	East-West (+/- 45 degrees)	25 degrees
Module Technology	Polycrystalline	Polycrystalline	Cadmium Telluride
Inverter CEC Efficiency	95 percent	95 percent	95 percent

Modeling Locations & Resource Data

- Defined regions that team felt had significantly different PV deployment potential and performance characteristics
- Identified representative locations in each region for which to pull solar data
- NREL's TMY3 data chosen to be representative of each location
- TMY3 data of Class II or higher chosen



Modeling and Loss Assumptions

- **System Voltage:** 600 Vdc
- **Module Quality:** According to typical warranties
- **Row Spacing:** Assumed to be sufficient enough for no inter-row shading between 9 am and 3 pm all year.
- **Thermal Parameters:** According to mounting (roof mount, ground mount)
- **Soiling:** Weather conditions in each region assessed to develop soiling loss assumptions.
- **AC wiring loss:** 0.5 percent
- **DC wiring loss:** 1.5 percent
- **Transformer loss:** 1 percent
- **Availability loss:** 1 percent, that is, system assumed to be available (operating) 99 percent of the time

Performance Estimates

Type	Location	DC Capacity Factor
1 MW Rooftop	Daggett	18.3%
	Fresno	16.3%
	Oakland	15.6%
	Riverside	16.9%
1 MW Tracking	Daggett	23.5%
	Fresno	20.5%
	Oakland	19.0%
	Riverside	20.9%
5 MW, 20 MW Fixed Tilt	Daggett	21.3%
	Fresno	18.8%
	Oakland	17.5%
	Riverside	19.5%

PV Cost Estimates

Cost Development Approach

- Detailed bottoms-up estimate based on B&V's engineer-procure-construct (EPC) methodology
- Market Pricing
  - Costs for projects where Black & Veatch is owner's engineer or lender's engineer
  - Financial statements for module suppliers (e.g., First Solar)
  - Recent project announcements/public/private data (other market information)
  - Hundreds of recent PPA bids
- All capital costs are on a $/Wdc basis and assume 2010 commercial operation date

Cost Uncertainty/Variability

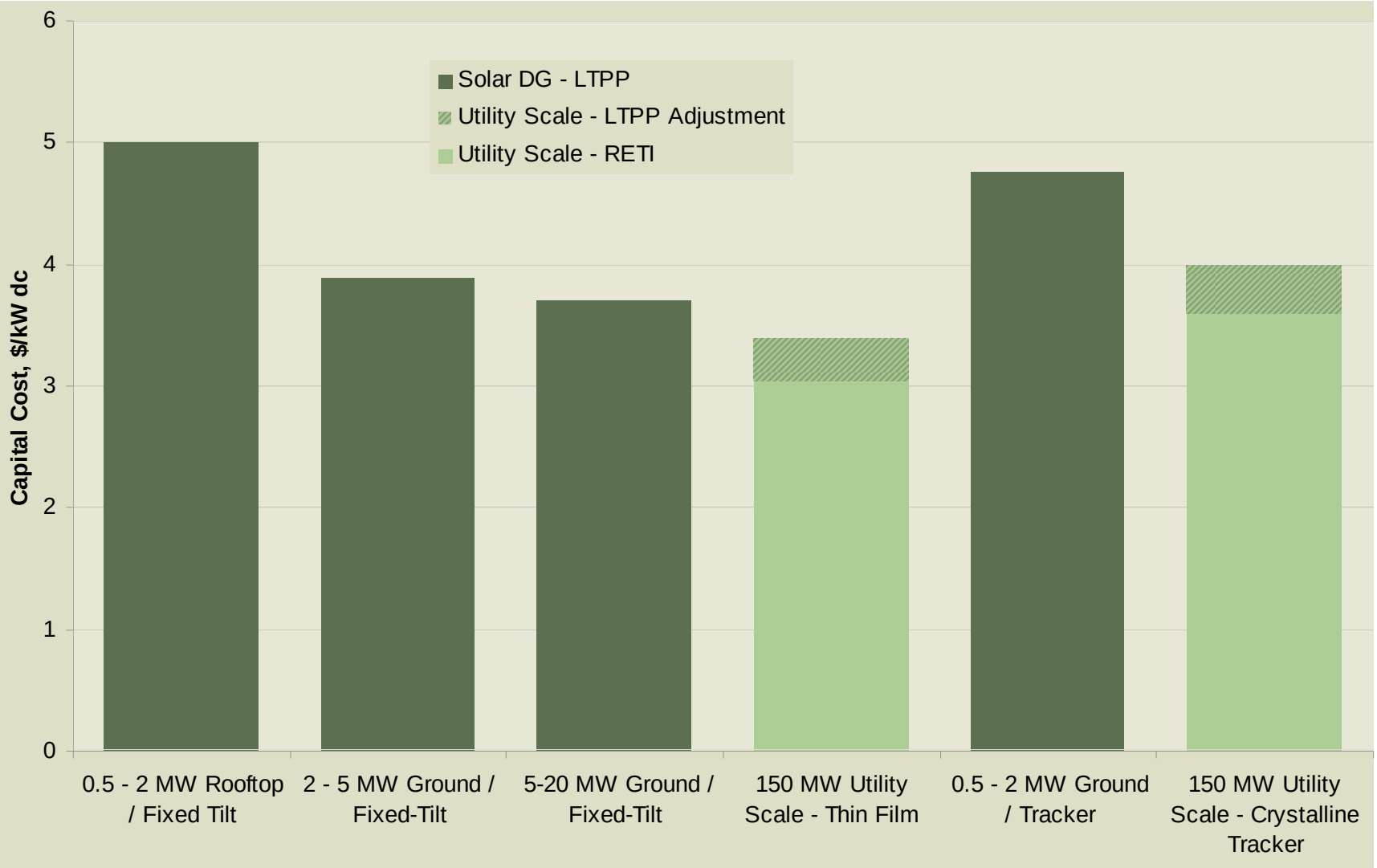
- Estimates are inherently uncertain and costs in the PV industry are "dynamic"
- The costs of CSI projects and other market sources appear to vary by approximately +/- 25 percent
- This variation is due to site specific factors, owner specific factors, and component/system pricing
  - Site specific factors are usually captured in the BOS and might include rooftop mounting issues, grading or foundation issues, shading considerations, interconnection issues or similar
  - Owner specific factors are captured in the Owner's costs and might include permitting issues, legal issues, land acquisition, or owner's management issues
  - Component/system pricing variation is related to market supply vs. demand, market efficiency, timing, etc.

Black & Veatch Cost Estimates for PV Systems

1 MW rooftop	$5.00/watt dc
1 MW tracking	$4.75/watt dc
5 MW ground	$3.90/watt dc
20 MW ground	$3.70/watt dc

Based on configurations identified earlier
As stated previously, typical cost uncertainty is +/- 25%

Comparison of PV Costs, Plus Large Central Station Costs



Example Breakdown of Component Costs

	20 MW	5 MW
Module	1.65 $/watt	1.65 $/watt
Support structure	0.82 $/watt	0.84 $/watt
Inverter	0.24 $/watt	0.25 $/watt
BOS	0.31 $/watt	0.40 $/watt
Owner's Costs	0.68 $/watt	0.76 $/watt
Total Capital Req.	3.70$/watt	3.90 $/watt

Appendix Material

Details on Component Costs

Module cost (5 MW and 20 MW)

- Black & Veatch has seen estimates between 1.3 and 2.25$/watt
- From Review of First Solar Financial Statements we derive 1.63$/watt
- From April 2010 SEIA report, SEIA indicates average 2009 costs at 1.85 to 2.25 $/watt.
- We have chosen 1.65 $/watt, which is near the First Solar data point and slightly below the midpoint (1.77) of the Black & Veatch low observation of 1.3$/watt and high SEIA point of 2.25$/watt

Structure Cost (5 MW and 20 MW)

- We have chosen 0.82-0.84 $/watt which is the result of reviewing quotes from three manufacturers.

Inverter Costs (5 MW and 20 MW)

- We have chosen 0.24-0.25 $/watt which is based on our experience, and verified with multiple vendors

BOS Cost (5 MW and 20 MW)

- BOS includes commodities like trenching, wire, electrical connections and grounding rods, step-up transformer, and similar items
- We have chosen 0.31 -0.40 $/watt after completing a bottoms up estimate.

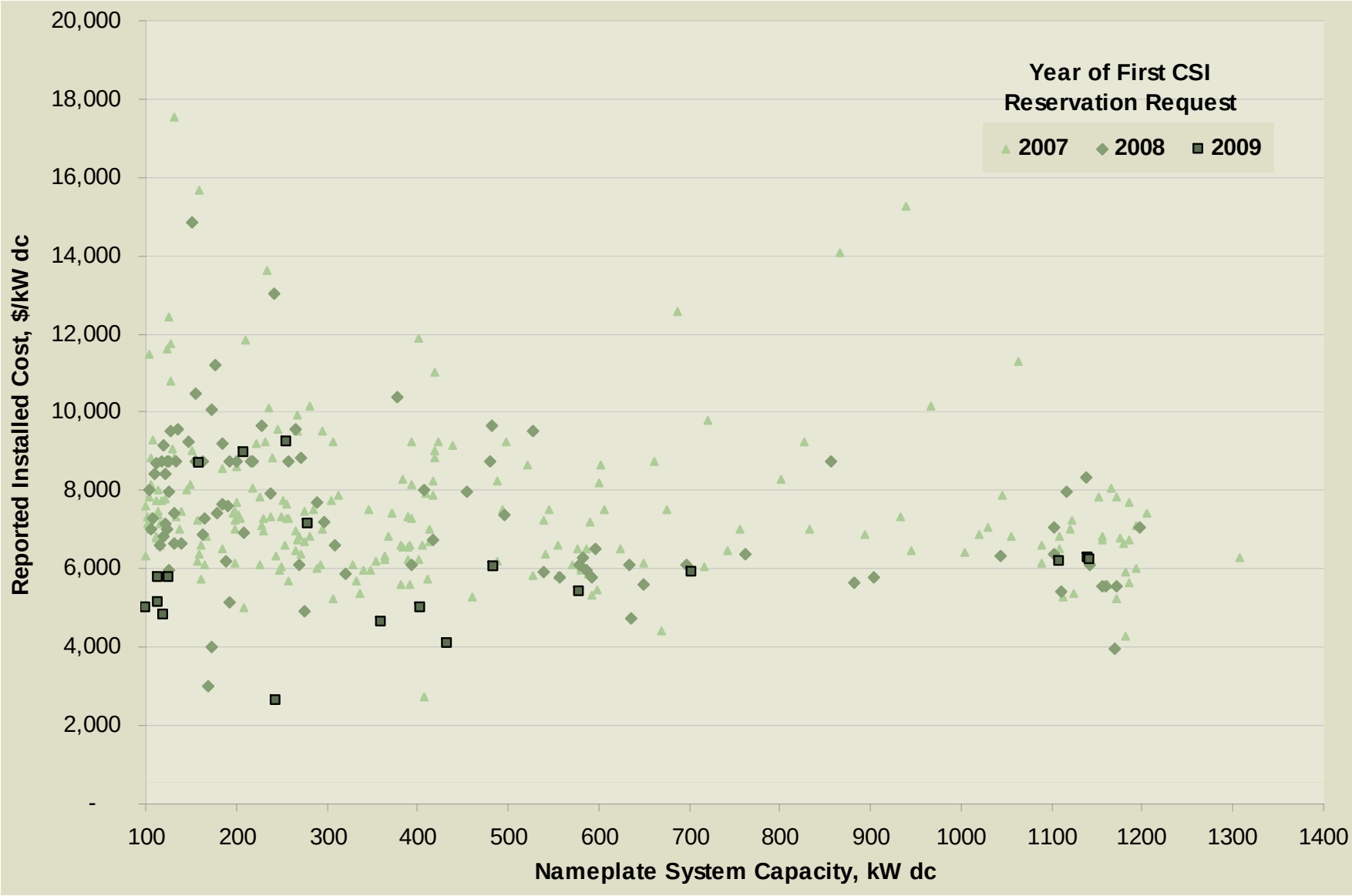
Owner's Costs (5 MW and 20 MW)

- Owner's costs include spare parts, water supplies, project development, owner's project management, sales and other taxes, insurance, advisory fees, legal, financing (including interest during construction), land/roof acquisition (as applicable), startup and construction support. There is a high degree of variation in this item due to unique customer approaches.
- We have chosen 0.68-0.76 $/watt after reviewing actual owner's costs for three development projects and reviewing allocation percentages made for previous studies (up to 25 percent)

Analysis of Data from California Solar Initiative

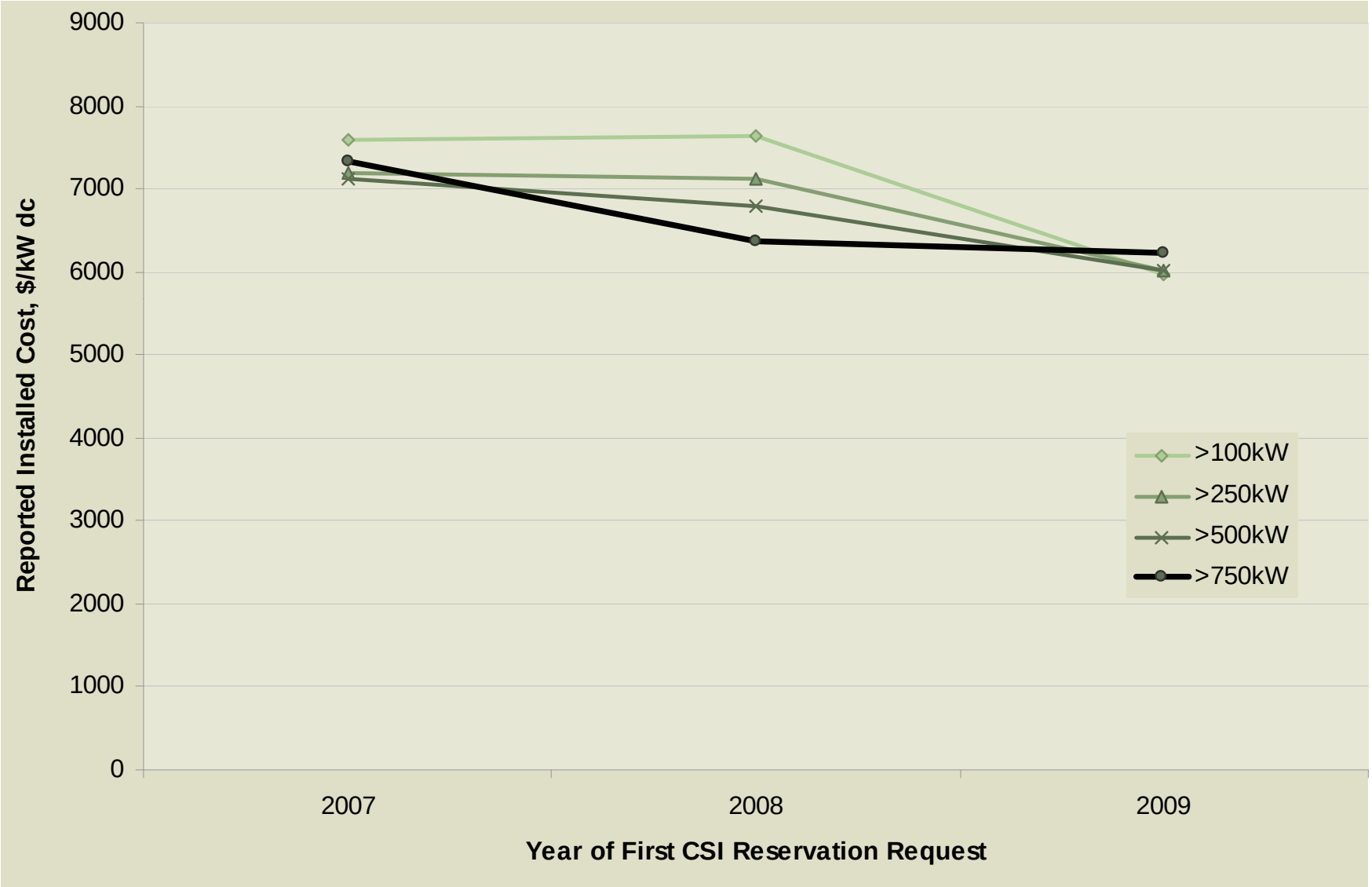
- Reported system cost data for systems installed under CSI
- Generally <1 MW
- Data is known to contain errors and other inconsistencies
- Data source: CSI PowerClerk, June 9, 2010
- Ratings are reported nameplate rating (kW dc)

Economies of Scale – Data from Installed Systems >100 kW



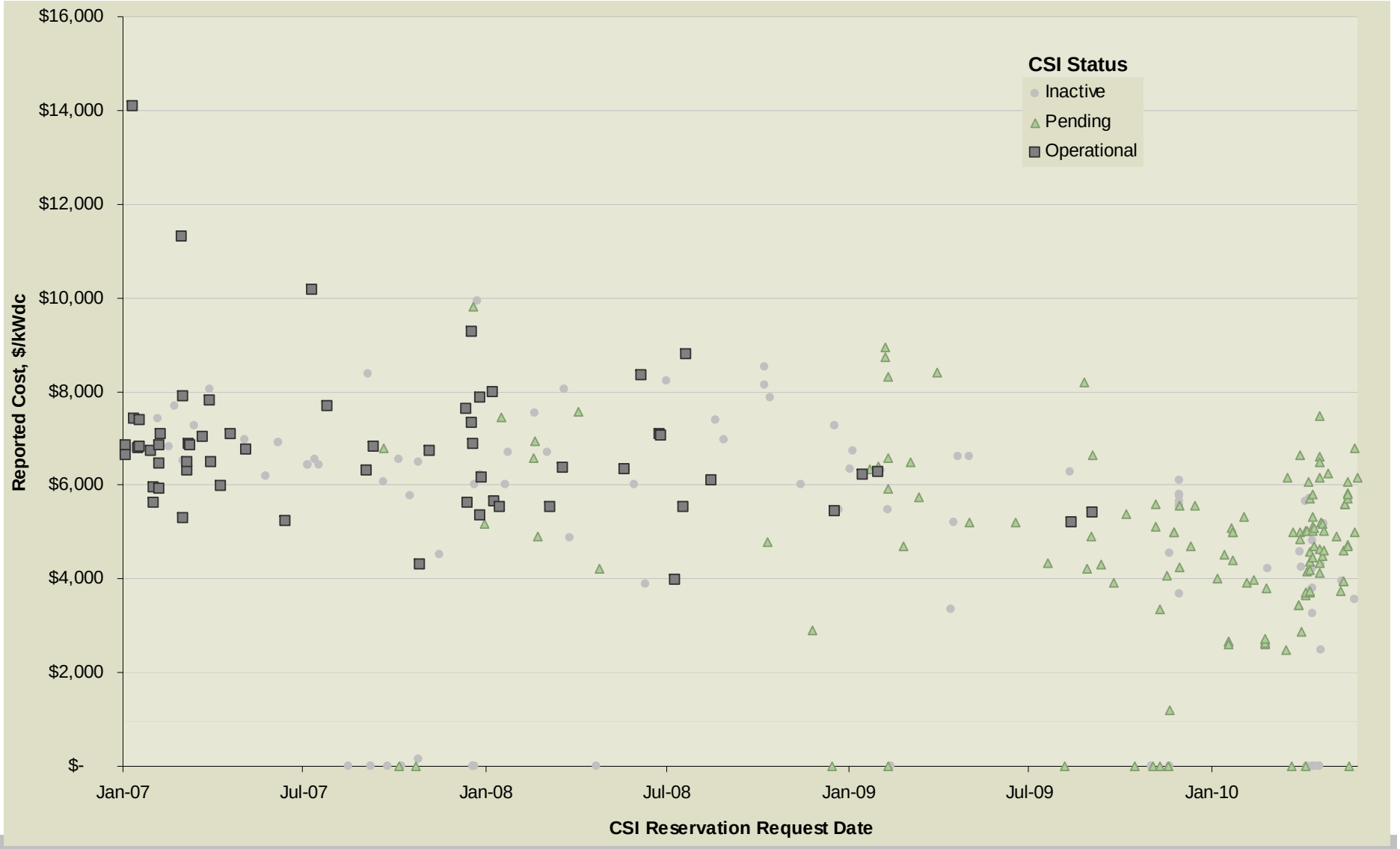
Data source: CSI PowerClerk, June 9, 2010

Falling System Costs – Installed Systems Only



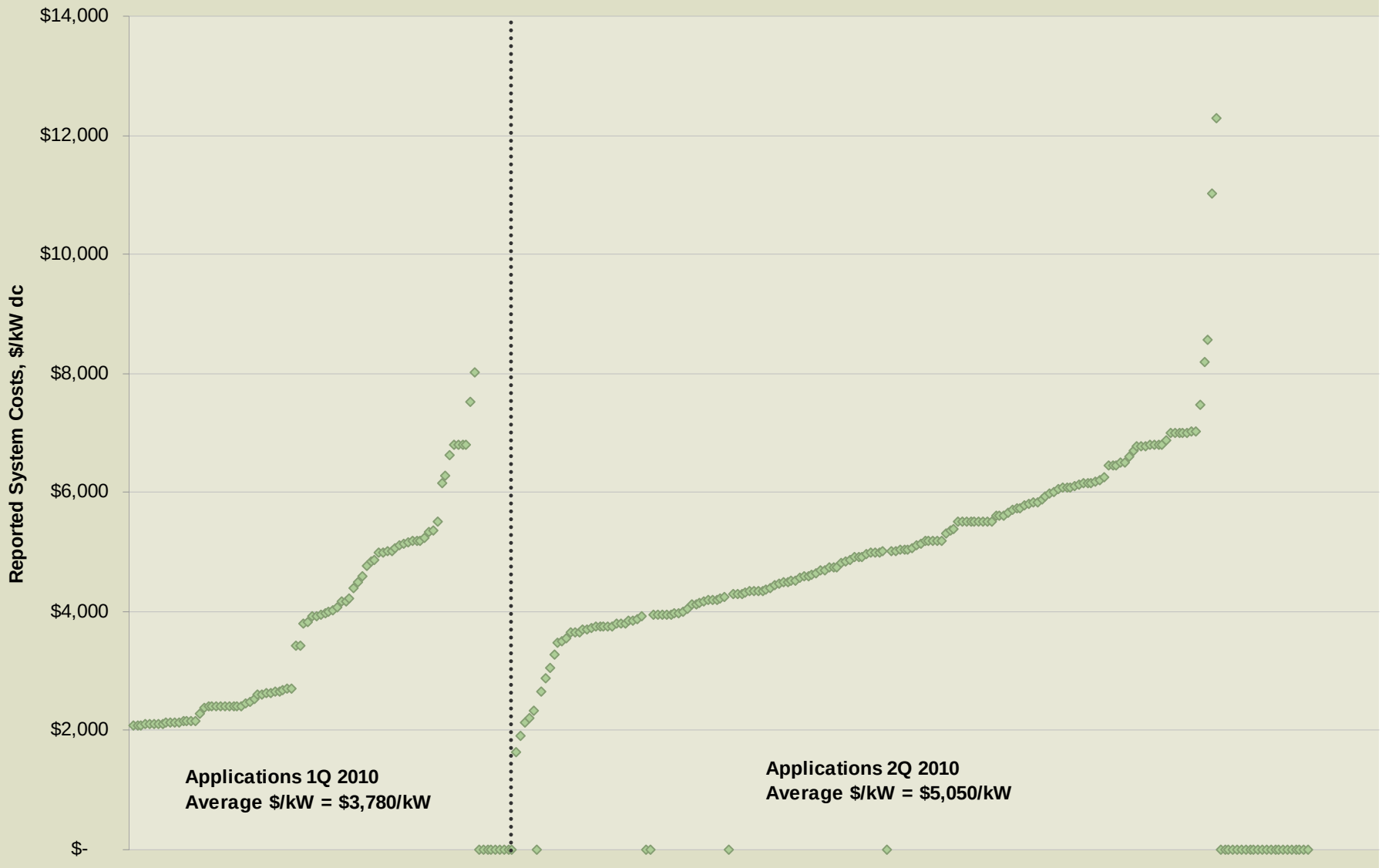
Data source: CSI PowerClerk, June 9, 2010

Data from Pending Applications Indicates Potentially Lower Costs, But Should be Treated Cautiously (Systems >750 kW Only)



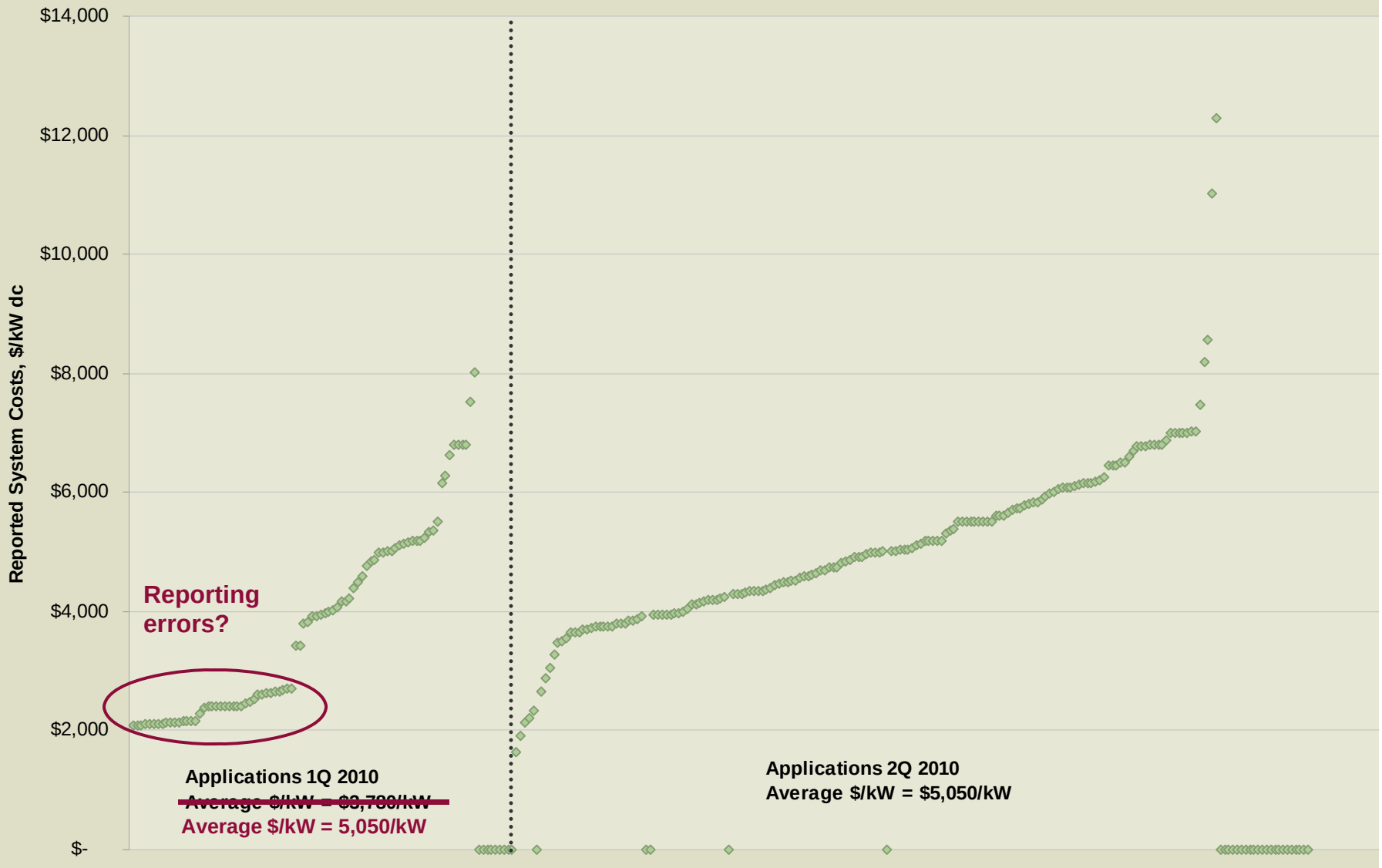
Data source: CSI PowerClerk, June 9, 2010

Most Recent CSI Pending Applications, >300kW



Data source: CSI PowerClerk, June 9, 2010

Most Recent CSI Pending Applications, >300kW



Data source: CSI PowerClerk, June 9, 2010

Performance Estimates for Large 150 MW Sites DC Capacity Factor

Desert

- Thin Film: 21.3%
- Tracker: 23.2%

Central Valley

- Thin Film: 18.8%
- Tracker: 21.3%

Energy+Environmental Economics

LTPP Solar PV

Potential and Levelized Cost of Energy (LCOE)

June 18, 2010

Overview of Presentation

- DG PV Potential estimates by size and location
  - Methodology
  - Results
- Levelized cost of energy estimates by size and location
  - LCOE Tool
  - Results
- Appendix
  - Potential Estimates
  - LCOE Input Assumptions (also available in tool on website)

Goals of Potential Analysis

- Develop PV Potential estimates
  - Identify ‘Easy to connect’ and ‘harder to connect’
  - 4 size and configuration categories
    - 0.5 – 2 MW Roof, 0.5 – 2 MW Ground, 2 – 5 MW Ground, 5 – 20 MW Ground
  - 4 locations across California
    - Desert, Central Valley, North Coast, South Coast

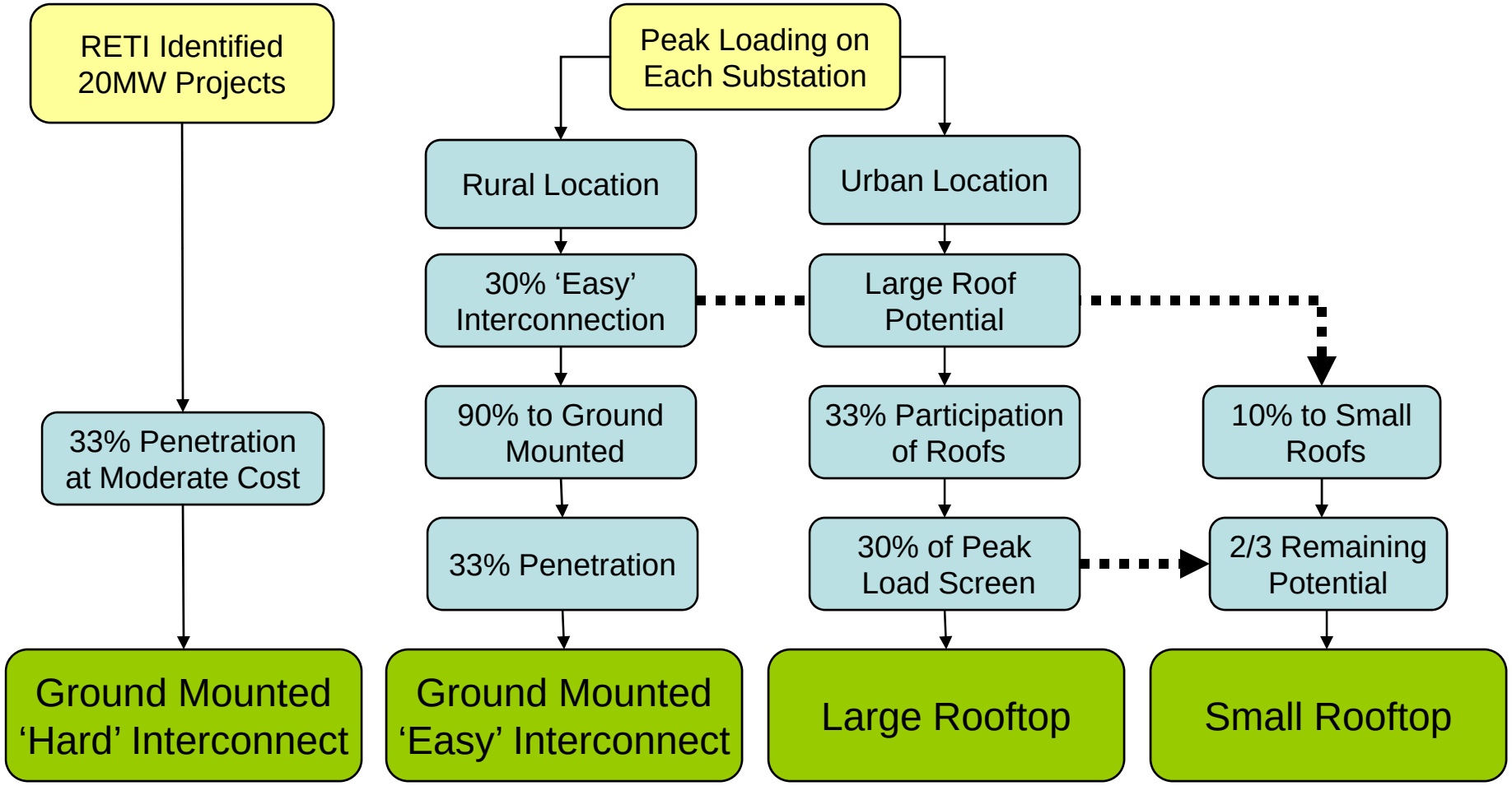
PV Potential Estimation

- Adjusted the 33% RPS Implementation Analysis potential study approach
  - Same underlying proprietary utility substation loadings and locations as used previously
  - Same large rooftop potential with satellite imagery
- Key changes
  - Added small roofs in rural areas
  - “Set aside” potential for current programs

Screening Assumptions

- ‘Easy’ Interconnection
  - Nameplate PV system is less than or equal to 30% of peak load at point of interconnection to avoid reverse flow
- Participation
  - 33% of large roof owners will participate
- Penetration
  - 33% of feeders accommodate ground-mounted systems up to the ‘easy’ interconnection limits
  - 33% of RETI identified large PV sites can be interconnected with a moderate transmission interconnection cost
  - 10% of rural ‘easy’ interconnection potential in small roofs

PV Potential Screening Method



Screening Steps

- Raw Potential (MWs):

RETI Identified Sites
27,500

Substation Load Total
39,323

- After Screening (MWs):

Hard-to-Interconnect	Easy-to-Interconnect				TOTAL
Ground Mounted (>30% of peak load)	Ground Mounted (<30% of peak load)	Large Rooftop	Small Rooftop	Easy-to-Interconnect Total	
9167	2350	3671	3235	**9257**	**18424**

- After Removing Existing Programs (MWs):

Hard-to-Interconnect	Easy-to-Interconnect				TOTAL
Ground Mounted (>30% of peak load)	Ground Mounted (<30% of peak load)	Large Rooftop	Small Rooftop	Easy-to-Interconnect Total	
9167	1728	3241	977	**5947**	**15113**

Modeled PV Potential (MW)

		Easy to Interconnect					Harder to Interconnect	TOTAL
		Ground Mounted (5-20MW)	Ground Mounted (2-5MW)	Ground Mounted (0.5-2MW)	Large Rooftop	Small Rooftop	RETI projects (>30%)	
PG&E	North Coast	151	46	13	779	18	1260	2266
	Central Valley	136	110	23	0	3	4267	4539
	TOTAL	**287**	**156**	**36**	**779**	**21**	**5527**	**6805**
SCE	Mojave Desert	55	9	2	0	14	947	1027
	Central Valley	99	14	2	0	420	467	1002
	South Coast	672	4	1	986	8	280	1951
	TOTAL	**827**	**27**	**5**	**986**	**442**	**1693**	**3981**
SDG&E	South Coast	86	2	0	138	103	153	483
	Mojave Desert	45	1	0	72	54	80	252
	TOTAL	**131**	**4**	**1**	**210**	**157**	**233**	**736**
Other	Central Valley	138	4	1	710	200	960	2013
	North Coast	26	1	0	133	38	180	377
	Mojave Desert	82	2	0	424	120	573	1202
	TOTAL	**246**	**7**	**1**	**1267**	**357**	**1713**	**3592**
TOTAL		**1492**	**193**	**43**	**3241**	**977**	**9167**	**15113**

Goals of PV LCOE Analysis

- Create a publicly available pro-forma tool that calculates a levelized cost (LCOE)
- Develop model inputs
  - Capital Costs and Operating Costs
  - Performance parameters
  - Financing assumptions
- Calculate levelized cost of solar PV
- Standardize the LCOE presentation

PV Financial Pro Forma Tool

- Balance complexity vs. applicability for a broad range of projects
- Some of the features:
  - Debt Service Coverage Ratio (DSCR) limit
  - Inverter replacement fund
  - Debt service reserve fund
- Available on E3 website for download;
  - http://www.ethree.com/public_projects/cpuc6.html

Example – Model Inputs

Location: Desert
Technology: 5-20 MW Ground Mounted

System Cost & Performance Inputs:

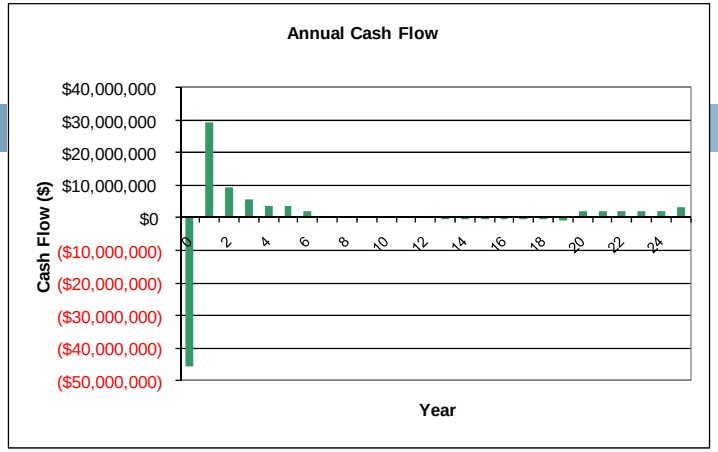
	Inputs
System Size (DC) (MW)	20
System Cost ($/watt DC)	$3.700
Annual DC Capacity Factor	21.3%
System lifetime (Years)	25
Degradation Factor (%/yr)	1.00%
O&M Costs ($/kW)	$20.0
O&M Cost Escalator (%/yr)	2.0%
Inverter replacement cost ($/W)	$0.250
Inverter replacement time (Years)	10
Insurance Expense ($/kW)	$20.0
Insurance Escalator (%/yr)	2.0%

Financing Inputs:

	Inputs
Percent Financed with Equity	60%
After-Tax WACC	8.25%
Debt Interest Rate	7.50%
Cost of Equity	*10.79%*
Target minimum DSCR	1.40
Debt Period in Years	20
Federal Tax Rate	35%
State Tax Rate	9%
Tax Credit Rate	30%
MACRS Term	5
Escalator	0%

Example – Cash flow

Location: Desert
Technology: 5-20 MW Ground Mounted



- Screenshot of cash flow:

Year	0	1	2	3	4	5	6	7
Energy Production (MWh)		**37,398**	**37,024**	**36,654**	**36,288**	**35,925**	**35,565**	**35,210**
Cost of Generation ($/MWh)		$167.8186	$167.8186	$167.8186	$167.8186	$167.8186	$167.8186	$167.8186
Operating Revenue		$6,276,144	$6,213,383	$6,151,249	$6,089,737	$6,028,839	$5,968,551	$5,908,865
Total Revenue		**$6,276,144**	**$6,213,383**	**$6,151,249**	**$6,089,737**	**$6,028,839**	**$5,968,551**	**$5,908,865**
O&M Costs		($408,000)	($416,160)	($424,483)	($432,973)	($441,632)	($450,465)	($459,474)
Inverter Replacement Cost		($500,000)	($481,250)	($462,500)	($443,750)	($425,000)	($406,250)	($387,500)
Insurance Costs		($408,000)	($416,160)	($424,483)	($432,973)	($441,632)	($450,465)	($459,474)
Total Costs		**($1,316,000)**	**($1,313,570)**	**($1,311,466)**	**($1,309,696)**	**($1,308,265)**	**($1,307,180)**	**($1,306,449)**
Operating Profit		**$4,960,144**	**$4,899,813**	**$4,839,783**	**$4,780,041**	**$4,720,575**	**$4,661,371**	**$4,602,417**
Interest Expense		($2,352,336)	($2,298,015)	($2,239,620)	($2,176,846)	($2,109,364)	($2,036,820)	($1,958,836)
Loan Repayment Expense (Principal)		($724,274)	($778,595)	($836,990)	($899,764)	($967,246)	($1,039,790)	($1,117,774)
Debt Service Reserve		$0	$0	$0	$0	$0	$0	$0
Interest earned on DSRF		$110,938	$110,938	$110,938	$110,938	$110,938	$110,938	$110,938
Net Finance Costs		**($2,965,672)**	**($2,965,672)**	**($2,965,672)**	**($2,965,672)**	**($2,965,672)**	**($2,965,672)**	**($2,965,672)**
State tax refund/(paid)		$1,067,983	$1,853,506	$1,016,326	$513,663	$512,954	$134,979	($243,499)
Federal tax refund (paid)		$26,165,147	$5,446,615	$2,922,281	$1,406,400	$1,403,842	$263,400	($878,857)
Taxes Saved/(Paid)		**$27,233,130**	**$7,300,121**	**$3,938,607**	**$1,920,063**	**$1,916,796**	**$398,379**	**($1,122,356)**
Equity Investment	($45,593,868)							
After-Tax Equity Cash Flow	**($45,593,868)**	**$29,227,602**	**$9,234,262**	**$5,812,717**	**$3,734,431**	**$3,671,699**	**$2,094,078**	**$514,389**

PV Bid Pricing vs. LCOE

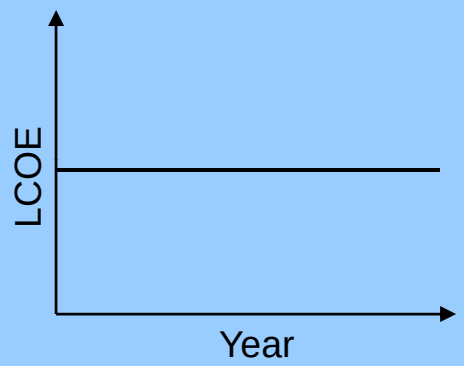
- The same $/kWh price can be presented in several different ways
- PV bids typically reflect the price *before* Time of Day (TOD) factors are applied
- Developers see the post-TOD value, which is the true cost of the PV system
- Escalators can skew costs when compared to flat levelized costs
- Results herein are post-TOD, flat nominal levelized

Comparison: PV LCOE metrics

Post-TOD flat nominal levelized used to show results

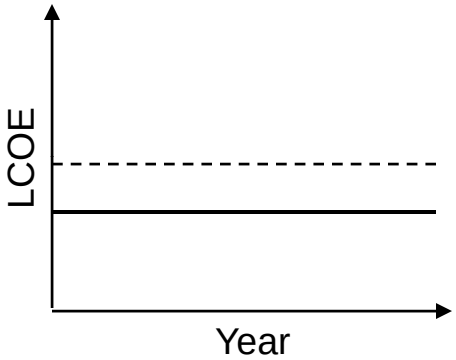
Post Time-Of-Delivery (TOD) Flat nominal levelized:

$0.1678/kWh



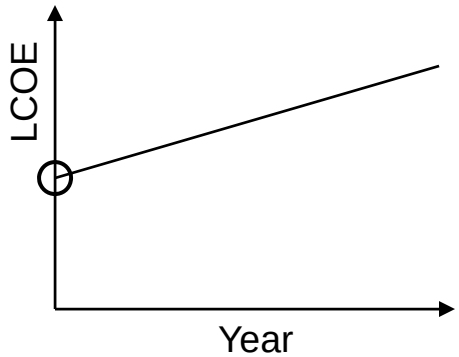
Pre-TOD Flat nominal levelized*:

$0.1266/kWh



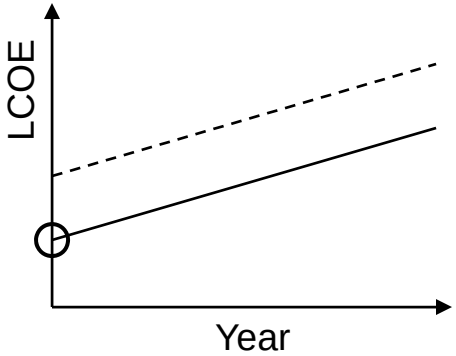
Post-TOD Year-1 cost with escalator:

$0.1441/kWh



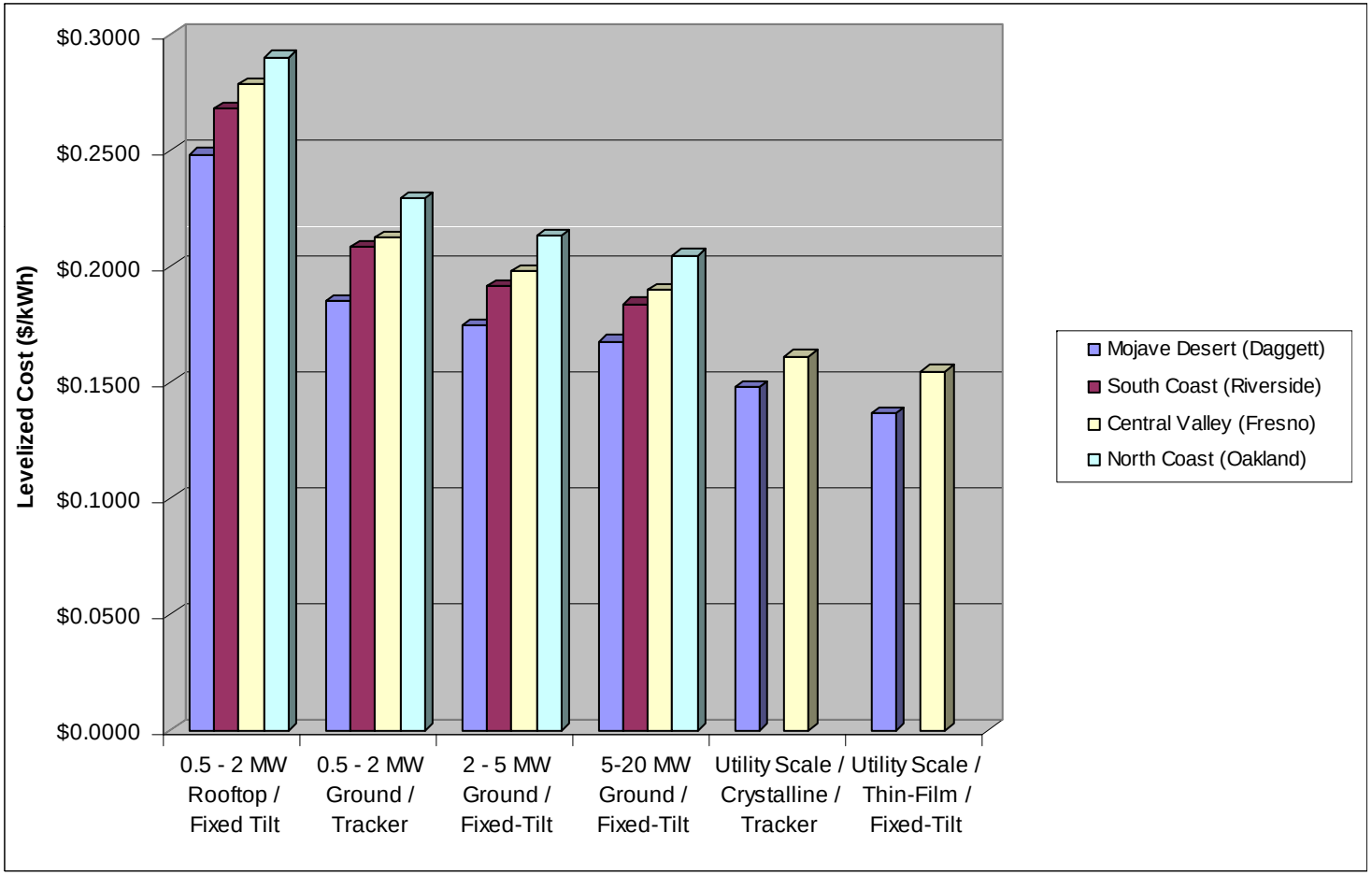
Pre-TOD Year-1 cost with escalator* :

$0.1087/kWh



Note: Costs shown correspond to a project in the 5-20MW ground mounted category in the desert.
*Using a TOD factor of 1.3257 (SCE TOD schedule using TMY3 output data from Daggett with a ground mounted 25°fixed tilt system)

Levelized Cost of Energy from PV



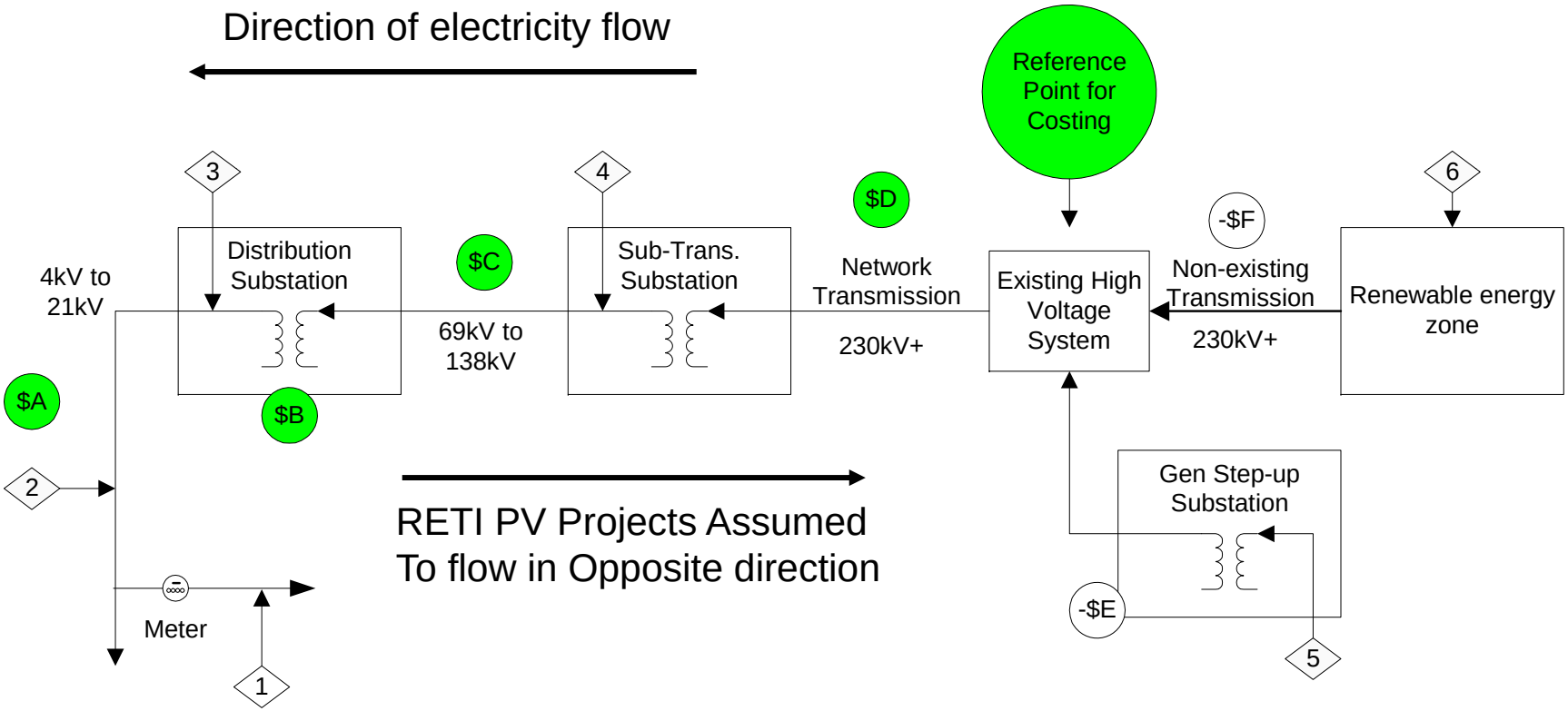
Results – Post-TOD Nominal LCOE
(Nominal $/kWh)

	0.5 - 2 MW Rooftop / Fixed Tilt	0.5 - 2 MW Ground / Tracker	2 - 5 MW Ground / Fixed-Tilt	5-20 MW Ground / Fixed-Tilt	150 MW Utility-Scale / Tracker	150 MW Utility-Scale / Fixed-Tilt
Mojave Desert (Daggett)	$0.2483	$0.1852	$0.1748	$0.1678	$0.1482	$0.1366
South Coast (Riverside)	$0.2683	$0.2085	$0.1916	$0.1840	N/A	N/A
Central Valley (Fresno)	$0.2788	$0.2127	$0.1979	$0.1900	$0.1612	$0.1548
North Coast (Oakland)	$0.2904	$0.2294	$0.2132	$0.2048	N/A	N/A

Energy+Environmental Economics

Appendix

Diagram of Interconnection Points

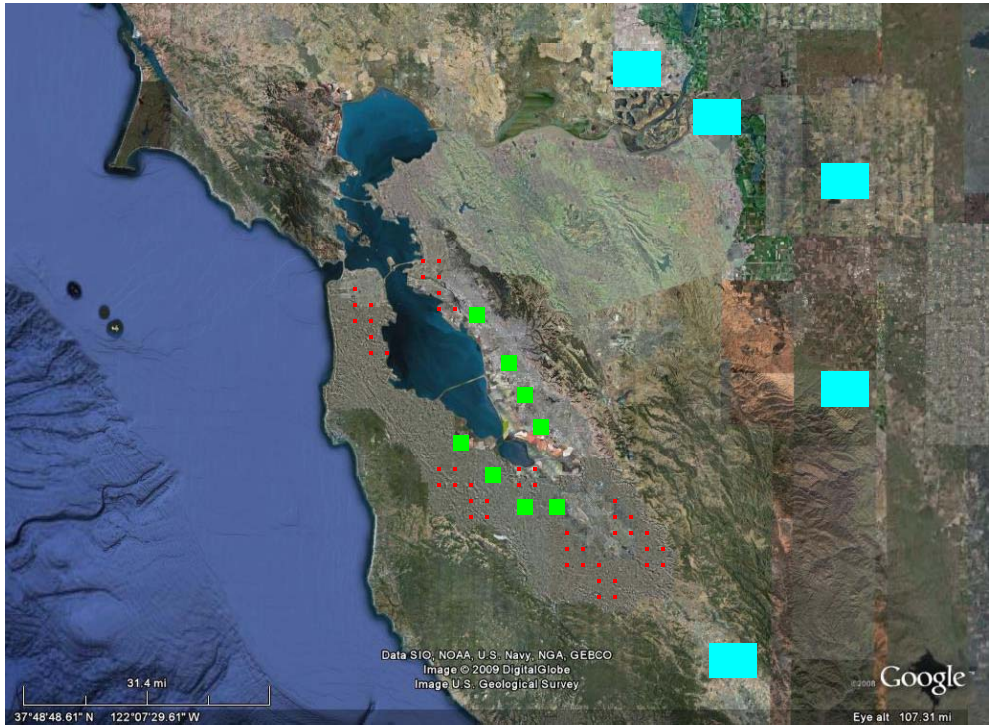


Distributed Solar PV

- 20 MW sites near non-urban 69 kV substations
- Smaller projects on rooftops, large commercial rooftops with 0.25 MW potential
- Limited by 30% peak load at a given substation

Illustrative Example of Distributed Solar PV

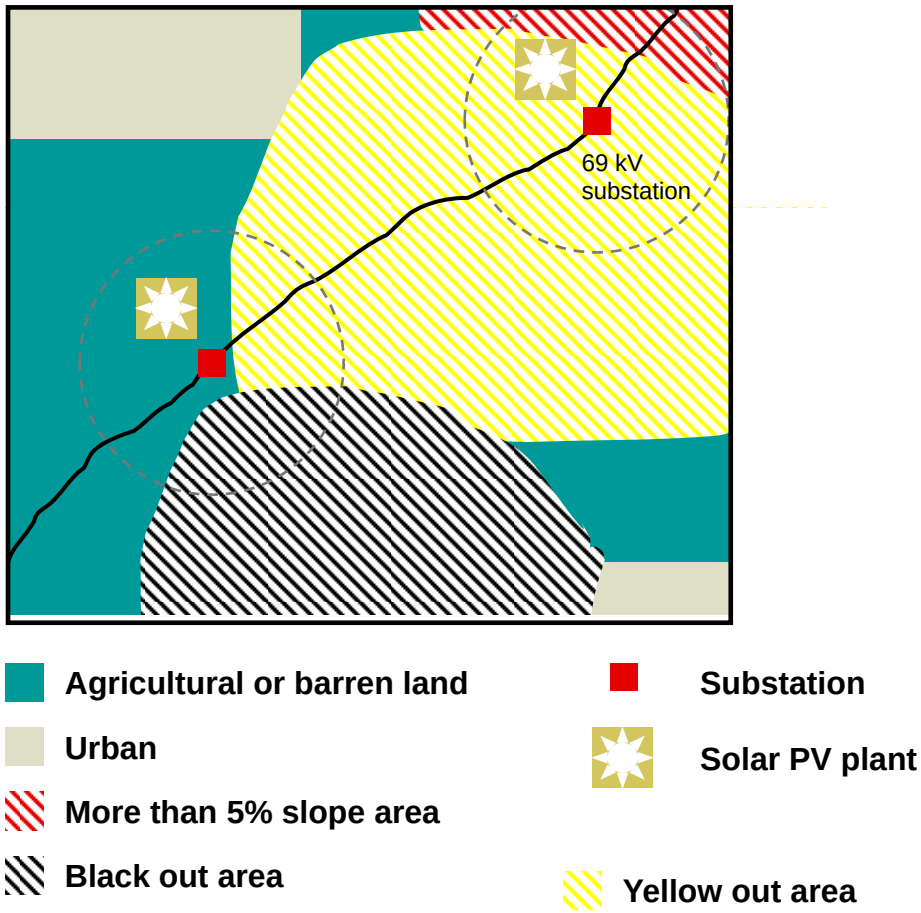
- 20 MW near substations
- Large commercial rooftops
- Residential rooftops



Ground Mounted PV

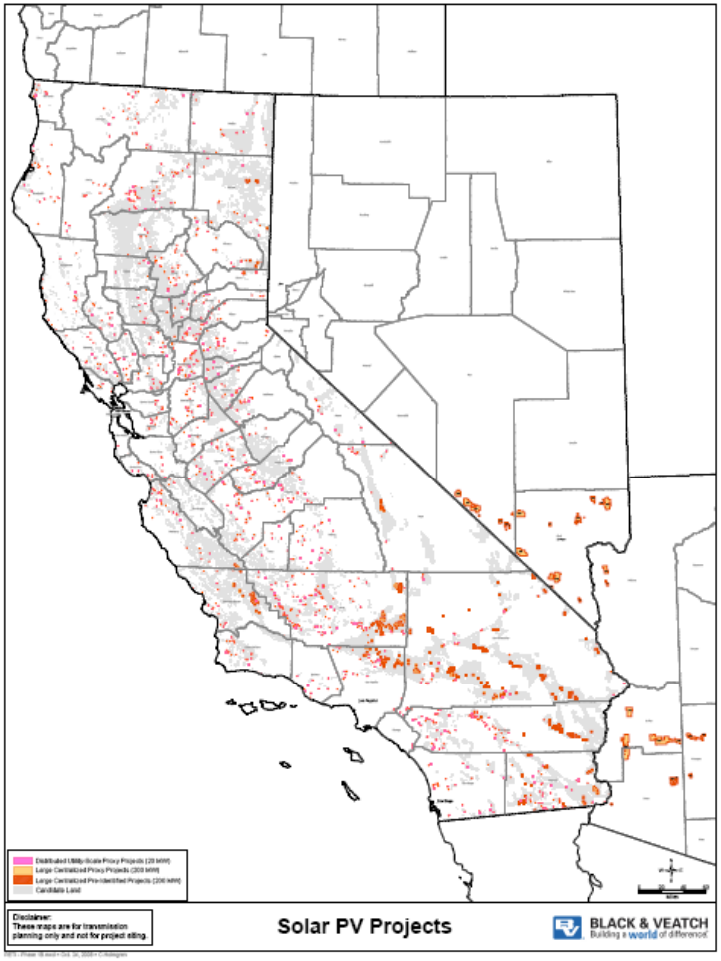
- Initial criteria
  - near sub stations equal or less than 69 kV
  - agricultural or barren land
  - less than 5% slope
- Environmental screen
  - Black out areas
  - Yellow out areas
- Land parcel
  - a continuous 160 acre plot (20 MWp)
  - within 20 miles

Example Map for Solar PV Non-Urban Projects



RETI Results on 20 MW Sites

- 27,000 MW nameplate PV sites identified
- ~1300 sites identified
- Filters Applied
  - 160 acres + for 20 MW
  - No sites within 2 miles of urban zones
  - Near substations, most are 2 to 3 miles of the distribution subs with 69kV+ high-side voltage
  - Land slope < 5%
- 20 MW on substations with high side voltage of 69kV
- 40 MW on substations with higher voltage than 69kV
- Assumed not to be Rule 21 compliant



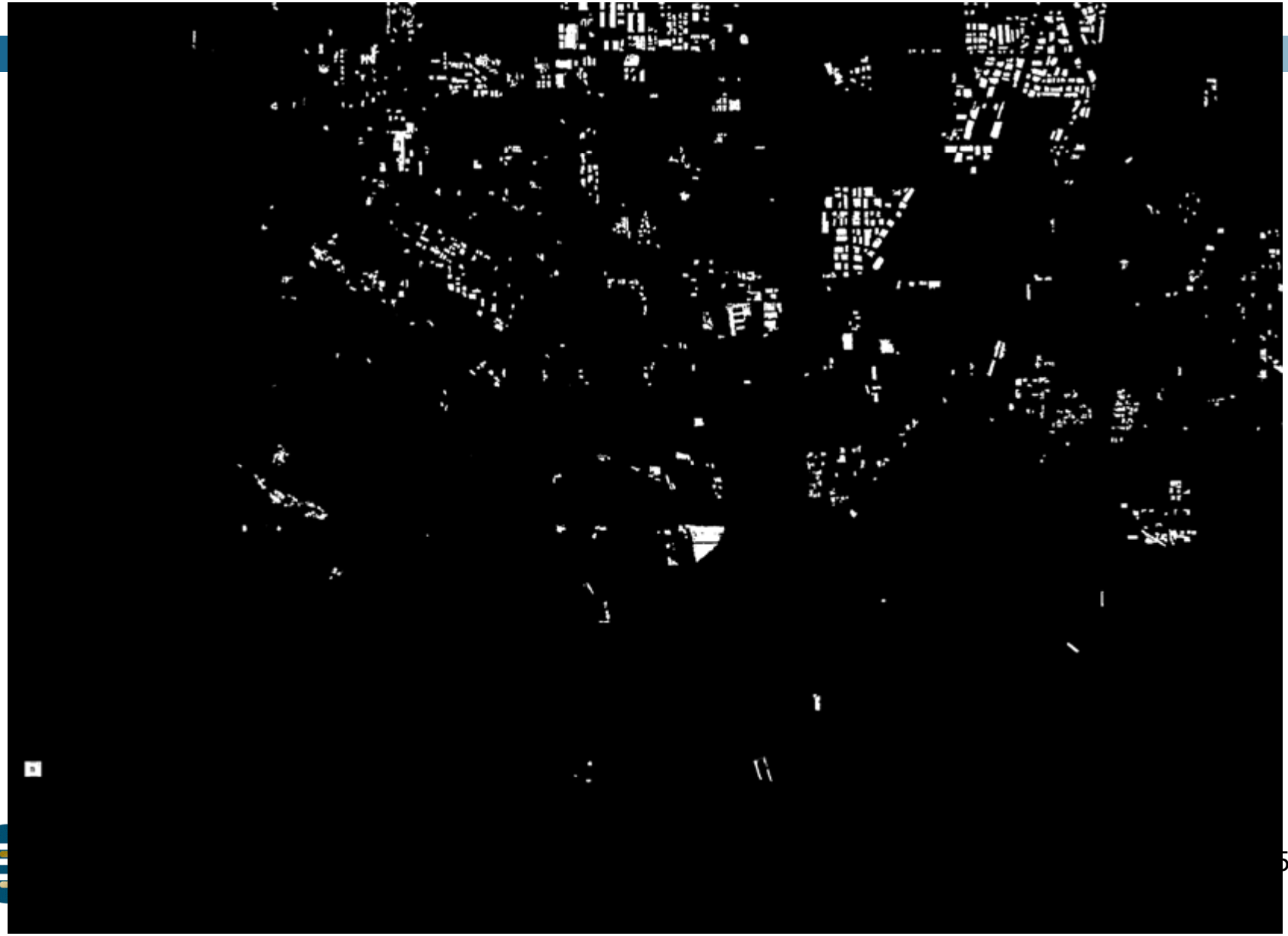
Black and Veatch Rooftop Analysis

- GIS used to identify large roofs in CA and count available large roof area
- Criteria
  - ‘Urban’ areas with little available land
  - Flat roofs larger than ~1/3 acre
  - Assumes 65% usable space on roof
  - Within 3 miles of distribution substation

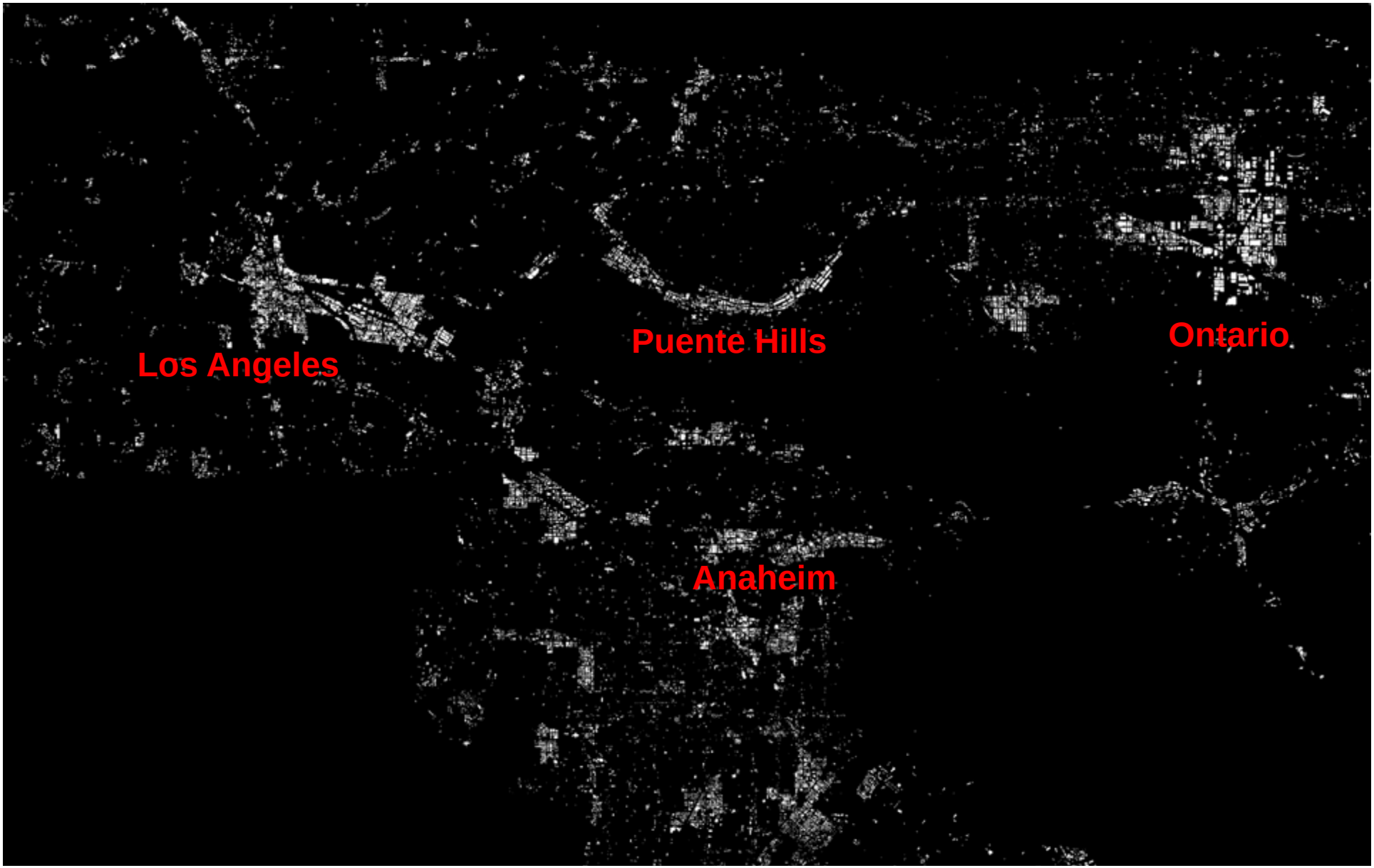
Solar Photovoltaic Rooftop Identification

Solar Rooftop Identification

Solar Rooftop Identification

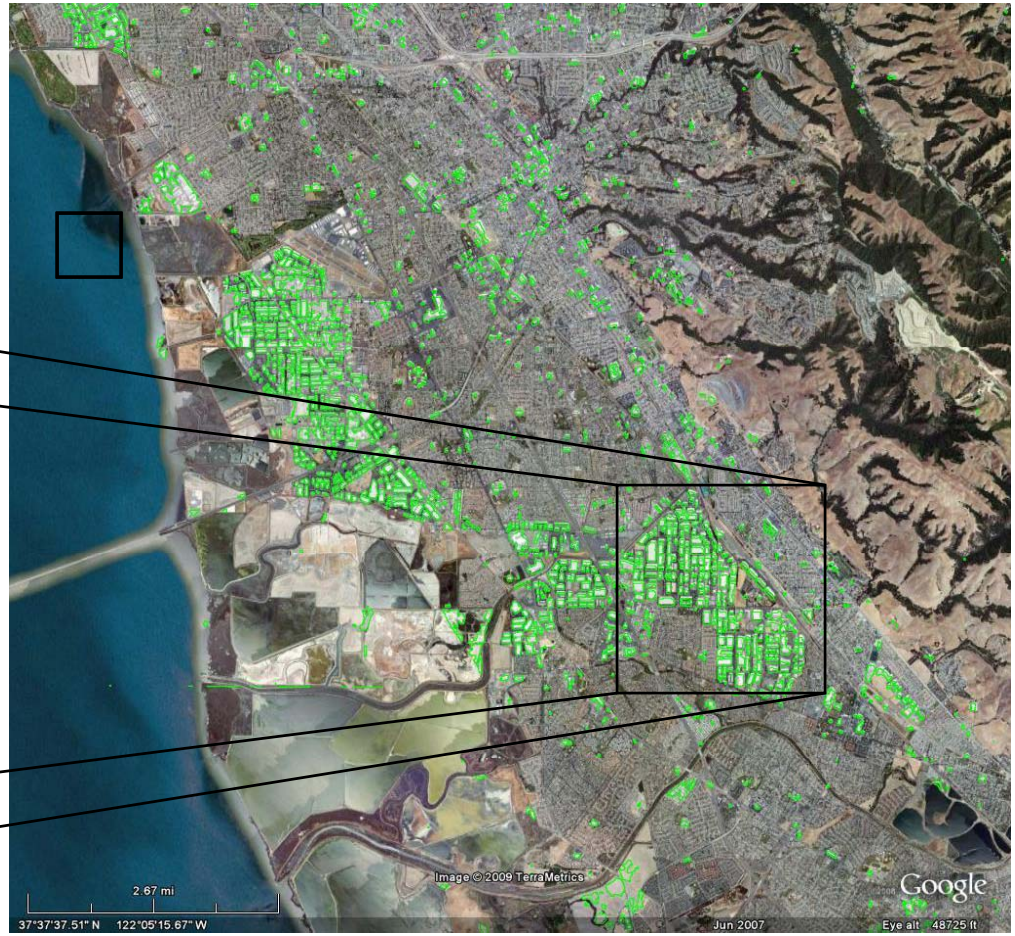


Los Angeles Area “Rooftop Resources”



East Bay Area Example

Analysis automates the counting of roof space and tallies total acreage of large roof space. Also checks proximity to distribution substation (not shown due to confidentiality).



Energy+Environmental Economics

Avoided Capacity Cost Assumption

- **Distribution: $34/kW-yr**
  - Used average of EE avoided costs
- **Subtransmission: $34/kW-yr**
  - Used average of EE avoided costs
- **Transmission: $0/kW-yr**
  - Network is more difficult
  - Set to zero for 33% RPS analysis

Issues

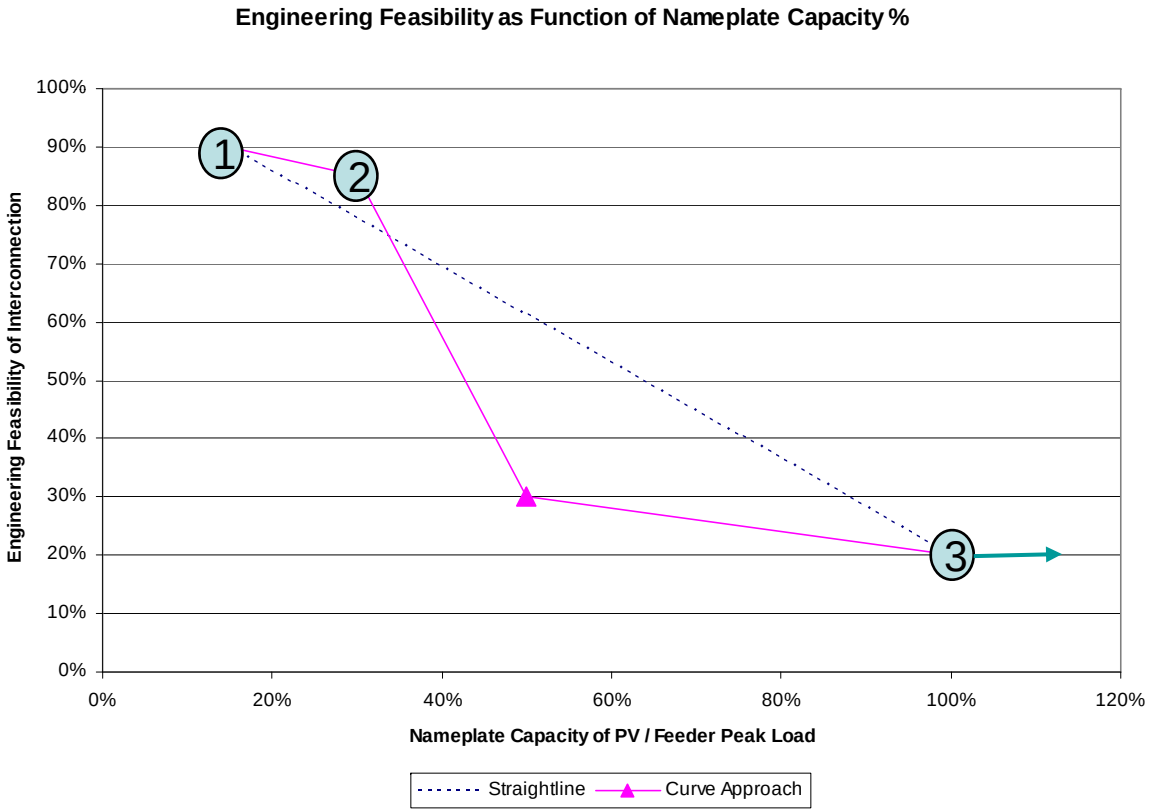
- Timeframe vs. geographic specificity – must use long time frame for avoided cost value
- Cost of non-Rule 21 RETI 20MW PV Installations not studied
  - Network transmission costs of $65/kW-year assumed for these resources

See EE avoided costs, R.04-04-025

Technical Feasibility of PV Connections that are >15% & <100% of Peak Load

- Assumption on PV engineering feasibility

Caveat
These numbers are based on an educated guess not on any engineering analysis.



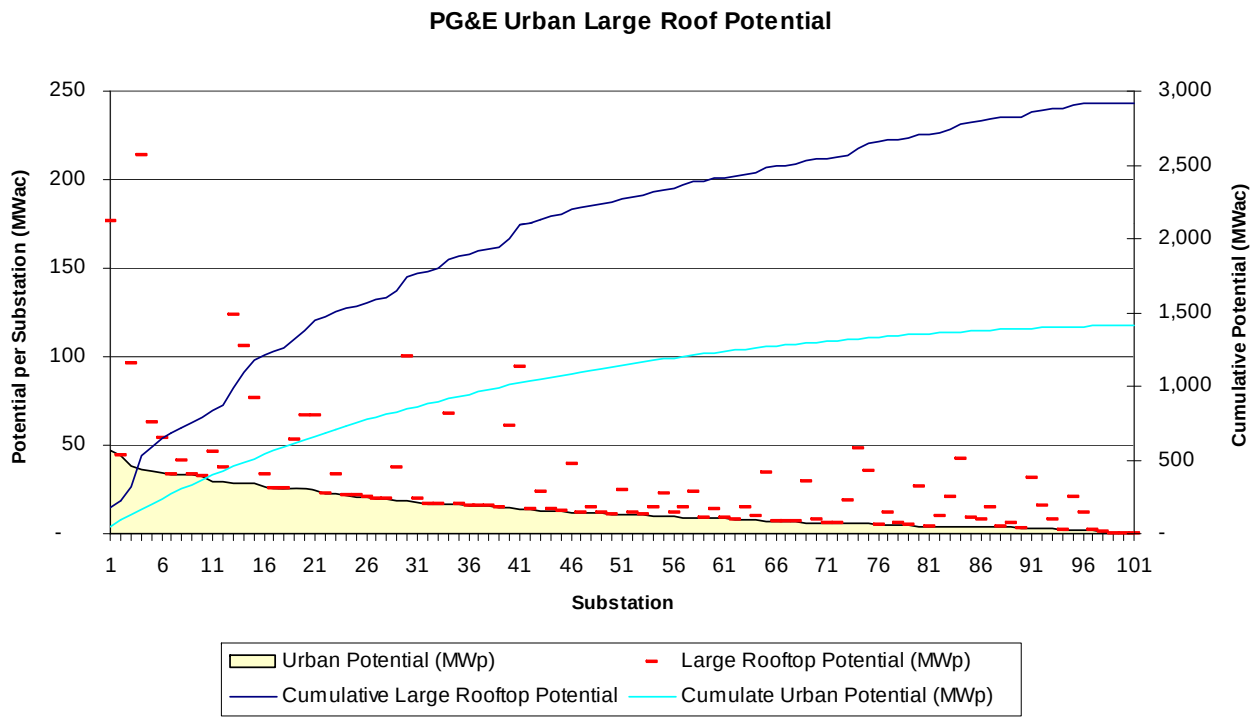
1 15% Peak Load
50% of in area PV

2 30% Peak Load
50% of in area PV

3 100+% Peak Load
RETI projects

Energy+Environmental Economics

PG&E Example – Bay Area



Clusters of large roofs make it impossible to do every roof and be below the 30% peak load.

PV LCOE Input Assumptions

- Capital Costs
- Capacity Factors
- Financing Assumptions
- Operating Costs

Black & Veatch Cost Estimates

1 MW rooftop	$5.00/watt dc
1 MW tracking	$4.75/watt dc
5 MW ground	$3.90/watt dc
20 MW ground	$3.70/watt dc

Based on configurations identified in B&V presentation
As stated previously, typical cost uncertainty is +/- 25%

Performance Estimates

Type	Location	DC Capacity Factor
1 MW Rooftop	Daggett	18.3%
	Fresno	16.3%
	Oakland	15.6%
	Riverside	16.9%
1 MW Tracking	Daggett	23.5%
	Fresno	20.5%
	Oakland	19.0%
	Riverside	20.9%
5 MW, 20 MW Fixed Tilt	Daggett	21.3%
	Fresno	18.8%
	Oakland	17.5%
	Riverside	19.5%

Financing Assumptions

- The following financing assumptions are used:

After-Tax WACC	8.25%
Debt Interest Rate	7.50%
Target DSCR	1.40
Debt Period in Years	20
Federal Tax Rate	35%
State Tax Rate	8.84%
Tax Credit Rate	30%
MACRS Term	5
Escalator	0%

- The model minimizes the % equity constrained to a target average DSCR of 1.40. This results in ~60% equity which slightly varies by technology and location.

Operating Costs

- Operating costs for the LTPP study are broken down into O&M, insurance and inverter replacement costs:

LTPP	O&M Costs ($/kWdc)	O&M Cost Escalator (%/yr)	Inverter replacement cost ($/Wdc)	Inverter replacement time (Years)	Insurance Expense ($/kWdc)	Insurance Escalator (%/yr)
Fixed Tilt	$20.0	2.0%	$0.250	10	$20.0	2.0%
Tracker	$25.0	2.0%	$0.250	10	$20.0	2.0%

- As a reference, operating costs in RETI are presented into a single O&M cost that includes all ongoing capital expenditures:

RETI (converted to $/kWdc)	O&M Costs ($/kWdc)	O&M Cost Escalator (%/yr)
Fixed Tilt	$32.0	0%
Tracker	$44.0	0%

March 12, 2010

Alan Solomon
Project Manager
California Energy Commission
1516 Ninth Street
Sacramento, CA 95814

DOCKET	
09-AFC-7	
DATE	MAR 12 2010
RECD.	MAR 15 2010

RE: **Palen Solar Power Project, Docket No. 09-AFC-7**
Responses to January 14, 2010 CEC Workshop Queries (Groundwater)
Technical Areas: Soil & Water Resources

Dear Mr. Solomon:

On March 11, 2010 Solar Millennium submitted responses to the January 14, 2010, CEC Workshop staff requests for additional information and clarification on several matters specific to local groundwater issues. It was discovered that the text portion of that submittal was from a prior submittal responding to related workshop queries regarding water resources, and therefore incorrect. The figures and tables submitted were in fact correct and the accompanying CD included all the correct material. Only the printed text was provided in error.

At your direction, we are resubmitting the entire package electronically. Please note that the text in this submittal is to supplant the text of the prior submittal of the same name.

If you have any questions on these data responses to the staff's workshop queries, please feel free to contact me directly.

Sincerely,

Alice Harron
Senior Director, Development

Solar Millennium LLC
1625 Shattuck Avenue, Suite 270
Berkeley, CA 94709-4611
tel (1) 510-524-4517
fax (1) 510-524-5516
Info@SolarMillennium.com
http://www.SolarMillennium.com

Responses to CEC Workshop, January 14, 2010

Soil and Water Resources (Groundwater)

Palen Solar Power Project

Docket No. 09-AFC-7

Alice Harron
Senior Director of Project Development
1625 Shattuck Avenue, Suite 270
Berkeley, CA 94709-1161

Groundwater Data Responses to January 14, 2010 CEC Workshop Queries – Palen Solar Power Project

Is RO permissible for dust control?

In an email to Paul Marshall of the CEC on February 11, 2010, Jennie Snyder of the Colorado River Regional Water Quality Control Board (RWQCB) indicated the discharge of RO brine for dust control would not be allowed. Solar Millennium is planning to have additional discussion of the decision with the RWQCB, though for the time being alternative options for brine management are being considered. In the event that the brine is managed using an evaporation pond or for any discharge of brine to land, the Board will require a Report of Waste Discharge (ROWD). Further, the RWQCB will also require a ROWD for the discharge to the septic and leach field even though the County of Riverside will permit the septic systems for the Project. This is because the proposed discharge is in excess of 5,000 gallons per day, and as per protocol the County would refer the project to the RWQCB who would require a ROWD. The ROWD for septic will be prepared in conjunction with the RO brine discharge ROWD and will be submitted upon determination by Solar Millennium of the brine management option.

Further discussion of where the LTU leachate/runoff will be discharged/disposed and analysis required prior to discharge (DR-S&W-199).

Excess wastewater or rain fall may occasionally accumulate in the land treatment unity (LTU). The LTU has been constructed with 2-foot high berms such that storm water will not drain into or from the LTU. Based on the frequency of storms in the area, it is anticipated that accumulation of rainwater within the containment would occur on a yearly basis. Each LTU is designed with a sump which will collect storm water runoff and/or leachate within the bermed area. Any storm water that accumulates within the LTU will be sampled for HTF (biphenyl and diphenyl ether) and amendment constituents (i.e., nitrate, phosphate, TDS). Sampling of the storm water will be conducted within 24 hours of the storm event and laboratory analyses will be run on a 24-hour turn-around-time. Standing water will be removed from the LTU within 48 hours. Following analytical results, free liquids will either be used as raw water feed in the process supply or removed using a vacuum truck. If HTF is not detected above the practical quantitation limit (PQL) and amendment concentrations are at or near background groundwater concentrations and below State of California primary or secondary maximum contaminant levels the water may be used as raw water feed in the plant process. If HTF is detected and amendment concentrations exceed background or drinking water standards, the waste will be properly disposed of at a licensed treatment storage and disposal facility.

Update the runoff recharge estimates (DR-S&W-194) to reflect 2, 5, and 10% of total calculated runoff value. Use the Basin inflow/outflow example from Genesis (WorleyParsons 2009b).

A revision to the water balance provided in the January 6, 2010 response to Data Request (DR)S&W-194 for the Chuckwalla Valley Groundwater Basin (Basin) was made to reflect a change in the estimate of infiltration from precipitation after Hely and Peck (1964) and to reflect the results of fieldwork in the northern portion of Palen Dry Lake completed by WorleyParsons (2009b). No other changes were made to the water balance estimates included in the January 6 response to DR-S&W-194.

In revising the infiltration estimate, the first step was to overlay the average annual isoheytal contours shown on Figure 6 from Hely and Peck (1964) onto the topography of the Chuckwalla Valley Groundwater Basin (Basin) (Figure DR-S&W-194-1 [rev1]). The second step was to multiply the

average annual precipitation within each contour times the area of the contour to derive an estimate of total precipitation in acre-feet for the Basin. Lastly, the total within each contour is multiplied by percentages of 3%, 5% and 10% representing an estimate of infiltration from precipitation within the contour and summing the individual areas to a total annual infiltration volume (acre-feet) for the Basin. Table DR S&W-194-1 (rev1) presents the estimate of total annual infiltration for the Chuckwalla Valley Groundwater Basin for these estimates of infiltration which vary from about 8,600 acre-feet (3%) to 28,600 acre-feet (10%). The infiltration estimate of 3% of precipitation compares favorably to the value estimated by WorleyParsons (2009a, Table DR-151-2) of 9,440 acre-feet.

In addition to changes made to the estimate of infiltration, the estimate of evapotranspiration (ET) and discharge through Palen Lake was revised, as the prior estimate appears to have been overly conservative. In the water balance provided on January 6, 2010, a discharge estimate of between about 1,000 and 2,000 acre-feet per year was provided under the assumption of ET rates of four to six inches, that shallow groundwater was present below the entirety of Palen Lake (4,260 acres), and with the entire lake acting as a wet playa. This estimate has been revised to reflect field work completed by WorleyParsons (2009b), and the mapping provided by Steinemann (1989) whose data suggests that water may be present at shallow depths below only about one half of the dry lake. In their investigation of Palen Lake in December 2009 (WorleyParsons 2009b), shallow hand-augured borings dug in the northern part of the lake encountered groundwater at a depth of about 8 feet below ground surface. In general, with uniform fine-grained soil conditions, at this depth, groundwater can discharge through capillary action and evaporation through a playa to a depth of about 10 feet (Lohman 1972, Todd 1980). Water level data from 1989 tend to corroborate shallow groundwater conditions below the north part of the lake (Steinemann 1989). However, water level contours suggest groundwater is present at depth of about 20 to 25 feet below the central and southern part of the lake. This suggests that only a portion of the lake, may be acting as a wet playa rather than the entire lake.

From their field survey of salt occurrence, results of the shallow boring program, and the absence of vegetation, Worley Parsons (2009b) concluded that 2,000 acres or about one-half of Palen Lake could be acting as a wet playa. Using Franklin Playa in Death Valley (Czarnecki 1997) as a model and revising the estimates of ET reported at Franklin considering the differences in water level data between the two areas, and adjusting for conditions in seasonality, WorleyParsons (2009b) concluded that about 350 acre feet per year (afy) could be discharging through the playa. This appears to be a reasonable estimate given that many of the features attributable to wet playas are absent from Palen Dry Lake.

From these changes, Table DR-S&W-194-2(rev1) approximating the Basin water balance was updated. The results of the update under an assumption that mountain front recharge would be about 3% of precipitation within the Basin, shows that there is a net surplus of water of about 2,200 acre-feet in the Basin water balance without the Palen Solar Power Project (PSPP), and about 1,900 acre-feet with the PSPP. Given the changes in water balance, the forecast water budget for the Basin as shown in Table 5.17-12(rev1) was updated using the revised balance as the baseline for year 2010. In the revised forecast, the recharge and discharge elements were not changed over the baseline year. This provides a conservative estimate in the forecast in that water use in parts of the Basin may decline through reduction in agriculture and at the Ironwood prison (GEI 2009). The forecast shows that during the construction period between 2011 and 2013, the PSPP will be about 35% of the total renewable water (i.e., amount of water recharge) during that period, and about 5% of the total water demand. Following construction of the PSPP, the operational water supply of about 300 acre-feet/year will represent between 3% and 8% of the total renewable water use, depending on the pumping schedule from other projects in the Basin after 2013. During operation, PSPP water supply represents about 1% to 2% of the total estimated demand within the Basin.

The cumulative demand from all the current and expected future sources result in a net annual and cumulative water budget deficit for the Basin beginning in 2014 and extending through 2043. The

maximum annual deficit is about 7,500 acre-feet, and is coincident with the onset of the proposed Eagle Crest Pump Storage project and the initial infilling of the lower ponds of the Eagle Crest project. Upon completion of all the proposed renewable projects, the annual deficit is about 1,300 acre-feet per year. Depending on the assumption of aquifer storativity, the cumulative decline in the average water level across the Basin after 30 is between less than about 0.5 foot and about 2 feet (Table 5.17-12[rev1]). It is anticipated that the water level decline would be greater in the areas of higher water demand both adjacent to current pumping centers and in the area of the renewable projects, and lesser further away from the pumping locations. Given its fractional contribution to the total water use, the PSPP does not represent a cumulatively considerable contribution to the water resource impacts to the Basin.

GEI, 2009, Eagle Mountain Pumped Storage Project No 13123 - Final License Application, Technnical Appendices for Exhibit E, Volume 3 of 6 Groundwater Supply Pumping Effects.

A.G. Hely and E.L. Peck, Precipitation, Runoff and Water Loss in the Lower Colorado River-Salton Sea Area, Geological Survey Professional Paper 486-B, 1964 (Hely & Peck, 1964).

Lohman, S. W., 1972, Ground-Water Hydraluics: Geological Survey Professional Paper 708: United States Geological Survey, Alexandria, Virginia.

Steinemann, A.C., 1989, Evaluation of Non-potable Groundwater in the Desert Area of Southeastern California for Powerplant Cooling. U.S., Geological Survey Water Supply Paper 2343. 44 pages.

Todd, D. K., 1980, Groundwater Hydrology, Second Edition: John Wiley and Sons, New York, New York.

WorleyParsons, 2009a, Data Requests – Response Set 1A, Genesis Solar Power Project, Riverside County, California. December 14.

WorleyParsons, 2009b, Technical Memorandum – Groundwater Resources Cumulative Impacts Analysis for Genesis Solar Power Project, Riverside County, California. December 30.

Provide evidence that Project water demand can be met without impact to nearby wells or creating Basin overdraft.

The groundwater model that was provided in the data response dated January 6, 2010, was revised to reflect an updated interpretation of the distribution of transmissivity within the Basin. Bedinger et al 1989, in their mapping of the Chuckwalla Valley show a zone of fine-grained sediment below Palen Dry Lake extending from the surface to the Mesozoic basement rock (Cross Section E-E'). Simoni (1981) described two test well borings (Palen Lake No.1 and No.2) dug south-southeast of the lake, just north of the PSPP site as being predominantly fine-grained to depths of 425 and 505 feet below the ground surface, respectively. The results of the borings by Simoni (1981) generally reflect similar fine-grained conditions that were encountered in the drilling of the observation wells dug as part of the PSPP AFC pumping test program. Additionally, the low-well yield experienced during the pumping test on former agricultural well 5S/17E-33N01 is suggestive of lower transmissivity conditions and fine-grain materials, although it is probable that the well condition and age (installed in 1958) contributed to well performance.

These data along with published data from across the Basin were used to refine and remap the transmissivity zones for the groundwater model (see Figure DR-S&W-207-3). The lower transmissivity value from the Project's recent aquifer test (1,000 ft^2/d) was applied to Zone 1, which

includes the PSPP site and Palen Dry Lake, as well as the area around Ford Dry Lake. Apart from this area, the lower transmissivity value previously determined by USGS (6,300 ft2/d) (Leake et al. 2007) was applied to Zone 2, which includes areas east and west of the central low-transmissivity zone. This value appears to be a reasonable approximation of transmissivity data reported in these areas in the western and eastern portions of the Chuckwalla Valley. In addition to the published transmissivity data shown on Figure DR-S&W-207-3, available pumping data and specific capacity data were used to map the transmissivity across the Valley (see Figure DR-S&W-207-4). Higher pumping rates reported in the area of CocoPah Farms were used to demark higher transmissivity zones due west of the PSPP site. It is important to emphasize that the numerical modeling is a 2-D simulation and as such the transmissivity values are uniformly applied through the model domain and assumed constant through the vertical extent of saturated sediments. This represents a conservative approach to the analysis of water supply and impacts from the Project, as it presumes vertical uniformity of aquifer characteristics that are not documented in the hydrostratigraphy for the Basin. The Basin shows significant heterogeneity and possibly higher transmissive sediments at depth below the Project and in the central portion of the Basin.

The “Project Only” and “Cumulative Projects” simulations were modeled following the pumping schedule shown on Table DR-S&W-207-1(rev1). The pumping schedule was updated based on information provided on the BLM Palm Springs South Coast Field Office website posted on December 21, 2009, under the “First-in-Line” Solar Applications and approved project applications. The PSPP pumping was distributed among four wells within the Project Right-of-Way (ROW), as this would more closely approximate actual conditions and because multiple wells will be required in what appears to be a low-transmissive aquifer both for construction and operational water supply. No other parameters within the model were changed over what was provided in the January 6, 2010 data response. The results of the modeling were provided for transient simulations of post- construction (model year 2013), mid-Project operations (year 2029) and at the end of 30 years of Project operation (year 2043). The electronic model files are provided in Attachment A.

Project-Only Simulation

The “Project Only” simulation presents the predictive results from the stress applied to the model from the proposed project pumping as shown on the schedule provided in Table DR-S&W-207-1(rev1). The radius of influence for the “Project Only” simulation shows that after construction period and proposed water use of about 480 afy over three years the drawdown to the one-foot contour remains within the PSPP (Figure DR-S&W-207a[rev1]). At the end of operation the one-foot contour extends outward to encompass the area of CocoPah Farms, but the five-foot contour remains within the PSPP (Figure DR-S&W-207b[rev1]). The one-foot contour does not encroach into the northern portion of Palen Dry Lake and into the area where there are reportedly mesquite trees. These simulations show that the PSPP would not be expected to significantly impact offsite water supply wells using a significance threshold of a drawdown of five feet or more.

The storage change was also calculated using the model flow budget. The largest net change occurs at the end of operation and the change represents about 10,500 acre-feet (Table DR-S&W-207-2 [rev1]). Assuming a total recoverable storage of 15,000,000 acre-ft in the basin (DWR, 1979), the impact of basin storage is insignificant even for the largest storage change at the end of Project operation (0.07%). As described above, the Project would not induce overdraft of the groundwater basin, as there is an estimated net surplus of water of about 2,000 acre-feet per year based on current estimates of recharge and discharge within the Basin (Table DR-S&W-194-2(rev1)).

Cumulative Projects Simulation

The “Cumulative Projects” simulation presents the predictive results from the stresses applied to the model from the multiple projects proposed for the Basin at the pumping schedule shown on the schedule provided in Table DR-S&W-207-1(rev1). The projects listed are those that have been identified as planned and reasonably foreseeable projects located with the Basin. The cumulative

impacts assessment begins with current conditions and applied the pumping stresses as scheduled to the model through a period of 30 years. The model results are shown in Table DR-S&W-207-2(rev1). As shown on Figure DR-S&W-208a(rev1) at the end of construction the drawdown to the one-foot contour remains within the PSPP. While the figure does not show it, as the model was tied to the water supply schedule for the PSPP, a cone of depression would be anticipated in the area of the pumping well or wells that would provide the initial water supply for the Eagle Crest Pump Storage project. At the end of the operation the influence from pumping at the PSPP extends beyond the site to within an area of CocoPah farms, but the five- foot drawdown contour remains within the site (see Figure 208b[rev1]). Similar to the results of the project-only simulation, offsite water supply wells are not impacted by the PSPP to a threshold of significance greater than five feet of drawdown. Additionally, the model suggests that there could be a water level change of between one and five feet in the area of the Mesquite population on the northern margin of Palen Dry Lake. The model shows that the influence for this change comes from pumping to the west and the Eagle Mountain Pumped Storage project and not the PSPP.

Larger cones of depression are developed around the Genesis and Eagle Mountain Pump Storage Project as would be anticipated given their higher operational water supply requirements. The concept of depression developed around the Genesis is likely exaggerated due to the application of a low transmissivity value for Zone 1 in this area. As noted above, the uniform application of transmissivity in a 2-D model is a conservative approach and the model prediction should not be considered a water table response. Site conditions would suggest that water for the PSPP would be produced from deeper sediments below an upper fine-grained zone that serves as an aquitard within the central and eastern portion of the Basin.

Storage change was also calculated using the model flow budget. As can be seen, the largest net change occurs at the end of operation (year 2043) and the change from all the Projects represents about 142,000 acre-feet. Assuming a total recoverable storage of 15,000,000 acre-ft in the basin (DWR 1979), the impact of basin storage is insignificant even for the largest storage change at the end of operation (about one %). As noted above, given its minor contribution, the PSPP does not contribute significantly to the change in storage for the Basin.

Provide site specific well testing at yield levels that support Project water demand.

Access for additional well testing was requested through the BLM on February 19, 2010. Initial discussions with the BLM indicate that because of past PSPP survey work on the site, a Determination of NEPA Adequacy (DNA) could be utilized to conduct the additional investigation. The request has been was made for multiple additional test wells with the initial test well proposed in the PSPP Unit #2 Power Block. Additional wells and their location will be based on the results of the installation and pumping test on the initial test well in the Unit #2 Power Block. A surface geophysical program, extending the work done for the Genesis Project westward onto the PSPP site will be conducted prior to the installation of the first test well. The investigation will be conducted to better characterize the hydrostratigraphy below the site, the depth of the bedrock and the water table to the north of the site in the direction of Palen Dry Lake.

Discuss thresholds of significance for impacts associated with drawdown (DR-S&W-233).

Discussion during the workshop revealed that a threshold of significance was not necessarily appropriate given concern over potential drawdown in the northern portion of Palen Dry Lake in an area of dissected playa where a population of mesquite trees has been mapped. It is important to note that a drawdown of five feet is appropriate for assessment of significance with respect to the potential for

impact to adjacent water wells. As noted above, a drawdown of five feet or more is not predicted beyond the PSPP boundary even after 30 years. This five-foot drawdown value has been used in many other CEC projects as a measure of significance, and as the basis for needing mitigation measures.

As regards consideration of a drawdown that could affect vegetation in the area of the dissected playa on the north margin of Palen Lake the following are offered:

- The population of mesquite trees is many miles (about five to eight miles) north of the PSPP. The recent groundwater model shows that pumping will not induce a drawdown of more than 0.1 foot in the northern portion of the playa.
- Below Palen Dry Lake, shallow groundwater (<10 feet in depth) is probably present on the northern portion of the lake. Mapping by Steinemann (1989) showed that water is present at depths below 10 feet in the central and southern part of the playa.
- For most Phreatophytes, the depth to groundwater is an important factor and variations of 2 to 6 feet in ground water levels could have adverse affects in root growth as well as survival. Vegetation of this type was not reported by WorleyParsons (2009a) in their assessment of the Palen Dry Lake. As noted above, no such drawdown variation is predicted by the PSPP groundwater model.
- In comparison, mesquite, which are present in the dissected area of the playa are a deep rooted plant known to send roots 50 feet or more in search of water. This effectively buffers the plant to slight variations in groundwater levels, particularly in the case of adult trees that are established (Pers. Communication, Jonathan Campbell February 2, 2010).
- Well data from well 5S/17E-6C01 indicate stable groundwater conditions on the north side of Palen Dry Lake. The water level history for this well has spanned several years including periods of higher pumping in support of agriculture both in the area of Desert Center and pumping at CocoPah Farms west of the PSPP. The hydrograph however, appears to reflect a regional response to changes in basin wide pumping not the local pumping to the west. Similarly, it would be anticipated that the pumping at the PSPP would not affect the water levels this far north of the site.

Given the distance to the mesquite tress, their deep rooted character, absence of other vegetation on the northern margin of the playa, and the model prediction showing that the PSPP will not induce drawdown of 1 foot or more in the areas of the trees, a threshold of significance less than five feet does not appear justified.

Campbell, Jonathan, Personal Communications, Dr. Campbell, Campbell and Associates, Los Angles California. February 3, 2010.

Steinemann, A.C., 1989, Evaluation of Nonpotable Groundwater in the Desert Area of Southeastern California for Powerplant Cooling. U.S., Geological Survey Water Supply Paper 2343. 44 pages.

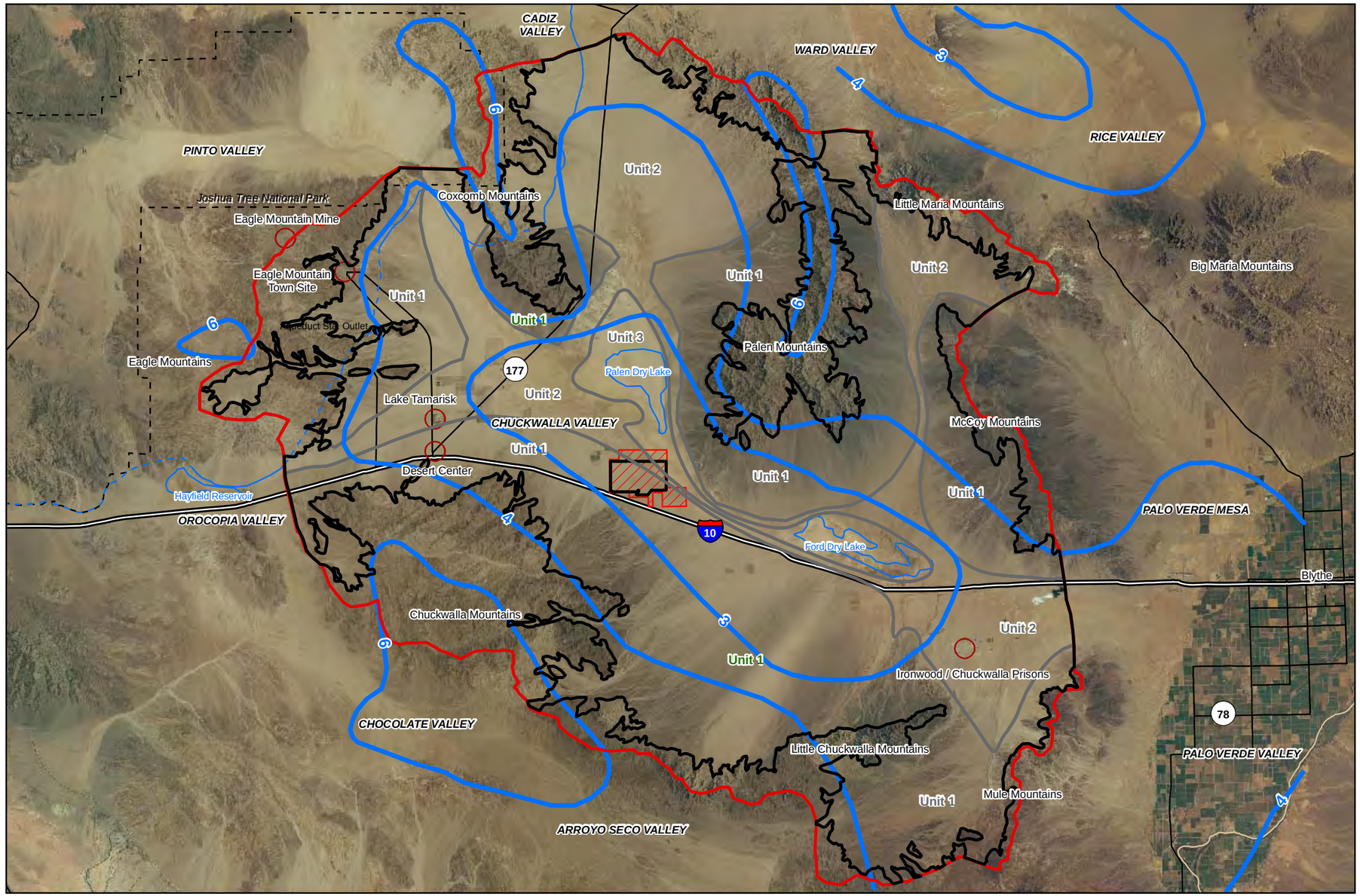
WorleyParsons, 2009b, Technical Memorandum – Groundwater Resources Cumulative Impacts Analysis for Genesis Solar Power Project, Riverside County, California. December 30.

Attachment A

MODFLOW Files

(See Modeling Files)

Figures



Map Location

Legend

- Project Right-of-Way
- Facility Footprint
- Colorado River Aqueduct
- Colorado River Aqueduct (Dash showing underground interval)
- Freeway
- Highway / Major Road
- Geographic/Cultural Area of Interest
- Chuckwalla Valley Groundwater Basin
- Chuckwalla Valley Watershed
- Average Annual Precipitation
- Runoff Curves (Distribution) Figure 10 After hely and Peck 1964)
  - Mountains
  - Unit 1 - Alluvium Steep Slope
  - Unit 2 - Alluvium Flat Slope
  - Unit 3 - Valley Alluvium

Data Sources:
Air Photo, California Spatial Information Library, NAIP, 2005 Riverside County

Water Basins, Department of Water Resources Website groundwater basin map file B118v3NAD27UTM10.zip

N W E S

0 6 12 Miles

1 inch = 380,160 inches

Palen Solar Power Project

Figure DR-S&W-194-1 (Rev. 1)
Average Annual Precipitation 1931-1961 (Hely & Peck, (1964)
Chuckwalla Valley Groundwater Basin

Palen Solar I, LLC

AECOM

Project: 60139694
Date: February 2010

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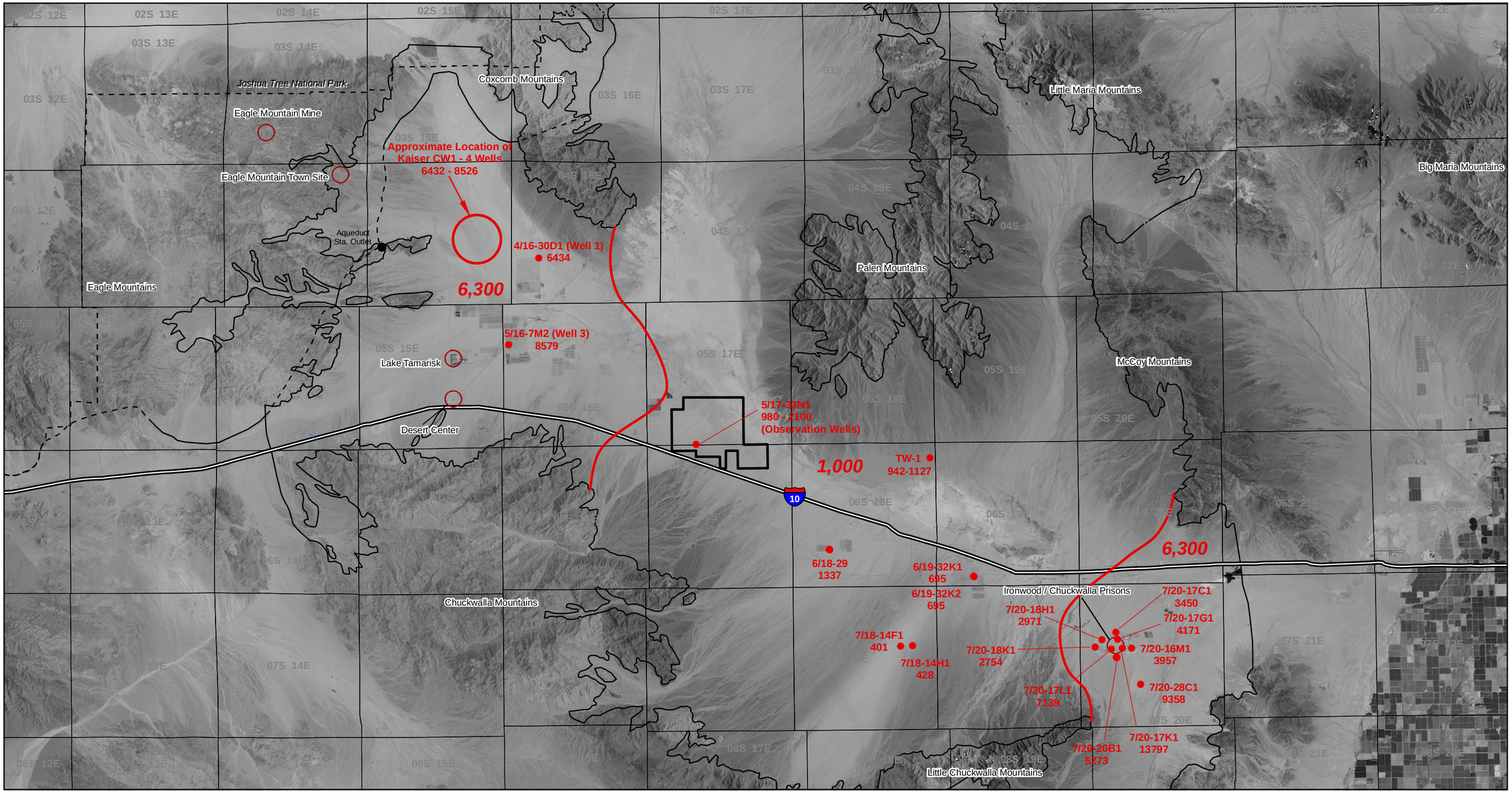

Map Location

Legend

- Project Right-of-Way
- Colorado River Aqueduct
- Colorado River Aqueduct (Dash showing underground interval)
- Chuckwalla Valley Groundwater Basin Boundary
- Freeway
- Geographic/Cultural Area of Interest
- 1337 — Groundwater Well with Reported Transmissivity Data (feet squared per day (ft^2/d))
- 6,300 — Transmissivity (ft^2/d)
- Boundary between Transmissivity Zones

Data Sources:
Air Photo, California Spatial Information Library, NAIP, 2005 Riverside County

Water Basins, Department of Water Resources Website groundwater basin map file B118v3NAD27UTM10.zip

N W E S

0 4 8 Miles

1 inch = 21,120 feet

Palen Solar Power Project

Figure DR-S&W-207-3
Transmissivity in the Chuckwalla Valley

Palen Solar I, LLC

AECOM

Project: 60139694
Date: February 2010

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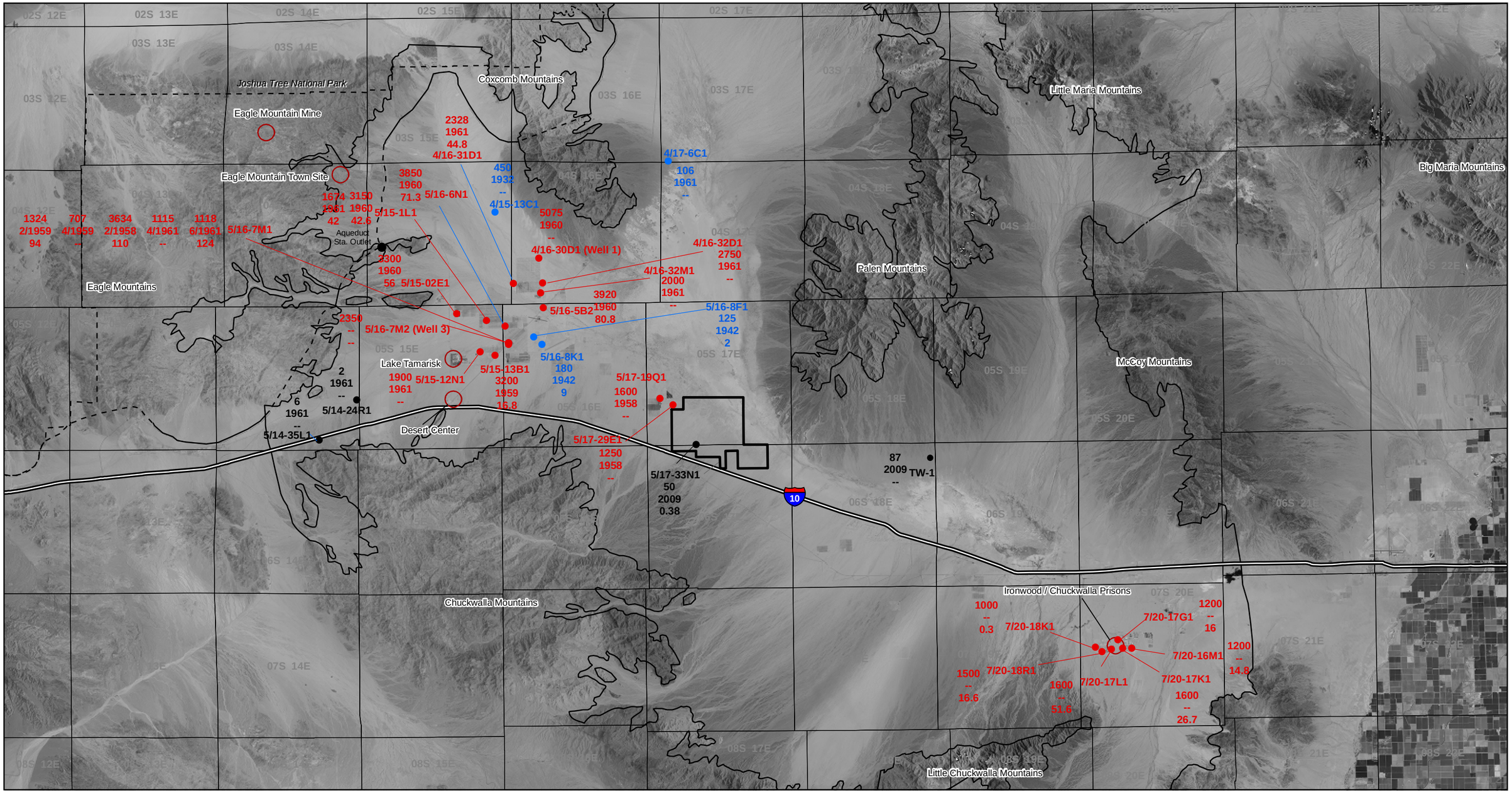

Map Location

Legend

- Project Right-of-Way
- Colorado River Aqueduct
- Colorado River Aqueduct (Dash showing underground interval)
- Chuckwalla Valley Groundwater Basin Boundary
- Freeway
- Geographic/Cultural Area of Interest
- Groundwater Well with Pumping Rates 0 - 100 gpm
- Groundwater Well with Pumping Rates 100 - 1000 gpm
- Groundwater Well with Pumping Rates >1000 gpm

50 — Pumping Rate (gpm)
2009 — Date Pumping Rate Reported
0.38 — Specific Capacity (gpm/ft) Estimated from data provided on the date reported. (--) Insufficient information to estimate specific capacity.

Data Sources:
Air Photo, California Spatial Information Library, NAIP, 2005 Riverside County

Water Basins, Department of Water Resources Website groundwater basin map file B118v3NAD27UTM10.zip

N W E S

0 4 8 Miles

1 inch = 21,120 feet

Palen Solar Power Project

Figure DR-S&W-207-4
Reported Pumping Rates in the Chuckwalla Valley

Palen Solar I, LLC

AECOM

Project: 60139694
Date: January 2010

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Joshua Tree National Park
Coxcomb Mountains
Eagle Mountain Mine
Eagle Mountain Town Site
First Solar Desert Sunlight
Aqueduct Sta. Outlet
enXco - Desert Lily
enXco - Eagle Mountain
Eagle Mountains
Eagle Crest Water Supply
Lake Tamarisk
Chuckwalla Solar 1
Desert Center
Little Maria Mountains
Big Maria Mountains
Palen Mountains
McCoy Mountains
Genesis
Genesis
enXco - Mule Mountain
Chuckwalla Mountains
Ironwood / Chuckwalla Prisons
Bullfrog-Mule Mountain
Little Chuckwalla Mountains
10

Map Location

OR ID NV UT CA AZ

Legend

- Project Right-of-Way
- Colorado River Aqueduct
- Colorado River Aqueduct (Dash showing underground interval)
- Chuckwalla Valley Groundwater Basin Boundary
- Freeway
- Geographic/Cultural Area of Interest
- Groundwater Well Location based on Latitude and Longitude in USGS Database
- Groundwater Well Location based on the State Well Number (approximate)
- Location of Pumping Well Use in Cumulative Impacts Assessment
- Proposed Renewable Projects as of 12/09

Data Sources:
Air Photo, California Spatial Information Library, NAIP, 2005 Riverside County

Water Basins, Department of Water Resources Website groundwater basin map file B118v3NAD27UTM10.zip

N W E S

0 4 8 Miles

1 inch = 21,120 feet

Palen Solar Power Project

Figure 5.17-17 (rev1) Renewable Projects in the Chuckwalla Valley

Palen Solar I, LLC

AECOM

Project: 60139694
Date: March 2010

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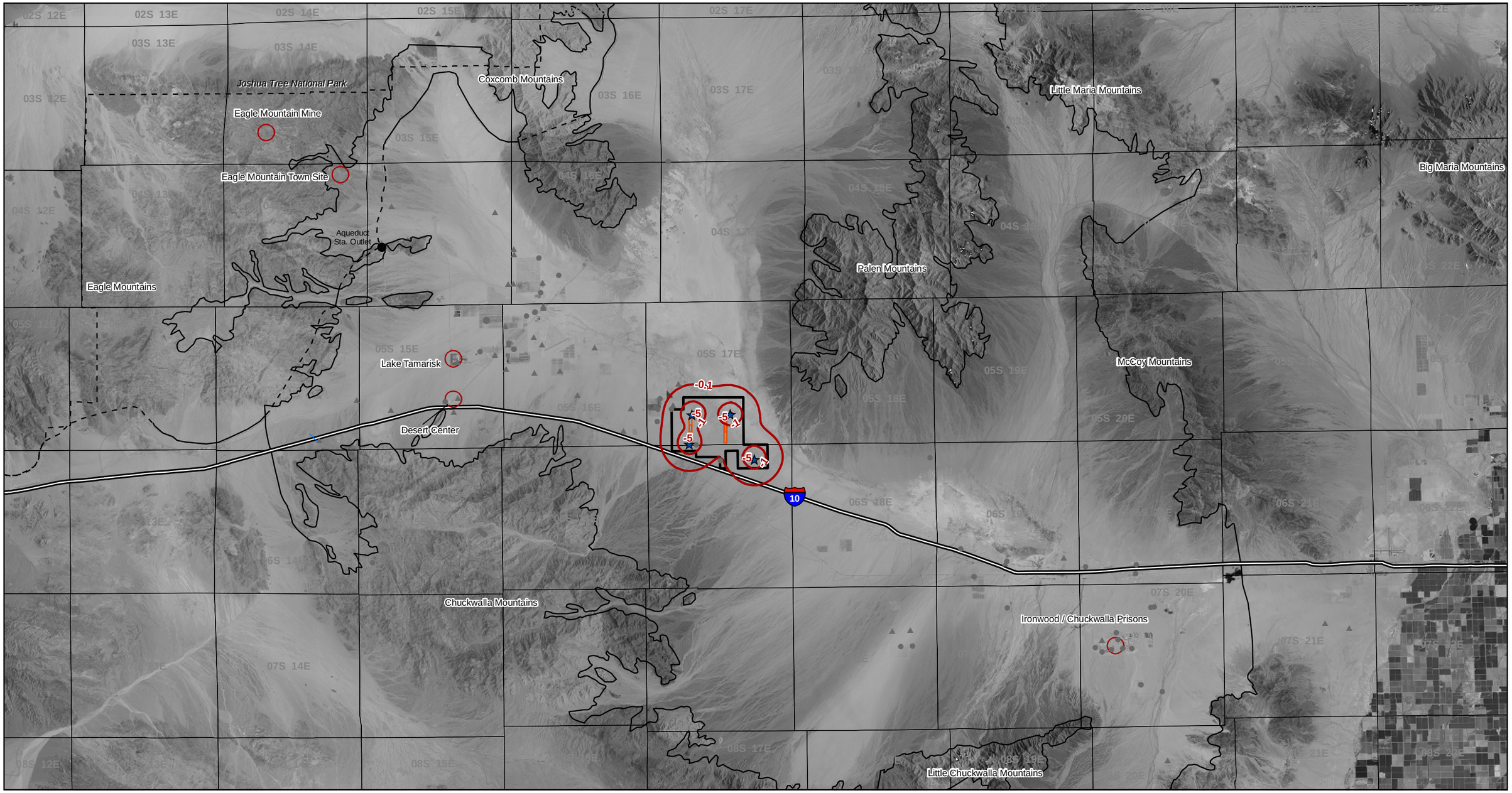

Map Location

Legend

- Project Right-of-Way
- Colorado River Aqueduct
- Colorado River Aqueduct (Dash showing underground interval)
- Chuckwalla Valley Groundwater Basin Boundary
- Freeway
- Geographic/Cultural Area of Interest
- Groundwater Well Location based on Latitude and Longitude in USGS Database
- Groundwater Well Location based on the State Well Number (approximate)
- Location of Pumping Well Used in the Model
- Model Predicted Drawdown; Negetive Indicates Reduction In Water Level

Data Sources:
Air Photo, California Spatial Information Library, NAIP, 2005 Riverside County

Water Basins, Department of Water Resources Website groundwater basin map file B118v3NAD27UTM10.zip

N W E S

0 4 8 Miles

1 inch = 21,120 feet

Palen Solar Power Project

Figure DR-S&W-207a (rev1)
Project Only
Construction Water Supply

Palen Solar I, LLC

AECOM

Project: 60139694
Date: March 2010

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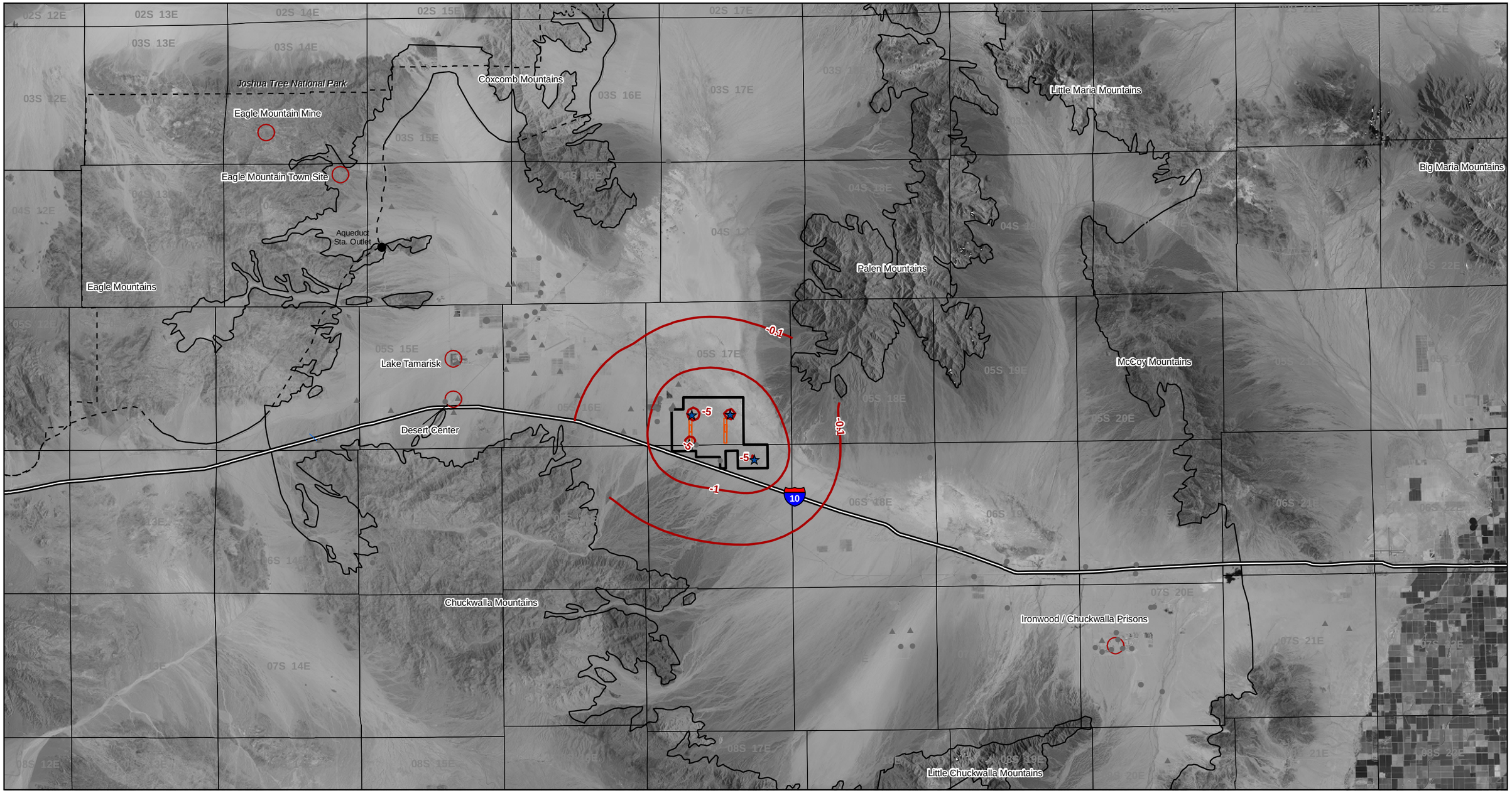

Map Location

Legend

- Project Right-of-Way
- Colorado River Aqueduct
- Colorado River Aqueduct (Dash showing underground interval)
- Chuckwalla Valley Groundwater Basin Boundary
- Freeway
- Geographic/Cultural Area of Interest
- Groundwater Well Location based on Latitude and Longitude in USGS Database
- Groundwater Well Location based on the State Well Number (approximate)
- Location of Pumping Well Used in the Model
- Model Predicted Drawdown; Negetive Indicates Reduction In Water Level

Data Sources:
Air Photo, California Spatial Information Library, NAIP, 2005 Riverside County

Water Basins, Department of Water Resources Website groundwater basin map file B118v3NAD27UTM10.zip

N W E S

0 4 8 Miles

1 inch = 21,120 feet

Palen Solar Power Project

Figure DR-S&W-207b (rev1)
Project Only
Operational Supply
End of 30 Years

Palen Solar I, LLC

AECOM

Project: 60139694
Date: March 2010

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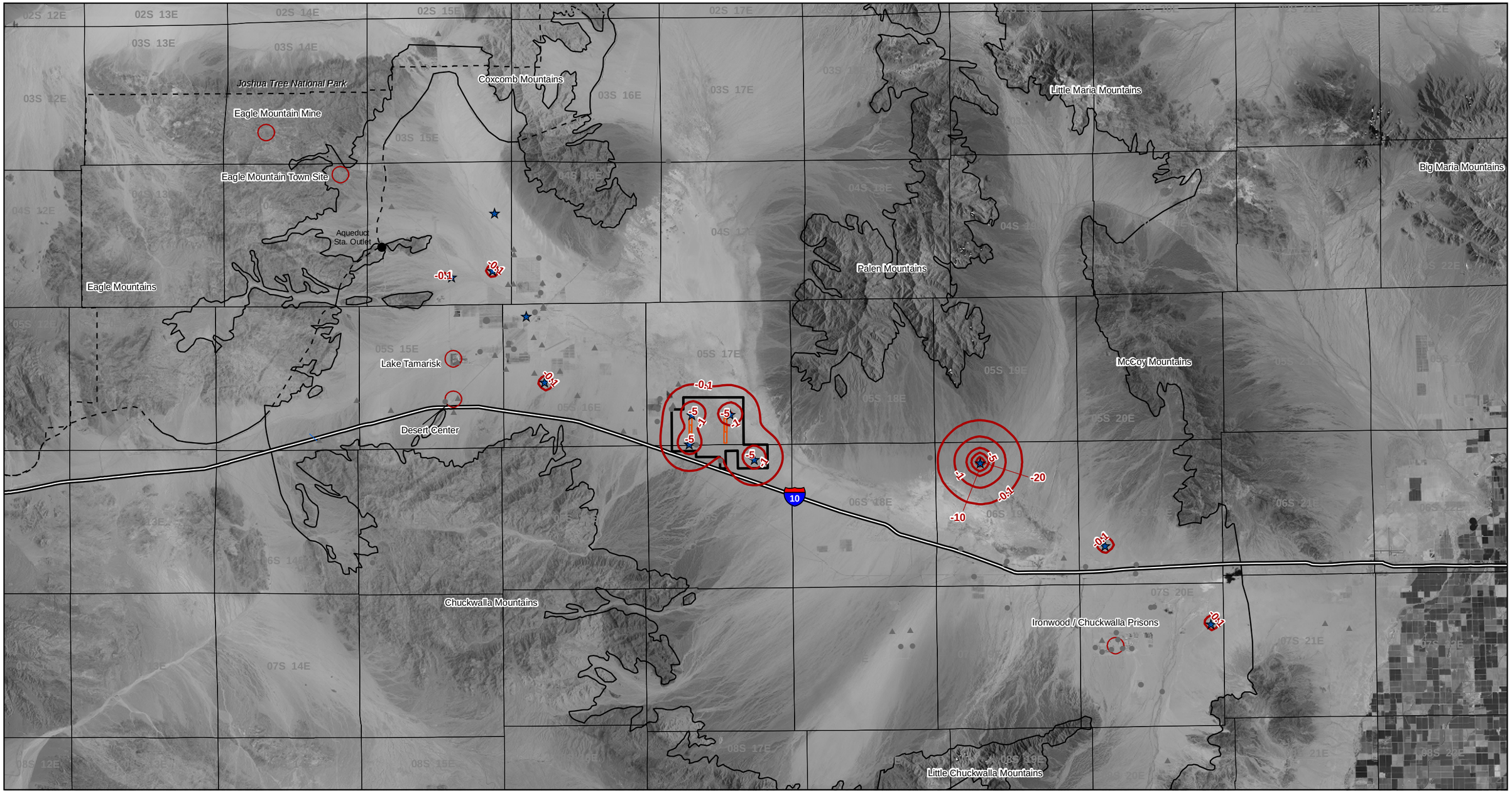

Map Location

Legend

- Project Right-of-Way
- Colorado River Aqueduct
- Colorado River Aqueduct (Dash showing underground interval)
- Chuckwalla Valley Groundwater Basin Boundary
- Freeway
- Geographic/Cultural Area of Interest
- Groundwater Well Location based on Latitude and Longitude in USGS Database
- Groundwater Well Location based on the State Well Number (approximate)
- Location of Pumping Well Used in the Model
- Model Predicted Drawdown; Negetive Indicates Reduction In Water Level

Data Sources:
Air Photo, California Spatial Information Library, NAIP, 2005 Riverside County

Water Basins, Department of Water Resources Website groundwater basin map file B118v3NAD27UTM10.zip

N W E S

0 4 8 Miles

1 inch = 21,120 feet

Palen Solar Power Project

Figure DR-S&W-208a (rev1)
Cumulative Impacts
Constructionl Supply
End of Palen Construction

Palen Solar I, LLC

AECOM

Project: 60139694
Date: March 2010

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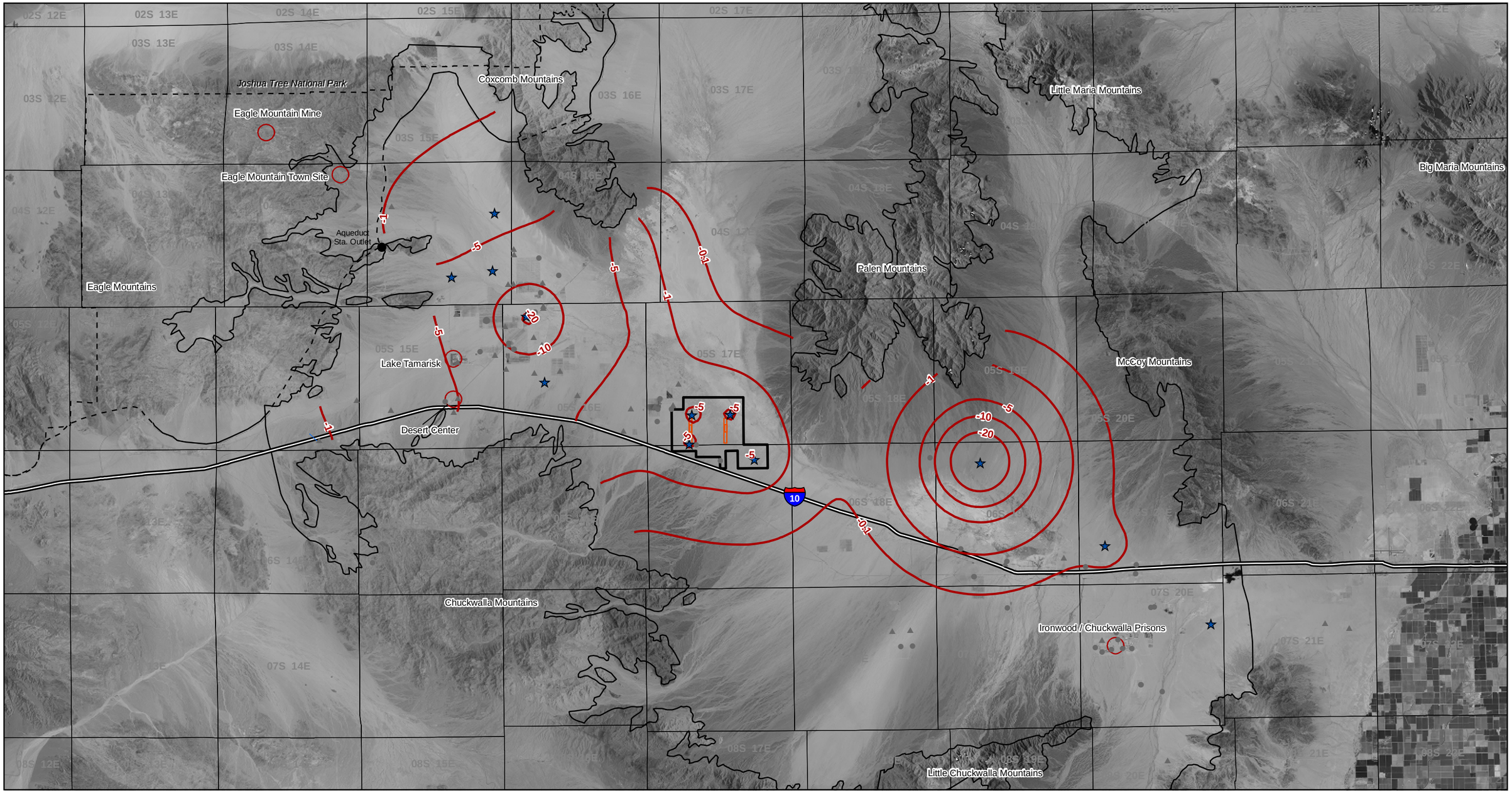

Map Location

Legend

- Project Right-of-Way
- Colorado River Aqueduct
- Colorado River Aqueduct (Dash showing underground interval)
- Chuckwalla Valley Groundwater Basin Boundary
- Freeway
- Geographic/Cultural Area of Interest
- Groundwater Well Location based on Latitude and Longitude in USGS Database
- Groundwater Well Location based on the State Well Number (approximate)
- Location of Pumping Well Used in the Model
- Model Predicted Drawdown; Negetive Indicates Reduction In Water Level

Data Sources:
Air Photo, California Spatial Information Library, NAIP, 2005 Riverside County

Water Basins, Department of Water Resources Website groundwater basin map file B118v3NAD27UTM10.zip

N W E S

0 4 8 Miles

1 inch = 21,120 feet

Palen Solar Power Project

Figure DR-S&W-208b (rev1)
Cumulative Impacts
Operational Supply
End of 30 Years

Palen Solar I, LLC

AECOM

Project: 60139694
Date: March 2010

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Tables

TABLE DR-S&W-194-1 (rev1)
SUMMARY OF INFILTRATION ESTIMATES
CHUCKWALLA VALLEY GROUNDWATER BASIN
PALEN SOLAR POWER PROJECT
RIVERSIDE, CALIFORNIA

Layer[1]	Area (acres)	Mean Annual Precipitation (inches)	Total Volume of Rainwater from Mean Annual Precip (AcFt)	Runoff Curve Classification	Total Volume of Infiltration (AcFt) Based on 2% of Annual Precip	Total Volume of Infiltration (AcFt) Based on 3% of Annual Precip	Total Volume of Infiltration (AcFt) Based on 5% of Annual Precip	Total Volume of Infiltration (AcFt) Based on 10% of Annual Precip
unit1-cw	30,303	5	12,626	Alluvium, Steep Slope	253	379	631	1,263
unit1-cw	211,498	4	70,499	Alluvium, Flat Slope	1,410	2,115	3,525	7,050
unit1-cw	41,073	3.5	11,980	Alluvium, Steep Slope	240	359	599	1,198
unit1-cw	12,077	4	4,026	Alluvium, Steep Slope	81	121	201	403
unit1-cw	910	4	303	Alluvium, Steep Slope	6	9	15	30
unit1-cw	194	4	65	Alluvium, Steep Slope	1	2	3	6
unit1-cw	81,233	5	33,847	Alluvium, Steep Slope	677	1,015	1,692	3,385
bedrock-chuckwalla	32,001	5	13,334	Mountains	267	400	667	1,333
bedrock-chuckwalla	21,456	5	8,940	Mountains	179	268	447	894
bedrock-chuckwalla	11,050	5	4,604	Mountains	92	138	230	460
bedrock-chuckwalla	109	5	46	Mountains	1	1	2	5
bedrock-chuckwalla	9,246	4	3,082	Mountains	62	92	154	308
bedrock-chuckwalla	10,042	4	3,347	Mountains	67	100	167	335
bedrock-chuckwalla	282	4	94	Mountains	2	3	5	9
bedrock-chuckwalla	3,480	4	1,160	Mountains	23	35	58	116
bedrock-chuckwalla	275	4	92	Mountains	2	3	5	9
bedrock-chuckwalla	90	4	30	Mountains	1	1	1	3
bedrock-chuckwalla	398	4	133	Mountains	3	4	7	13
bedrock-chuckwalla	316	4	105	Mountains	2	3	5	11
bedrock-chuckwalla	39,340	5	16,392	Mountains	328	492	820	1,639
bedrock-chuckwalla	194	5	81	Mountains	2	2	4	8
unit3-cw	28,973	3	7,243	Alluvium, Flat Slope	145	217	362	724
unit2-cw	198,558	3	49,640	Alluvium, Steep Slope	993	1,489	2,482	4,964
bedrock-chuckwalla	89,161	6	44,581	Mountains	892	1,337	2,229	4,458
Totals	**822,257**		**286,248**		**5,725**	**8,587**	**14,312**	**28,625**

Notes

1 Bedrock and unit distribution within the Chuckwalla Valley Groundwater Basin are shown on Figure Dr-S&W-194-1(rev1).

Palo Verde

Layer ID See Figure J3-1	Area (acre	Mean Annual Precipitation (inches)	Total Volume of Rainwater from Mean Annual Precip (AcFt)	Runoff Curve Classification	Runoff Curve Number	Runoff (% of preciptation)	Total Annual Volume of Runoff (AcFt)	Total Volume of Infiltration (AcFt) Based on 2% of Annual Precip	Total Volume of Infiltration (AcFt) Based on 5% of Annual Precip	Total Volume of Infiltration (AcFt) Based on 10% of Annual Precip
unit1-pvm	23,695	4	7,898	Alluvium, Steep Slope	74	3.5%	276	158	395	790
bedrock-pvm	5,624	4	1,875	Mountains	93	29.1%	546	37	94	187
bedrock-pvm	16,819	6	8,409	Mountains	93	29.1%	2,447	168	420	841
bedrock-pvm	13,571	4	4,524	Mountains	93	29.1%	1,316	90	226	452
bedrock-pvm	18,298	4	6,099	Hills	83	10%	610	122	305	610
unit1-pvm	79,574	5	33,156	Alluvium, Steep Slope	74	3.5%	1,160	663	1,658	3,316
unit2-pvm	382	4	127	Hills	83	10%	13	3	6	13
unit2-pvm	122,370	4	40,790	Alluvium, Flat Slope	69	2%	816	816	2,039	4,079
Totals	**280,332**		**102,878**				**7,184**	**2,058**	**5,144**	**10,288**

Layer	acreage	area_sqft
unit1-cw	30,303	1320002743.44
unit1-cw	211,498	9212833369.72
unit1-cw	41,073	1789142528.84
unit1-cw	12,077	526058812.18
unit1-cw	910	39641479.81
unit1-pvm	23,695	1032152345.57
unit1-cw	194	8443225.22
unit1-cw	81,233	3538514482.92
bedrock-chuckwalla	32,001	1393943702.58
bedrock-chuckwalla	21,456	934623172.53
bedrock-chuckwalla	11,050	481350332.09
bedrock-chuckwalla	109	4767047.89
bedrock-chuckwalla	9,246	402742865.63
bedrock-chuckwalla	10,042	437418376.08
bedrock-chuckwalla	282	12276607.76
bedrock-chuckwalla	3,480	151571007.92
bedrock-chuckwalla	275	11964135.40
bedrock-chuckwalla	90	3912598.02
bedrock-chuckwalla	398	17318994.45
bedrock-chuckwalla	316	13784939.02
bedrock-chuckwalla	39,340	1713660284.08
bedrock-chuckwalla	194	8443225.22
bedrock-pvm	5,624	244970650.36
bedrock-pvm	16,819	732615560.10
bedrock-pvm	13,571	591160710.00
bedrock-pvm	18,298	797066150.51
unit1-pvm	79,574	3466236442.09
unit2-pvm	382	16626030.69
unit3-cw	28,973	1262054663.00
unit2-cw	227,531	9911247064.79
unit2-cw	28,973	1262054663.00
unit2-pvm	122,370	5330421580.05
bedrock-chuckwalla	89,161	3883866675.68

TABLE DR-S&W 194-2 (rev1)

WATER BALANCE
CHUCKWALLA VALLEY GROUNDWATER BASIN
PALEN SOLAR POWER PROJECT
RIVERSIDE COUNTY, CALIFORINA

RECHARGE AND DISCHARGE		APPLICATION FOR CERTIFICATION (AUGUST 2009)	MOUNTAIN FRONT RECHARGE AFTER HELY AND PECK (1964) - RECHARGE 3% OF RUNOFF	MOUNTAIN FRONT RECHARGE AFTER HELY AND PECK (1964) - RECHARGE 2% OF RUNOFF	BASIS FOR ESTIMATE	WATER BALANCE ESTIMATES REPORTED BY OTHERS (Acre-feet pre year)					
						Metzger, et al., 1973 USGS Professional Paper 486-G	CH2MHill, 1996[9]	B&V, 1998	URS, 2000	GEI, 2009	WorleyParsons (2009a)[11]
		Acre-feet per year	Acre-feet per year	Acre-feet per year							
RECHARGE (INFLOW)											
UNDERFLOW from OROCOPIA[1]		**1,000**	**100**	**100**	After URS (2000). Selected lower of the two estimates to provide a conservative estimate of recharge from this source.	--	1,700	--	100 to 1,000	1,700	3,500
UNDERFLOW from PINTO VALLEY[2]		**2,500**	**2,500**	**2,500**	After CH2M-Hill (1996) and GEI (2009).	--	2,500	--	--	2,500 - 3,200	
UNDERFLOW from CADIZ[3]		**0**	**0**	**0**	Assumed no inflow from Cadiz, though CH2M-Hill (1996) concluded flux into the Chuckwallla from this basin	--	2,500	0	--	0	
PERCOLATION from						--	--	--	--	--	--
	AGRICULTURE RETURN	**584**	**639**	**639**	Estimated to be 10% of the annual usage of 6,389 AFY (GEI 2009) - assumed drip irrigation efficiency of 90%.	--	--	--	--	--	800
	LAKE TAMARISK LEAKAGE	**0**	**0**	**0**	Assumed to be zero. Construction of Lake Tamarisk uncertain, as such assume complete containment.	--	--	--	--	--	--
	MOUNTAIN FRONT[4]	**5,540**	**8,587**	**5,725**	See Table DR-S&W-194-1(rev1)	--	--	--	--	5,540	9,440
	LEACHFIELD RETURN[5]	**834**	**834**	**834**	After GEI (2009)	--	--	--	--	834	831
BEDROCK		**0**	**0**	**0**	Although recharge to the alluvial aquifer is possible from the bedrock there is insufficient well data to determine flux.	--	--	--	--	--	--
	TOTAL (INFLOW)[6]	**10,458**	**12,660**	**9,798**		--	**12,240**	--	--	**10,571 to 11,331**	**14,571**
DISCHARGE (OUTFLOW)											
UNDERFLOW to PALO VERDE MESA[6]		**400**	**400**	**400**	After Metzger (1973). Value assumed over multiple investigations.	400	400	400	--	400	400
DIVERSION						--	--	--	--	--	--
	AGRICULTURE	**5,840**	**6,389**	**6,389**	After GEI (2009) Table 10 - Technical Exhibit E, Volume 3 of 6.	--	--	--	--	6389	10471
	MUNICIPALand DOMESTIC[7],[8]	**3,351**	**3,351**	**3,351**	After GEI (2009) - compilation of estimates for Desert Center, Lake Tamarisk (CSA 51) and Prisons	--	--	--	--	3351	
EVAPOTRANSPIRATION						--	--	--	--	--	--
	Palen Dry Lake[10]	**0**	**350**	**350**	After WorleyParsons 2009b. Evaporation from Palen Dry Lake based on assumption that 1/2 the lake is acting as a wet playa (2,000 acres), and the discharge is seasonal occuring 3 months during the year with an ET rate of about 2 inches.	--	--	--	--	--	350
	Ford Dry Lake	**0**	**0**	**0**	Evaporation from Ford Dry Lakes assumed to be zero as depth of water estimated to be greater than 50 feet bgs.	--	--	--	--	--	--
EXPORT		**0**	**0**	**0**	No export is indicated in published reports	--	--	--	--	--	--
PALEN SOLAR POWER PROJECT		**300**	**300**	**300**	Operational requirements (mirror, process and domestic supply)/Dry Cooled Project.	--	--	--	--	--	--
	TOTAL (OUTFLOW)	**9,591**	**10,490**	**10,490**		**400**	**400**	**400**		**10,140**	**11,221**
	NET WITHOUT PSPP	**867**	**2,170**	**-692**		--	**0**	--	--	**765 to 1,525**	**3,350**
	NET WITH PSPP WATER USE	**567**	**1,870**	**-992**							

NOTES

1. CH2MHill (1996) and GEI (2009) underflow estimates from "Groundwater Conditions in the Eagle Mountain Area" after Mann J. C., 1986 (no confirmation estimates provided).
   URS calculation based on hydraulic conductivity range of 10 to 100 ft/day, gradient of 0.0002ft/ft, an aquifer width of 11,000 feet and a saturated thickness of 500 feet.
   Lower value used in the estimate as noted by the analysis provided in Data Request DR-194 for analysis in the Hely and Peck (1964) analysis of recharge.
2. CH2MHill (1996) and GEI (2009) underflow estimates from "Groundwater Conditions in the Eagle Mountain Area" after Mann J. C., 1986 (no confirmation estimates provided).
3. CH2MHill (1996)underflow estimate based on Cadiz Valley being similar size to Pinto Valley.
4. GEI (2009) assumed 10% of precipitation falling on the mountain front would recharge groundwater (value used in the AFC - September 2009). For estimates of recharge after Hely and Peck (1964) refer to Table DR-Soil and Water-194-1.
5. This estimate reflects personal communication from GEI with Department of Public Health and personnel for prisons and assuming 150 gallons/person/day for Lake Tamarisk/Desert Center/Eagle Mountain.
6. Underflow calculated by Metz, et. al (1973). using transmissivity of 30,000 gpd/ft (for Bouse Formation), gradient of 3 feet/mile, and a 4-mile width and 500 foot depth for the saturated section.
7. Water supply well for Eagle Mountain School is screened in bedrock aquifer, not included in GEI (2009) estimate
8. CSA 51 - County Service Area 51
9. Total estimated inflow reported by CH2MHill (1996) from BLM and Riverside County EIS/EIR for the Eagle Mountain Landfill.
10. Loss from Palen Dry Lake is discussed in detail in response to the work shop request to consider revision to the water balance and the estimate of runoff (February 2010).
11. Estimate of water balanced after WorleyParsons (2009a). Total Diversion (agriculture and domestic) of 10,471 afy (Table DR-148/DR-151-2) differs from future water budget estimate of 9,871 afy (Table 2, WorleyParsons 2009b))

REFERENCES

Application for Certification for the Palen Solar Power Project, September 2009.
Black and Veatch and Woodward-Clyde, 1998, Phase I Technical Feasibility Report for Off-Stream Storage on the Colorado River Aqueduct.
CH2M-Hill, 1996, Appendix C1 - Technical Memorandum, Elaboration on Specific Hydrogeologic Concepts Discussed in the Eagle Mountain Landfill and Recycling Center Environmental Impact Study/Environmental Impact Report.
GEI, 2009, Eagle Mountain Pumped Storage Project No 13123 - Final License Application, Technnical Appendices for Exhibit E, Volume 3 of 6 Groundwater Supply Pumping Effects.
Hely and Peck, 1964, Precipitation, Runoff and Water Loss in the Lower Colorado River - Salton Sea Area, Geological Survey Professional Paper 486-B (prepared in cooporation with the US Weather Bureau.
Metzger and others, 1973, Geohydology of the Needles area, Arizona, California and Nevada: U.S. Geological Survey Professional Paper 486-J.
Steinemann, 1989,
URS Corporation, 2000, Feasibility Assessment Hayfield Lake/Chuckwalla Valley Groundwater Conjunctive-Use Project, Prepared for Metropolitan Water District of Southern California, Volumes I-III.
WorleyParsons, 2009a, Data Requests – Response Set 1A, Genesis Solar Power Project, Rivreside County, California. December 14 (Table DR-148 and DR-151-2).
WorleyParsons, 2009b,Technical Memorandum – Groundwater Resources Cumulative Impacts Analysis for Genesis Solar Power Project, Riverside County, California. December 30.

TABLE 5.17-12 (rev1)
CUMULATIVE WATER BUDGET
CHUCKWALLA GROUNDWATER BASIN
RIVERSIDE COUNTY, CALIFORNIA

PROJECT[1]	PROPONENT	BLM SERIAL ID	TECHNOLOGY	SOURCE	USE	WATER USE - SOLAR and OTHER RENEWABLE PROJECTS (AFY)															COMMENTS
						2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2043	
Chuckwalla Solar I	Chuckwalla Solar I LLC	CA 48808	Photovoltaic (200MW)	Groundwater	Construction	--	20	20	10	--	--	--	--	--	--	--	--	--	--	--	Updated from CEC email (12-16) transmitting Table "Cumulative Projects - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09)
					Operational	--	--	5	7	10	10	10	10	10	10	10	10	10	10	10	
Eagle Mountain Soleil [8]	enXco	CA 49491	Photovoltaic (100MW)	Groundwater	Construction	--	--	10	10	--	--	--	--	--	--	--	--	--	--	--	Updated from CEC email (12-16) transmitting Table "Cumulative Projects - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09)
					Operational	--	--	--	--	5	5	5	5	5	5	5	5	5	5	5	
Desert Lily Soleil [8]	enXco	CA 49492	Photovoltaic	Groundwater	Construction	--	--	20	20	20	--	--	--	--	--	--	--	--	--	--	Updated from CEC email (12-16) transmitting Table "Cumulative Projects - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09)
					Operational	--	--	--	--	--	5	5	5	5	5	5	5	5	5	5	
Solel Mohave Solar Park	Deset Lily	CA 49494	Parabolic Trough (500MW)	Groundwater	Construction	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	Project withdrawn. Application rejected (First-In-Line Solar Applications, BLM (12-21-09))
					Operational	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Desert Sunlight Solar Farm	First Solar	CA 48649	Photovoltaic (550MW)	Groundwater	Construction	--	9	9	9	--	--	--	--	--	--	--	--	--	--	--	Updated from CEC email (12-16) transmitting Table "Cumulative Projects - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09)
					Operational	--	--	--	--	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	
Eagle Mountain Pump Storage	Eagle Crest Energy Company, LLC	PAD/FERC (January 2009)	Pump - Storage (1300MW)	Groundwater	Construction	--	--	--	--	8,066	8,066	8,066	--	--	--	--	--	--	--	--	Updated from CEC email (12-16) transmitting Table "Cumulative Projects - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09)
					Operational	--	--	--	--	--	--	--	1802	1802	1802	1802	1802	1802	1802	1,802	
Genesis Solar Energy	Genesis Solar LLC	CA 48880	Parabolic Trough (250MW)	Groundwater	Construction	--	813	813	813	--	--	--	--	--	--	--	--	--	--	--	Updated from CEC email (12-16) transmitting Table "Cumulative Projects - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09)
					Operational	--	--	--	--	1,644	1,644	1,644	1,644	1,644	1,644	1,644	1,644	1,644	1,644	1,644	
Mule Mountain Solar Project	Bullfrog Green Energy, LLC	CA 49097	Photovoltaic (500MW)	Groundwater or water trucked in for mostly mirror washing	Construction	--	20	20	20	--	--	--	--	--	--	--	--	--	--		Updated from CEC email (12-16) transmitting Table "Cumulative Projects - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09)
					Operational	--	--	0.25	0.5	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	
Mule Mountain Soleil	enXco	CA 49488	Photovoltaic (200MW)	Groundwater	Construction	--	--	10	10	--	--	--	--	--	--	--	--	--	--	--	Updated from CEC email (12-16) transmitting Table "Cumulative Projects - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09)
					Operational	--	--	--	--	5	5	5	5	5	5	5	5	5	5	5	
Palen Solar Power	Solar Millennium LLC	CA 48810	Parabolic Trough (484MW)	Groundwater	Construction	--	480	480	480	--	--	--	--	--	--	--	--	--	--	--	Updated from CEC email (12-16) transmitting Table "Cumulative Projects - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09)
					Operational	--	--	--	--	303	303	303	303	303	303	303	303	303	303	303	
TOTAL WATER USE - RENEWABLE PROJECTS (AFY)[2]						0	1,342	1,388	1,380	9,755	9,740	9,740	3,476	3,476	3,476	3,476	3,476	3,476	3,476	3,476	
DISCHARGE FROM OTHER SOURCES (AFY)[3]						10,490	10,490	10,490	10,490	10,490	10,490	10,490	10,490	10,490	10,490	10,490	10,490	10,490	10,490	10,490	
RECHARGE (AFY)[4]						12,660	12,660	12,660	12,660	12,660	12,660	12,660	12,660	12,660	12,660	12,660	12,660	12,660	12,660	12,660	
YEARLY BALANCE (AFY)[5]						2,170	828	782	790	-7,585	-7,570	-7,570	-1,306	-1,306	-1,306	-1,306	-1,306	-1,306	-1,306	-1,306	
CUMULATIVE CHANGE (AFY)[6]						2,170	2,998	3,780	4,570	-3,014	-10,584	-18,153	-19,459	-20,764	-22,070	-23,375	-24,681	-25,986	-27,292	-53,402	
CUMULATIVE BASINWIDE CHANGE IN WATER LEVEL (assuming a storage coefficient of 0.20) (INCHES)[7]						0.2	0.30	0.4	0.5	-0.3	-1.0	-1.8	-1.9	-2.1	-2.2	-2.3	-2.4	-2.6	-2.7	-5.3	
CUMULATIVE BASINWIDE CHANGE IN WATER LEVEL (assuming a storage coefficient of 0.05) (INCHES)[7]						0.9	1.2	1.5	1.8	-1.2	-4.2	-7.2	-7.7	-8.2	-8.8	-9.3	-9.8	-10.3	-10.8	-21.2	

NOTES

1 Chuckwalla Solar I (Chuckwalla Solar I LLC) - Plan of Development, Chuckwalla Solar I, february 2009.
Desert Lily Soleil (enXco5) - Plan of Development, Desert Lily Soleil Project, October 2008.
Desert Lily (Solel) - Plan of Development, Mojave Solar Park/Desert Lily Project, October 2007.
Desert Sunlight Solar Farm (First Solar) - Plan of Development Optisolar, October 2008.
Eagle Mountain Pump Storage Project - Estimates provided from the Eagle Mountain Pumped Storage Project No. 13123 - Final License Application, Eagle Crest Energy Company June 2009 (EIS Table 14).
Genesis Solar Energy (Genesis Solar LLC) - Plan of Development, Genesis Solar Energy Project, June 2009.
Mule Mountain Solar Project (Bullfrog Green Energy, LLC) - Plan of Development, Mule Mountain Solar Project, May 2009
Mule Mountain Soleil (enXco2) - Plan of Development, Mule Mountain Soleil Project, enXco February 2009.
Palen Solar Power Plant - Estimates provided from the AECOM Water, "Water Wastewater Report - Palen Solar Power Project July 2009 (Appendix L).

2 Sum of projected water use by year for the identified renewable energy projects.

3 Discharge from other sources other than solar or renewable energy projects (see Table DR-S&W-194-2 (rev1)). Assumption is that the discharge kept constant over the term of the analysis (30 years).

4 Estimate of recharge from basin water balance provided on Table DR-S&W-194-2 (rev1). Recharge was assumed to be constant over 30 years.

5 Difference between discharge (inclusive of renewable projects and other sources) and recharge.

6 Cumulative difference between recharge and discharge.

7 Change in the regional water level following the equation shown below (Fetter 1988). Negative numbers indicate a decline or reduction in the water level by the amount shown.

8 There is conflict between the CEC and BLM lists as to whether these projects will be permitted. They have been included for completeness though they may well not be part of the cumulative water budget for the Chuckwalla Valley Groundwater Basin.

DEFINITIONS

AFY	Acre feet per year
AF	Acre feet - (325,829 gallons)
FERC	Federal Energy Regulatory Commission
LLC	Limited Liability Corporation
MW	Megawatts

ESTIMATE OF BASINWIDE WATER LEVEL CHANGE

V = A*S*dh
V - volume of water released or taken into storage
A - area of the aquifer (605,000 acres)
S- aquifer storage (assumed to be 0.10)
dh - change in water level (inches)

TABLE DR-S&W-207-1 (rev1)
PUMPING SCHEDULE FOR CUMULATIVE WATER BUDGET ASSESSMENT
PALEN SOLAR POWER PROJECT

PROJECT[1]	PROPONENT	BLM SERIAL ID	TECHNOLOGY	SOURCE	USE	WATER USE - RENEWABLE PROJECTS (AFY)									COMMENTS [3]
						2010	2011	2012	2013	2014	2015	2016	2017	2018-2043	
Chuckwalla Solar I	Chuckwalla Solar I LLC	CA 48808	Photovoltaic (200MW)	Groundwater	Construction	--	20	20	10	--	--	--	--	**--**	Updated from CEC email (12-16) transmitting Table "Cumulative Projests - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09)
					Operational	--	--	5	7	10	10	10	10	**10**	
Eagle Mountain Soleil [1]	enXco	CA 49491	Photovoltaic (100MW)	Groundwater	Construction	--	--	10	10	--	--	--	--	**--**	Updated from CEC email (12-16) transmitting Table "Cumulative Projests - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09).
					Operational	--	--	--	--	5	5	5	5	**5**	
Desert Lily Soleil [1]	enXco	CA 49492	Photovoltaic	Groundwater	Construction	--	--	20	20	20	--	--	--	**--**	Updated from CEC email (12-16) transmitting Table "Cumulative Projests - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09)
					Operational	--	--	--	--	--	5	5	5	**5**	
Solel Mohave Solar Park [2]	Deset Lily	CA 49494	Parabolic Trough (500MW)	Groundwater	Construction	--	--	--	--	--	--	--	--	**--**	Updated from CEC email (12-16) transmitting Table "Cumulative Projests - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09). Project Withdrawn.
					Operational	--	--	--	--	--	--	--	--	**--**	
Desert Sunlight Solar Farm	First Solar	CA 48649	Photovoltaic (550MW)	Groundwater	Construction	--	9	9	9	--	--	--	--	**--**	Updated from CEC email (12-16) transmitting Table "Cumulative Projests - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09)
					Operational	--	--	--	--	3.8	3.8	3.8	3.8	**3.8**	
Eagle Mountain Pump Storage	Eagle Crest Energy Company, LLC	PAD/FERC (January 2009)	Pump - Storage (1300MW)	Groundwater	Construction	--	--	--	--	8,066	8,066	8,066	8,066	**--**	Updated from CEC email (12-16) transmitting Table "Cumulative Projests - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09)
					Operational	--	--	--	--	--	--	--	--	**1,802**	
Genesis Solar Energy	Genesis Solar LLC	CA 48880	Parabolic Trough (250MW)	Groundwater	Construction	--	813	813	813	--	--	--	--	**--**	Updated from CEC email (12-16) transmitting Table "Cumulative Projests - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09)
					Operational	--	--	--	--	1,644	1,644	1,644	1,644	**1,644**	
Mule Mountain Solar Project	Bullfrog Green Energy, LLC	CA 49097	Photovoltaic (500MW)	Groundwater	Construction	--	20	20	20	--	--	--	--		Updated from CEC email (12-16) transmitting Table "Cumulative Projests - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09)
					Operational	--	--	0.25	0.5	0.7	0.7	0.7	0.7	**0.7**	
Mule Mountain Soleil	enXco	CA 49488	Photovoltaic (200MW)	Groundwater	Construction	--	--	10	10	--	--	--	--	**--**	Updated from CEC email (12-16) transmitting Table "Cumulative Projests - I-10 Corridor" and First-In-Line Solar Applications, BLM (12-21-09)
					Operational	--	--	--	--	5	5	5	5	**5**	
Palen Solar Power	Solar Millennium LLC/Chevron	CA 48810	Parabolic Trough (484MW)	Groundwater	Construction	--	480	480	480	--	--	--	--	**--**	As proposed in the AFC (August 2009)
					Operational	--	--	--	--	303	303	303	303	**303**	

NOTES

1 **There is conflict between the CEC and BLM lists as to whether these projects will be permitted. They have been included for completeness though they may well not be part of the cumulative water budget for the Chuckwalla Valley Groundwater Basin.**
2 **This project has been withdrawn. The application has been rejected.**
3 **First-In-Line Solar Applications - http://www.blm.gov/pgdata/etc/medialib/blm/ca/pdf/pa/energy/solar.Par.45875.File.dat/Renew_Energy_2_09_solar.pdf**

TABLE DR-S&W-207-2 (rev1)
RESULTS FROM PREDICTIVE SIMULATIONS
NUMERICAL GROUNDWATER MODEL
PALEN SOLAR POWER PROJECT
CHUCKWALLA VALLEY GROUNDWATER BASIN
RIVERSIDE, CALIFORNIA

Model Runs[1]	Zone 1[3]		Zone 2[3]		Zone 3[3]		Period of interest	Max drawdown, ft				Change in storage, af[4]
	T, ft2/d	S	T, ft2/d	S	T, ft2/d	S		Well 1	Well 2	Well 3	Well 4	
Run 7	1,000	0.2	6,300	0.2	26,000	0.2	2013	11.67	6.49	11.69	6.50	1,440
							2029	9.78	5.97	9.96	6.48	6,288
							2043	10.76	6.75	10.96	7.51	10,530
Run 15[2]	1,000	0.2	6,300	0.2	26,000	0.2	2013	11.67	6.49	11.69	6.50	4,109
							2029	9.80	5.97	10.00	6.48	89,633
							2043	10.93	6.76	11.23	7.54	142,526

Notes

1 Run 7 is the "Project Only" simulation and Run 15 is the "Cumulative Impacts" Assessment
2 Refer to Table DR-S&W-207-1 (rev1) for the water use schedule for the renewable projects identified in the model
3 Figure DR-S&W-207-3 shows the areal distribution of transmissivities used in the model
4 Model input and output files provided in Attachment A

STATE OF CALIFORNIA
ENERGY RESOURCES CONSERVATION AND DEVELOPMENT COMMISSION

In the Matter of:
APPLICATION FOR CERTIFICATION
for the *PALEN SOLAR POWER PROJECT*

Docket No. 09-AFC-7
PROOF OF SERVICE
(Revised 12/28/2009)

APPLICANT

Alice Harron
Senior Director of Project Development
1625 Shattuck Avenue, Suite 270
Berkeley, CA 94709-1161
harron@solarmillenium.com

Gavin Berg
Senior Project Manager
1625 Shattuck Avenue, Suite 270
Berkeley, CA 94709
berg@solarmillennium.com

APPLICANT'S CONSULTANT

Arrie Bachrach
AECOM Project Manager
1220 Avenida Acaso
Camarillo, CA 93012
arrie.bachrach@aecom.com

COUNSEL FOR APPLICANT

Scott Galati, Esq.
Galati/Blek, LLP
455 Capitol Mall, Suite 350
Sacramento, CA 95814
sgalati@gb-llp.com

Peter Weiner
Matthew Sanders
Paul, Hastings, Janofsky & Walker LLP
55 2nd Street, Suite 2400-3441
San Francisco, CA 94105
peterweiner@paulhastings.com
matthewsanders@paulhastings.com

INTERESTED AGENCIES

Holly L. Roberts, Project Manager
Bureau of Land Management
Palm Springs-South Coast Field Office
1201 Bird Center Drive Palm Springs, CA 92262
CAPSSolarPalen@blm.gov

California ISO
e-recipient@caiso.com

INTERVENORS

Tanya A. Gulesserian,
Marc D. Joseph
Adams Broadwell Joseph & Cardozo
601 Gateway Boulevard, Suite 1000
South San Francisco, CA 94080
tgulesserian@adamsbroadwell.com

ENERGY COMMISSION

Jeffrey D. Byron
Commissioner and Presiding Member
jbyron@energy.state.ca.us

Kristy Chew, Adviser to Commissioner Byron
kchew@energy.state.ca.us

Karen Douglas
Chair and Associate Member
kldougla@energy.state.ca.us

Raoul Renaud
Hearing Officer
rrenaud@energy.state.ca.us

Alan Solomon
Project Manager
asolomon@energy.state.ca.us

Lisa DeCarlo
Staff Counsel
ldecarlo@energy.state.ca.us

Public Adviser's Office
publicadviser@energy.state.ca.us

DECLARATION OF SERVICE

I, Carl Lindner, declare that on, March 12, 2010, I served and filed copies of the attached Palen Solar Power Project Data Response materials:

Responses to January 14, 2010 CEC Workshop Queries (Groundwater)
Technical Area: Soil & Water Resources

The original document, filed with the Docket Unit, is accompanied by a copy of the most recent Proof of Service list, located on the web page for this project at:

[http://www.energy.ca.gov/sitingcases/solar_millennium_palen]

The document has been sent to the other parties in this proceeding (as shown on the Proof of Service list) and to the Commission's Docket Unit, in the following manner:

(*Check all that Apply*)
For service to all other parties:

__X___ sent electronically to all email addresses on the Proof of Service list;

_____ by personal delivery or by overnight delivery service or depositing in the United States mail at Camarillo, California with postage or fees thereon fully prepaid and addressed as provided on the Proof of Service list above to those addresses **NOT** marked "email preferred."

AND

For filing with the Energy Commission:

__X_ sending an original paper copy and one electronic copy, mailed respectively, to the address below (preferred method);

OR

_____ depositing in the mail an original and 12 paper copies, along with 13 CDs, as follows:

CALIFORNIA ENERGY COMMISSION
Attn: Docket No. 09-AFC-7
1516 Ninth Street, MS-4
Sacramento, CA 95814-5512

docket@energy.state.ca.us

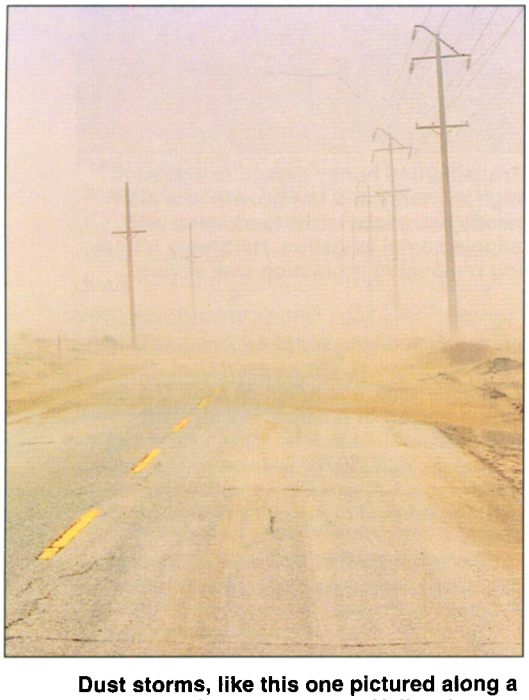
I declare under penalty of perjury that the foregoing is true and correct.

Carl E. Lindner

About 25% vegetative cover is typical for the western Mojave Desert, and is sufficient to prevent soil losses from wind erosion.

Wind barriers offer short-term solution to fugitive dust

David A. Grantz ❑ David L. Vaughn ❑ Robert J. Farber
Bong Kim ❑ Tony VanCuren ❑ Rich Campbell



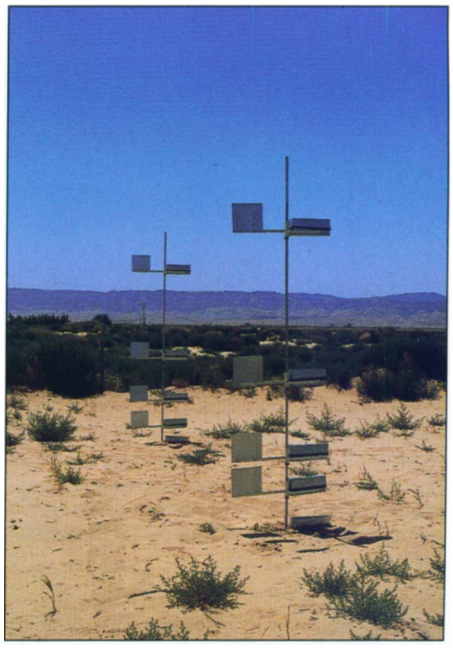
Dust storms, like this one pictured along a county road in the Antelope Valley, have led to serious traffic accidents and violations of air quality standards.

Wind-blown fugitive dust is a widespread problem in the arid west, resulting from land disturbance or abandonment and increasingly limited water supplies. Soil-derived particles obstruct visibility, cause property damage and contribute to violations of health-based air quality standards for fine particles (PM-10). These dry lands are often difficult to revegetate, yet they may require immediate stabilization. We evaluated the effectiveness of three types of mechanical wind barriers, which can be installed more rapidly and more reliably than revegetation, in suppressing dust emissions. Wind fences, furrows and scattered roughness elements, such as plastic cones, are shown to reduce fugitive dust emissions in areas of the Mojave Desert that resisted revegetation.

The western United States is characterized by large areas of arid and semiarid land. Following disturbance by construction, agriculture or recreational activities, these lands are subject to wind-driven emissions of fugitive dust. Population expansion, rising demand for limited water resources and increased pumping costs are increasing the extent of fallow and abandoned arid and semiarid land subject to such wind erosion.

As the forces exerted by the wind overcome the forces that bind soil particles to the surface, soil loss occurs. Dislodged soil particles may roll across the surface (creep), or they may bounce (saltation), dislodging further particles with each impact. This process leads to a cascade effect resulting in massive emissions of dust. Fugitive dust affects crops and native vegetation by abrading and burying plants and by blocking sunlight. Blowing dust has also caused traffic accidents

Wind fences provided effective control of blowing fugitive dust in areas with over-blown sand that resisted revegetation efforts.



Fugitive dust was measured with BSNE passive samplers that collected suspended particles larger than about 45 microns in aerodynamic diameter.

in California's Central Valley and in the Antelope Valley of the western Mojave Desert.

Theoretical relationships between saltation activity of coarse particles and vertical fluxes of fine particles emitted from the surface suggest that control of wind erosion in arid and semiarid regions helps to reduce fugitive emissions of soil-derived fine particles, and also mitigates violations of health-based National and State Ambient Air Quality Standards for particulate matter (PM-10 and PM-2.5). These fine particles, with aerodynamic equivalent diameters of 10 and 2.5 micrometers and much finer than a human hair, are drawn deeply into the lung, where they may be associated with adverse health effects.

Roughness elements — such as wind fences, shrub vegetation, furrows, rocks and soil aggregates — absorb wind energy, disrupt movement of sand grains and reduce particulate emissions. In this study, we evaluated the effectiveness of a number of mechanical barriers.

Western Mojave Desert

The Antelope Valley is an arid region that is subject to periodic high-wind events and emissions of fugitive dust. Formerly a high-quality agricultural area with artesian wells and low-cost groundwater resources, it is now undergoing a slow process of urbanization and agricultural withdrawal. Land abandonment, off-road vehicle usage, extensive sheep grazing and increased incidence of wildfire have all contributed to the expansion of severely disturbed areas without stable perennial vegetation. These areas are subject to emissions of fugitive dust. Native vegetation in this area covers about 25% of the surface of undisturbed land, and is sufficient to prevent such wind erosion. Following disturbance, the stabilizing soil crust is disrupted and native perennial plant species are replaced by ephemeral annual species such as Russian thistle (*Salsola pestifer;* tumbleweed), mustards and grasses. These leave the surface periodically barren, and the resulting seasonal erosion further destabilizes the surface and prevents perennial shrub establishment, perpetuating a cycle of disturbance.

During the prolonged drought of 1985 to 1992, the metropolitan areas of Lancaster and Palmdale and the unincorporated area of Antelope Acres were inundated with wind-blown fugitive dust and fine particulate matter emitted from disturbed upwind areas of the Antelope Valley. In 1989, 1990 and 1991, the South Coast Air Quality

TABLE 1. Control of fugitive dust by various types of wind barriers

Year	No. of weekly samples	Barrier type	Mean wind speed		Maximum wind gust		Sampler height	Average control
			m/s	*mph*	*m/s*	*mph*	*m*	*%*
1992	3	Wind fence	3.3	7.4	20.5	45.9	0.2	71
	3		3.3	7.4	20.5	45.9	1.0	67
	3		3.3	7.4	20.5	45.9	2.0	54
1994	8		5.6	12.5	24.2	54.1	1.0	63
1995	16		4.0	8.9	25.2	56.4	1.0	69
1995	3	Furrows	3.6	8.1	19.6	43.8	0.20	93
	3		3.6	8.1	19.6	43.8	0.37	76
	3		3.6	8.1	19.6	43.8	0.67	66
	6		4.4	9.8	25.2	56.4	1.0	56
	3		3.6	8.1	19.6	43.8	1.16	24
	3		3.6	8.1	19.6	43.8	2.00	33
1996	10	Roughness elements	4.8	10.7	22.8	51.0	0.20	64
	10		4.8	10.7	22.8	51.0	0.37	66
	10		4.8	10.7	22.8	51.0	0.67	40
	10		4.8	10.7	22.8	51.0	1.16	25
	10		4.8	10.7	22.8	51.0	2.00	15

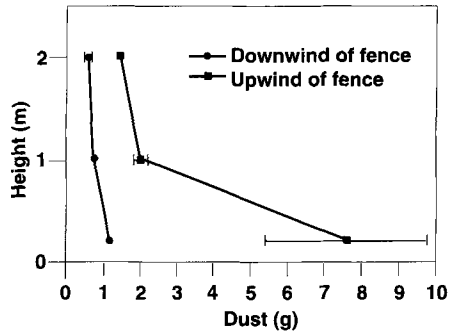


Fig. 1. Effect of wind fences on the vertical distribution of suspended fugitive dust, relative to the area upwind of the wind fences (squares). Wind speed at 2.0 m averaged 2.7 m/s (6 mph) during this 7-day sample period, with gusts up to 15.2 m/s (34 mph).

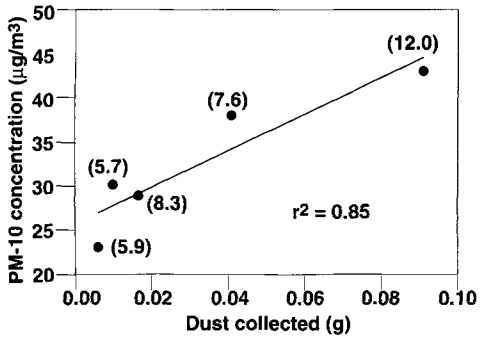


Fig. 2. Atmospheric concentrations of PM-10 measured with a high volume sampler were significantly related to collections of dust at 2.0 m with the BSNE samplers. Data are 48-hour samples under varying conditions of mean wind speed (mph in parentheses).

Management District reported 25, 22 and 11 exceedances of the California State standard for PM-10 (50 $\mu g/m^3$, 24-hour average), with a maximum 24-hour average of 780 $\mu g/m^3$, occurring in 1991. In response to the increasing severity of wind-blown dust and persistent particulate air quality violations, a locally based multiagency working group, the DustBusters Taskforce, was convened to consider mitigation strategies.

An Emergency Watershed Protection (EWP) program was funded by the USDA Soil (now Natural Resources) Conservation Service (NRCS). The EWP revegetation program was the first NRCS program of its kind to target wind erosion. About 2,500 acres of the most seriously disturbed lands were treated with the EWP protocol of furrowing and revegetation. Areas within the EWP area that were overburdened with drifting sand did not respond to the furrowing and seeding. In these areas, wind fences were installed along roadways and upwind of threatened residential areas.

In the EWP area and in surrounding areas of experimental plots, we evaluated the effectiveness of these wind fences erected across the prevailing wind. We also evaluated the effectiveness of widely spaced, discrete "roughness elements" consisting of plastic cones, and of furrows installed across the wind, in reducing fugitive dust emissions from extensive areas of disturbed land. These techniques have the capability to provide rapid surface stabilization in areas where vegetation is absent and difficult to reestablish.

Particle sampling

Suspended coarse particulate matter, dust, was sampled with passive collectors (BSNE samplers), which efficiently collected coarse suspended particles larger than about 45 microns in aerodynamic equivalent diameter. The BSNE samplers were deployed at several heights on 10-foot lengths of pipe driven into the soil. The mass of dust collected in the BSNE samplers was determined on a regular schedule.

We evaluated airborne concentrations of PM-10 at one location with a USEPA reference method High Volume Sampler with a 10-micron Size Selective Inlet located 6.6 feet (2.0 meters) above the surface. This was co-located with two BSNE samplers at the same height.

To evaluate contrasting barrier techniques, we compared dust collected upwind and downwind of the barriers, or dust collected downwind of treated and untreated areas.

Wind fences

In spring 1992, three parallel wind fences (4-foot height, 55% porosity) of ultraviolet-stabilized plastic tied to T-stakes were established 33 feet apart, perpendicular to prevailing winds, on a 60-acre area of Cajon loamy sand with overlying wind-blown sand with 1,500 feet fetch of uniform disturbed surface. This intensive grouping of fences was designed to protect a specific downwind group of residential buildings. A duplicate array of BSNE samplers, at heights of 0.7, 3.8 and 6.6 feet (0.2, 1.0 and 2.0 meters), was deployed along this fetch in a transect from a stable region of natural vegetation at the upwind boundary, through the unconsolidated sandy area containing the wind fences, to the leeward edge.

We collected samples at weekly intervals over an evaluation period of approximately 3 months. Wind speeds ranged from calm to gusts of over 45 mph. During a period of moderate maximum wind velocity near 33 mph, resulting in significant dust collections upwind of the fences, the wind fences significantly decreased fugitive emissions by about 80% near the ground and about 60% at 1.0 and 2.0 meters (fig. 1). When averaged over three weekly sample periods (two periods in April and one in May 1992) that yielded substantial fugitive dust collections, the wind fences exerted greater than 50% control at all measurement heights (table 1). The balance of the sampling periods in spring 1992 were characterized by relatively calm winds with low emissions of fugitive dust. These same fences were evaluated in spring 1994, yielding nearly identical results at the 1.0 meter height (table 1).

The collections of coarse dust by the BSNE samplers in 1992 were strongly related to airborne concentrations of fine particles determined with the High Volume PM-10 Sampler (fig. 2). This supports the suggestion that control of wind erosion may mitigate violations of air quality standards for fine particles, at least under the low-wind conditions of this comparison.

In 1994, we also evaluated identical wind fences at a different abandoned agricultural site that was overburdened with much deeper, drifting wind-blown sand. At two locations, we established less intensive groupings of three single wind fences, 164 feet (50 meters) apart, perpendicular to the prevailing wind to evaluate a potential control measure for extensive areas, where a dense network of barriers would be cost prohibitive.

The widely spaced fences disrupted the fetch at periodic intervals. Al-

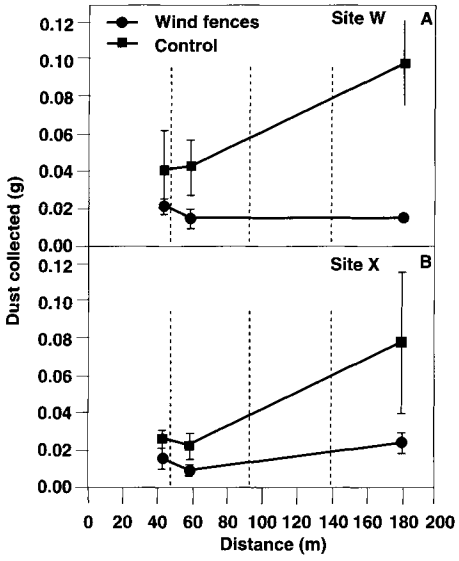


Fig. 3. Effect of wind fences (vertical broken lines) on the relationship between fetch across a disturbed surface and fugitive dust collections at 1.0 m in adjacent plots with (circles) or without wind fences. Data are means of three sample periods, at replicate locations with an overburden of sand in the western Antelope Valley. Wind speed at 2.0 m averaged 6.1 m/s (13.6 mph) with gusts up to 24.2 m/s (54 mph).

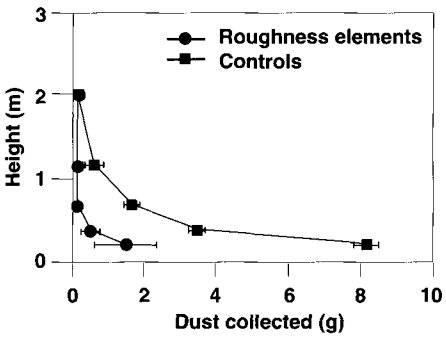


Fig. 4. Effect of widely dispersed roughness elements (circles) on the vertical distribution of suspended fugitive dust relative to a similar area without roughness elements. Wind speed at 10 m averaged 8.0 m/s (18 mph) during this 7-day sample period, with gusts up to 23 m/s (51 mph).

though emissions from the control plots increased substantially with increasing downwind fetch, those from the plots treated with wind fences did not (fig. 3). Collection of suspended dust was reduced at all points along the plot at the 1.0-meter measurement height, even just upwind of the first fence.

Wind fences were effective in reducing fugitive dust at all of the test sites in all years (table 1). Averaged over all periods and locations, including calm periods of low fugitive dust emissions, the wind fences reduced suspended particles by about 66% at 1.0 meters, although the effectiveness was greater during periods of high wind. Wind fences require an initially large input of labor and materials, but they provide an immediately effective and persistent method of controlling wind-blown fugitive dust.

Furrows

Furrowing is commonly used for controlling wind erosion in arid as well as more mesic environments. The resulting complex and rough soil surface exposes more aggregated particles to the wind and increases the wind speed required to initiate particle movement. Dislodged particles also become trapped in wind-protected locations, suppressing saltation and interrupting the chain reaction that leads to massive dust emissions.

We established furrows across the wind on a 328-by-656-foot barren site of Hesperia fine sandy loam with an adjacent control plot. Replicate BSNE samplers were installed at several heights up to 6.6 feet (2 meters) (n = 3 per height) at the downwind edge of each plot. The furrows reduced fugitive dust collections at all heights (table 1), ranging from a 93% reduction near the soil surface to a 24% to 33% reduction above 1.0 meter. The furrows significantly increased the threshold friction velocity, a measure of wind speed needed for dust emissions, from about 45 to about 65 cm/s. Heavy soils that readily form aggregates are more likely than sandy soils to respond to a furrowing treatment. In situations of arable soil overburdened with windblown sand, furrowing may be ineffective, while deep ripping may be effective in bringing large aggregates to the surface and reducing dust emissions.

Furrowing is commonly used to control wind erosion, by exposing aggregates, making the surface rougher and requiring higher wind speeds to initiate particle movement.

The common agronomic practice of furrowing across the wind was successful in rapidly reducing fugitive dust and soil erosion from this fallow field in the Antelope Valley. However, a general disadvantage of such tillage in the Antelope Valley and other arid areas is that it discourages establishment of desirable native perennial shrubs such as *Atriplex* spp. and rabbitbrush *(Chrysothamnus nauseosus)*, and encourages invasion by nitrophilic annuals such as Russian thistle. Nevertheless, the rapid stabilization of furrowing may promote revegetation of some highly unstable sites, because continual surface erosion also inhibits shrub establishment.

Dispersed barriers

After we evaluated furrowing, we lightly disked the same treated and control plots to a uniform surface free of annual species. The control plot remained in a barren condition while plastic cones (base diameter 8 inches, top diameter 4 inches, height 24 inches) were dispersed approximately on a grid of 7.5 by 30 feet over the entire plot. We evaluated the effectiveness of these dispersed roughness elements in suppressing fugitive dust weekly with replicate BSNE samplers at five heights downwind of each plot.

The dispersed roughness elements significantly reduced fugitive dust emissions, especially near the soil surface, during a high-wind collection period (fig. 4). The reduced fetch between the barriers reduced the wind speed near the ground, decreased the

Discrete roughness elements, such as these small plastic cones used for herbivory protection of transplanted seedlings, disrupt wind flow patterns at the soil surface and help reduce fugitive dust emissions.

mass of particles in saltation, and minimized entrainment into the bulk airstream. Over 10 weekly sampling periods, dust collections were reduced by about two-thirds near the ground, but only by about 15% at 6.6 feet (2.0 meters) (table 1).

Although these plastic cones were initially selected as plant shelters for revegetation efforts, their effectiveness in reducing dust emissions despite the complete failure of plant establishment suggests that many types of discontinuous roughness elements could provide rapid relief from dust emissions. If they are unsightly or nondegradable, such objects could be removed once revegetation becomes established.

All wind barriers effective

We evaluated a variety of nonvegetative wind barriers under contrasting conditions in a severely disturbed arid region.

Wind barriers of all types were effective in controlling fugitive dust emissions from areas that were resistant to long-term revegetation. Furrows installed perpendicular to the prevailing winds reduced emissions by more than 50% at heights up to 3.3 feet (1.0 meter), but the surface disturbance associated with tillage was not conducive to natural shrub establishment. Wind fences installed perpendicular to the prevailing winds were also effective in reducing saltation near the soil surface and in reducing suspended particles downwind of the fences by approximately 90% under high-wind conditions. Wind fences are costly to install, but they provide persistent suppression of wind-blown dust, at least until local deposition buries the fence. Widely spaced, individual, dispersed roughness elements were also effective in reducing fugitive dust emissions.

Although natural or facilitated revegetation with native shrubs is likely to be even more effective and sustainable than the artificial wind barriers evaluated here, revegetation may not be feasible at all sites nor achievable in a timely fashion. Therefore mitigation of soil erosion and particulate air pollution in arid and semiarid regions requires land managers and the regulatory community to explore a full range of vegetative and mechanical mitigation strategies.

D.A. Grantz is Plant Physiologist and Extension Air Quality Specialist and D.L. Vaughn is Staff Research Associate, Department of Botany and Plant Sciences and Statewide Air Pollution Research Center, UC Riverside; R.J. Farber is Senior Research Scientist, Southern California Edison Company, Rosemead; B. Kim is Air Quality Specialist, South Coast Air Quality Management District, Diamond Bar; T. VanCuren is Air Pollution Research Specialist, California Air Resources Board, Sacramento; and R. Campbell is District Conservationist, Natural Resources Conservation Service, Lancaster.

Further reading

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SUSAN V. LEE

Vice President, San Francisco Operations

ACADEMIC BACKGROUND

M.S., Applied Earth Science, Stanford University, 1984
B.A., Geology, Oberlin College, 1977

PROFESSIONAL EXPERIENCE

Ms. Lee has over 25 years of technical and managerial experience in environmental assessment, and she currently manages Aspen's San Francisco Office. Her expertise is in management of environmental assessment for infrastructure and energy projects (renewable energy projects, electric transmission lines, pipelines, and gas-fired power plants) under both the California Environmental Quality Act (CEQA) and the National Environmental Policy Act (NEPA). Ms. Lee has managed preparation of several major controversial transmission line and pipeline siting EIR/EISs, including the Sunrise Powerlink, Path 15, Jefferson-Martin, Tri-Valley, and Devers–Palo Verde No. 2. Prior to employment at Aspen, Ms. Lee worked for 10 years with the Federal government [the U.S. Minerals Management Service (MMS) and the U.S. Geological Survey (USGS)].

Ms. Lee has worked for Aspen Environmental Group since 1993. She has contributed to both technical and project management aspects of Aspen's environmental projects, including the following:

- **California Energy Commission**. Ms. Lee has supported CEC staff since the fall of 2000. To date, she has prepared analyses for 14 power plants throughout the State, and she has also contributed to several special project reports. She has participated in numerous public workshops and hearings around the state, and completed the CEC's Expert Witness Training. Her major efforts for the CEC include the following:
  - Ms. Lee is managing the Alternatives and Cumulative impact analyses for several solar thermal projects on public lands, coordinating NEPA issues with BLM staff and CEQA issues with the Energy Commission's Project Manager.
  - Ms. Lee managed preparation of the CEC's first comprehensive dry cooling analysis for a coastal power plant using once-through cooling, the **Morro Bay Power Plant Modernization Project**. She managed a team of authors who developed a preliminary cooling design, and provided impact analysis.
  - Ms. Lee has prepared staff assessment **Alternatives Analyses** (consistent with CEQA and the CEC's procedures) for the CEC's staff reports considering proposed new or re-powered power plants at South Bay (San Diego), Blythe (BEP II), Morro Bay, El Segundo, Avenal, San Joaquin Valley, Potrero Unit 7 (San Francisco), Tracy, East Altamont, Henrietta, and the San Francisco Electric Reliability Project. She also prepared the alternatives analysis for the CEC's Blythe Transmission Modifications Project. In addition to preparing staff assessment sections documenting comparative impacts of alternatives, this work includes making presentations at PSA Workshops and testifying at Evidentiary Hearings.
  - Ms. Lee managed a three-year transmission corridor modeling project, **Planning Alternative Corridors for Transmission (PACT)**, in conjunction with the CEC PIER Environmental Program. The model uses Geographic Information Systems and decision modeling to assist in comparing potential alternative transmission corridors. Aspen's work included overall contract management, as well as development and management of a Project Steering Committee and six Technical Advisory Groups.
  - Ms. Lee prepared a detailed Background Report and made a presentation at an Energy Commission workshop on "**Comparative Alternatives to Transmission**" as part of the Integrated Energy Policy Report (IEPR) 2004 Update process. This project evaluated non-wires alternatives to transmission lines;

ongoing work is related to development of a methodology for consideration of these alternatives as part of the transmission planning process.

- Ms. Lee served as the CEC's **Project Manager** for the Small Power Plant Exemption (SPPE) environmental review process for the Woodland Generation Station 2, an 80-megawatt power plant proposed by the Modesto Irrigation District.
- Ms. Lee managed preparation of **Power Plant Cooling Options Reports** for the Potrero Unit 7 Project, Morro Bay, SMUD Cosumnes, and El Segundo power plants. These analyses include conceptual design of dry cooling systems, hybrid cooling systems, and water supply options including use of reclaimed water in both once through and hybrid cooling systems.
- Ms. Lee has provided management and technical support to Aspen's preparation of several reports for the CEC: the Environmental Performance Report, the Coastal Power Plant Study, and the Alternative Generation Technology study.

- **California Valley Solar Ranch EIR.** Under contract to San Luis Obispo County, Ms. Lee is managing preparation of an EIR to evaluate development of a 250 MW solar photovoltaic power facility on nearly 4,000 acres in the Carrizo Plain.
- **SDG&E Sunrise Powerlink Transmission Project EIR/EIS**. Under a $14 million contract to the CPUC, and under a Memorandum of Understanding with the Bureau of Land Management (BLM), Ms. Lee managed preparation of an EIR/EIS for a highly controversial 150-mile transmission line from Imperial County to coastal San Diego County.
- **SCE Devers–Palo Verde No. 2 Transmission Line Project EIR/EIS**. Under contract to the CPUC, Ms. Lee managed preparation of an EIR/EIS to evaluate the impacts of a constructing a 230-mile 500 kV transmission line between the Palo Verde generating hub in Arizona and SCE's Devers Substation.
- **Long-Term Procurement Planning and Barriers to Renewable Power Implementation**. For the CPUC, Ms. Lee and a team of environmental and economic specialists developed environmental and economic data and developed timelines of permitting and barriers to implementing the proposed 33 percent Renewable Portfolio Standard, including ranking and screening of available energy resources.
- **Jefferson-Martin 230 kV Transmission Line Project**. Ms. Lee managed preparation of an EIR for PG&E's proposed 27-mile transmission line through scenic San Mateo County in the Highway 280 corridor, urban Colma and Daly City, and across San Bruno Mountain for the California Public Utilities Commission (CPUC).
- **PG&E Northeast San Jose Transmission Reinforcement Project**: Ms. Lee served as the Project Manager for this CPUC contract to evaluate PG&E's proposed transmission improvements in Santa Clara and Alameda Counties.
- **PG&E Tri-Valley 2002 Capacity Increase Project.** Ms. Lee managed preparation of the Draft and Final EIRs for this controversial and complex project during 2000 and 2001, which was certified by the CPUC in May 2001. The Draft EIR (over 800 pages) evaluated proposed transmission lines and substations in the Tri-Valley area (Cities of Pleasanton, Dublin, Livermore, and San Ramon) of Alameda and Contra Costa Counties, and responded to a high level of local concern regarding electric and magnetic fields (EMFs).

David Vidaver

David Vidaver has been employed by the California Energy Commission since 1998. He is currently head of the Procurement and Resource Adequacy Unit of the Electricity Analysis Office (EAO), supervising eight staff responsible for assessments of the procurement activities and resource adequacy of the state's investor-owned and public utilities, and directs collaborative staff involved in the California Public Utilities Commission's (CPUC) proceedings on long-term procurement, resource adequacy, and planning reserve margins.

Mr. Vidaver is an Energy Commission representative to inter-agency working groups on once-through cooling and infrastructure needs in the South Coast Air Basin, and is Project Manager for a statewide infrastructure assessment being conducted for the 2011 Integrated Energy Policy Report.

Previously, Mr. Vidaver has supervised EAO's simulation modeling group, and evaluated temperature-demand relationships as an analyst in the Commission's Demand Analysis Office. He has been a member of the Northwest Power and Conservation Council's Generation Resource Advisory Committee for the development of its 4th and 5th Regional Power Plans. He has authored, co-authored and contributed to numerous Energy Commission reports, presented studies at numerous workshops and conferences, and provided expert testimony before the Energy Commission and the CPUC.

Mr. Vidaver has degrees in Political Science from UC Berkeley and Agricultural Economics from UC Davis.

Carolyn Chainey-Davis, botanist

Over 23 years experience conducting biological inventories and impact assessments, rare plant and noxious weed surveys, large-scale vegetation mapping, wetland delineations, large-scale watershed assessments, designing and implementing mitigation & monitoring plans, habitat management plans, and restoration plans throughout California. Ms. Chainey-Davis field experience includes a diverse group of clients and projects from large transmission and hydro relicensing projects to urban and residential development projects, local, state and federal agencies, resource conservation organizations, landfill and mine reclamation projects, and many more. She led Garcia and Associates (GANDA) botanical studies for numerous FERC relicensing projects (PG&E & SCE) including Stanislaus River, Upper North Fork Feather River, Pit River, Vermillion, Bucks Lake and Poe hydro-relicensing projects, Transmission Separation project, Lower Owens River riparian monitoring, and hundreds of other large and small projects around the state.

Ms. Davis is past President of the California Native Plant Society, Nevada and Placer County Chapter and is a co-author of the recently published field guide "*Wildflowers of Nevada and Placer Counties*", published by the California Native Plant Society. Ms. Davis completed her wetland training at Portland State University and is certified for conducting wetland delineations based on the U.S. Army Corps of Engineers Wetland Delineation Manual. Ms. Chainey-Davis is skilled in the use of Trimble GeoExplorer series Global Positioning (GPS) equipment. As a botanist, she apprenticed for several years under some of the state's leading botanists, vegetation and wetland ecologists, including Robert Holland. Ms. Davis' continuing education includes several annual intensive botanical taxonomy workshops through the U.C. Berkeley Jepson Herbarium.

A Sampling of Relevant Project Experience

Project: **Beacon Solar Energy Project Rosamond Water Alternative**
Client: **California Energy Commission (CEC)**
Conducted detailed habitat assessment and vegetation mapping for a 40-mile alternative water pipeline alignment near Mojave, CA, in support of the Final Staff Assessment. CEC evaluated the feasibility of BSEP using an alternative source of water other than onsite potable groundwater and identified City of Rosamond tertiary treated wastewater as a feasible source. Prepared supplemental report describing the vegetation resources occurring along the southern 23 miles of the 39.61-mile Rosamond water pipeline alignment, including vegetation mapping and a rare plant habitat assessment. Assisted staff in the impact assessment for the proposed and preferred alternative.

Project: **Lower Owens River Monitoring Program**
Client: **Ecosystem Sciences**
Member of a team of three biologists to design long-term monitoring program for collecting and analyzing data on riparian habitat and key wildlife habitat characteristics on 62 miles of the Lower Owens River. Directed field efforts to collect baseline data at 350 sites. Future monitoring, conducted after the initiation of appropriate flow and land management practices, will be compared against the baseline to determine if changes resulting from proposed restoration efforts (augmented stream flows) are consistent with the LORP goals and objectives.

Project: **Open ended Contract for Biological Services**
Client: **Southern California Edison (SCE)**
Led Garcia and Associates (GANDA) botanical studies (vegetation mapping, habitat assessments, etc.) in support of various SCE construction and relicensing projects in the central and southern Sierras, Sierra east slope and Great Basin region, and the eastern edge of the San Joaquin Valley.

182 Grove Street Nevada City, CA 95959 [ph] 530.478.1963 [cell] 530.205.6218 bighair60@att.net

Project: **Stanislaus River Hydroelectric Project Relicensing Studies**
Client: **Pacific Gas and Electric Company, Technical and Ecological Services**
Led GANDA field efforts to conduct floristically-based botanical studies for the Federal Energy Regulatory Commission relicensing of four hydroelectric and transmission line projects located on the Stanislaus River, Stanislaus National Forest. Riparian and watershed vegetation mapping and sampling, special-status plant surveys, noxious weed mapping, and identify and map culturally significant Native American botanical resources for local tribes in support of the Federal Energy Regulatory Commission relicensing process. Prepared draft and final reports.

Project: **Owens Lake Dust Control Project**
Client: **Garcia and Associates**
Conducted two years of floristically-based special status plant surveys and wetland delineations for the Los Angeles Department of Water and Power Owens Lake Dust Control mitigation project.

Project: **Kern River Natural Gas Pipeline**
Client: **Garcia and Associates**
Conducted floristically-based special status plant surveys for the Daggett and Goodsprings segments of the interstate pipeline.

Project: **Pit River Hydroelectric Project Relicensing Studies**
Client: **Pacific Gas and Electric Company, Technical and Ecological Services**
Led field efforts to conduct floristically-based special status plant surveys, noxious weed surveys, upland habitat mapping, and riparian vegetation classification and mapping for PG&E's Pit 3, 4, and 5 hydroelectric project in Shasta County in support of the Federal Energy Regulatory Commission relicensing process. Prepared draft and final reports.

Project: **Upper North Fork Feather River and Poe Hydroelectric Projects, Lake Almanor Habitat Management Plan**
Client: **Pacific Gas and Electric Company, Technical and Ecological Services**
Led field efforts to conduct floristic surveys for special-status plant species and noxious weeds on the Upper North Fork Feather River (Plumas and Lassen National Forests) and Poe Project Included GIS-based riparian and upland vegetation mapping in support the Federal Energy Commission relicensing process. Prepared draft and final reports. Also conducted detailed mapping of the wet meadows around Lake Almanor and prepared a long-term habitat management plan for meadow resources and willow flycatcher habitat.

Project: **Transmission Separation Project**
Client: **Foster Wheeler Environmental Corporation**
Led field efforts to conduct floristically-based special-status plant surveys and noxious weed surveys for the PG&E Transmission Separation Project. GANDA botanists conducted surveys on selected transmission line segments and their associated access roads on USDA Forest Service (USFS) lands in the Plumas, Shasta-Trinity, Tahoe, and Eldorado National Forests, created GIS-based vegetation and noxious weed maps, and analyzed potential threats to special-status plant populations. Prepared draft and final reports.

Project: **Nevada and Placer County projects – large and small subdivisions, infrastructure development, etc.**
Client: **Susan Sanders Biological Consulting and Beedy Environmental Consulting**
Conducted biological inventory and impact analyses and prepared mitigation plans for over 100 large and small subdivisions and infrastructure development projects in Nevada and Placer County. Lead writer and botanist. All projects included vegetation mapping, habitat assessments, floristic surveys, and mitigation planning. Prepared detailed habitat management plans and recreation/ trail plans for over a thousand acres of open space.

Project: **Dog Ranch-Salmon Creek Conservation Project**
Client: **Robert Holland**
Conducted endangered species surveys and documented over 300 occurrences of special status plants (using Trimble data dictionary and population sampling protocol) for a proposed conservation easement/land swap on a 400+ acre ranch in Humboldt County on the Samoa Peninsula.

182 Grove Street Nevada City, CA 95959 [ph] 530.478.1963 [cell] 530.205.6218 bighair60@att.net

Project: **Field Guide to *Epilobium* in the Sierra Nevada, Tahoe National Forest**
Client: **U.S.D.A. Forest Service, Tahoe and Inyo National Forests (Open-ended Contract)**
Conducted surveys for rare *Epilobiums* at seven sites in the Tahoe and Inyo National Forests and prepared a field guide to the genus *Epilobium* in the Sierra Nevada, with illustrations and keys to identification.

Project: **Bear Valley Meadow Restoration**
Client: **American Rivers**
Sample design and long-range monitoring design and protocol for a large-scale meadow restoration project in Placer County. Included detailed vegetation mapping, conducting baseline inventory, and preparing report on sample design and results of baseline monitoring.

Project: **Shirttail Creek Conservation Easement**
Client: **Beedy Environmental Consulting for Conservation Biology Institute**
Conducted biological inventory and conservation assessment for 800-acre property on Shirttail Creek in the American River watershed using protocol developed by The Nature Conservancy for conservation planning. Lead writer and botanist.

Project: **Natural Heritage 2020 Nevada County Watershed Assessment**
Client: **County of Nevada and Sierra Business Council**
Lead botanist for a countywide watershed and ecosystem assessment. A two-year process funded by the Sierra Business Council and the County of Nevada to create a GIS database and biotic inventory of the county's natural habitats and wildlife resources, including an assessment of vegetation, special status and invasive for 98 sub-watershed basins in the county. Prepared botanical sections of the report, verified accuracy of more than 40 GIS data themes, assessed the extent and quality of each of the county's ecosystem types, potential to support special-status plants and animals.

Project: **Special Status Plant Surveys and Habitat Mapping for Rock Creek/Cresta Hydroelectric**
Client: **Pacific Gas and Electric Company, Technical and Ecological Services**
Conducted floristically-based special status plant surveys and habitat mapping for PG&E's Rock Creek-Cresta hydroelectric facility project area and 72-mile transmission line in Plumas, Butte, Yuba and Sutter counties.

Project: **Osborne Hill Open Space Habitat Management Plan**
Client: **Susan Sanders Biological Consulting**
Prepared detailed, goal-driven, long-range habitat management plan for 250 acres of open space for a residential development in Nevada County. Included guidelines for forest management to promote old-growth conditions, fuels management specifications, habitat management specifications, and designs and implementation plan for recreational trails, educational signage, and formation of an independent non-profit land trust to manage the open space. Prepared similar plans for several other residential developments in Nevada County.

Project: **Ragsdale Creek Setback Study**
Client: **Susan Sanders Biological Consulting & County of Nevada**
Identified, described, and mapped important biological resources on an urban stream in Nevada County and recommended appropriate development setbacks to avoid/minimize impacts, assessed potential impacts to the creek as a result of adjacent development, and recommended mitigation measures to reduce impacts. Coordinated with County GIS Department in production of map of sensitive resources, and presented results of study to citizen advisory committee.

Project: **Open ended Contract for Biological Services, Various Transmission Projects**
Client: **Pacific Gas & Electric Company (PG&E)**
Led Garcia and Associates (GANDA) botanical studies (rare plant surveys, vegetation mapping, habitat assessments, etc.) in support of various PG&E transmission projects throughout California, including Kern #304, Northeast San Jose Reinforcement, Atlantic-Del Mar, Butte Reinforcement, and many more.

Project: **Open ended Contract for Biological Services, Transmission Relicensing Projects**
Client: **Southern California Edison (SCE)**
Led Garcia and Associates (GANDA) botanical studies (vegetation mapping, habitat assessments, etc.) in support of various SCE construction and relicensing projects in the central and southern Sierras, Sierra east slope and Great Basin region, and the eastern edge of the San Joaquin Valley.

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Andrew Collison, Ph.D.

Principal / Senior Geomorphologist

Dr. Collison is a geomorphologist and hydrologist with seventeen years experience working with sediment transport, geomorphology and hydrology issues. He has worked on projects on the West Coast from Northern Washington to the Mexican border, as well as the Southeastern USA, Europe and South East Asia. Dr. Collison sits on several independent scientific advisory panels including those for the State Water Resources Control Board's Hydromod Team, the Southern California Wetland Recovery Program, the North Coast Regional Water Quality Control Board's Independent Scientific Panel for the PALCO Timber Harvest Plan, the Southern California Coastal Watersheds Research Program Hydromod Panel and San Francisco Estuary Institute's Napa River project. He is a co-author of the SWRCB's 401 Training Manual and developed and taught the State Board's bank stability training course. Prior to PWA, Dr. Collison was a Visiting Scientist worked on erosion and sediment transport issues at the USDA Agricultural Research Service's National Sedimentation Laboratory, Oxford, MS, for 2 years. Following his PhD he was appointed as a geomorphology professor at King's College, University of London, England for 7 years.

Education

Ph.D. 1993 — Department of Geography, University of Bristol, Bristol, UK. Geomorphic and hydrologic effects of vegetation on hillslope stability

B.S. 1989 — Department of Geography, University College London, London, UK. Included classes in desert geomorphology and arid environments, basic geomorphology, applied geomorphology, hydrology and geoarchaeology.

Awards

University College London Mead Scholar, 1988
Institute of Civil Engineers Trevithick Award for best publication in civil engineering journal, 1994

Employment

1994-2000 Lecturer in Geomorphology, King's College, University of London, UK
2000-2002 Visiting Scientist, USDA National Sedimentation Laboratory, Oxford, MS
2002-2006 Senior Associate, Philip Williams & Associates, Hydrology consultants
2006-2008 Associate Principal, Philip Williams & Associates, Hydrology consultants
2002-2006 Principal, Philip Williams & Associates, Hydrology consultants

Selected Project Experience

Expert Witness Reports and Testimony

US Environmental Protection Agency, Calleguas Creek bank erosion case, 2010. Dr. Collison is acting as an expert witness for the US EPA and the US Department of Justice in an enforcement action under the Clean Water Act. The alleged violation involved illegal fill of a Water of the United States. Dr Collison prepared an initial expert report and is currently preparing testimony.

California Energy Commission Genesis Solar Power Project, Riverside County, 2010. Prepared and presented expert testimony for a proposed power plant with a focus on how the project would affect geomorphic and biological processes.

North Coast Regional Water Quality Board, Pacific Lumber dispute, 2003-4. A member of the independent scientific panel for the dispute between PALCO and NCRWQCB over sustainable logging rates and sedimentation impacts in the Eel River basin. Heard testimony and prepared an expert report to the Executive Board of the NCRWQCB.

Earth Justice, Pacific Lumber dispute, 2004-05. Prepared expert testimony and was deposed in the dispute between Earth Justice/EPIC and PALCO over logging and sediment impacts to the Eel River basin.

Dry Creek channel evolution and erosion, Healdsburg, 2004. For Sayer and Wilson, Attorneys. Prepared an expert report on the effects of Warm Springs Dam and Russian River gravel mining on channel response in Dry Creek.

Other relevant experience

California Energy Commission Calico Solar Power Project, San Bernardino County, 2010. Conducted a site assessment, geomorphic analysis, sediment budget and impact assessment for the proposed solar power plant with a focus on how the project would affect geomorphic and biological processes.

California Energy Commission Rice Solar Power Project, Riverside County, 2010. Conducted a site assessment, geomorphic analysis, and impact assessment for the proposed solar power plant with a focus on how the project would affect geomorphic and biological processes.

Smugglers Gulch Sedimentation, Tijuana Estuary, 2004. For California State Parks. Project Manager and Geomorphologist. PWA reviewed hydrology, hydraulic and sediment transport data to look at the potential impact of the Border Fence and cross-border flows from Mexico on the Tijuana River and its Estuary.

Identifying the Source, Rate and Fate of Sediment in the Laguna de Santa Rosa, Sonoma Co., CA, 2002-04. For US Army Corps of Engineers. Project Manager and lead geomorphologist. The Laguna de Santa Rosa is an ecologically important wetland and also functions as a flood water store, reducing flood potential on the Russian River. Both roles are threatened by accelerated sedimentation rates. PWA carried out a watershed assessment of sources, production rate, and delivery processes for sediment in the Laguna watershed, to help inform and prioritize management of the area.

Developing Safe Flow Release Standards to Protect Creeks, Alameda County, CA. 2007-09 For East Bay Municipal Utility District (EBMUD). Geomorphology Lead. EBMUD periodically releases water from storage facilities into creeks, raising the potential for clean-water scour in receiving streams and triggering concern from the RWQCB. PWA adapted hydromod methods developed for the SFD Bay counties to assess the risk of a receiving water eroding and allow non-damaging releases to be calculated.

Bear River Levee Setback Project, Yuba Co., CA, 2006-07. For TRLIA. PWA assessed the geomorphic and sediment transport effects, and provided designs for ecological features, for a 2 mile levee setback at the confluence of the Bear and Feather Rivers. The project was awarded the 2008 ASCE California Region Flood Control Project of the Year.

401 Permit, and Bank Stabilization Training for State and Regional Water Quality Control Board Staff, CA, 2004. For UC Davis Extension Service. Task Manager and Geomorphology lead. PWA helped to develop the curriculum, wrote a manual, and provided the hydrology and geomorphology component of a training package for Board Staff. The courses, run through UC Davis, provides staff with training in channel and watershed geomorphology so that they can make well-grounded decisions with regard to 401 Permit applications and mitigation requirements.

Sediment Transport and Sediment Management on the Pájaro and San Benito Rivers. For the Pájaro River Watershed Flood Prevention Authority. Project Manager and lead geomorphologist. The Pájaro River is the subject of a proposed flood plan that is threatened by potential difficulties obtaining permits for sediment removal. Dr. Collison led three studies into sediment transport in the Pájaro River and its principal tributary and sediment source, the San Benito River. The studies involved one and two dimensional sediment transport modeling to identify the source and rate of sediment delivery, the fate of sediment and the effects of redesigning the flood project to better manage sediment. The recommendations of the study have led to a redesign of the USACE flood project.

Kellogg Creek Fish Passage Improvement Project, Calistoga, CA, 2008-09. For the Peter Michael Winery. Project Director. Kellogg Creek flows through Peter Michael Winery and has some of the best spawning and rearing potential for steelhead and possibly coho salmon in the Russian River watershed. This is countered by four flow diversion weirs that are partial barriers to fish migration. PWA will design solutions to enhance fish passage over the weirs by retrofitting them and creating higher tailwater pools. Phase I will explore water rights impacts, phase II will focus on design. Phase II will consist of concept and plan development.

Vino Farms Bank Erosion Assessment, Healdsburg, 2006. For Russian River Streamkeeper and Trout Unlimited. Project Manager and Lead Geomorphologist. PWA was asked to assess a proposed bank stabilization design for the confluence of Dry Creek and the Russian River. We performed a historic channel evolution assessment on the Russian River and reviewed hydraulic data. Based on our analysis the design was modified to be more effective and to have a lower impact.

San Diego County Hydromodification Program, 2008-09. Geomorphology lead. Led the work to develop flow control criteria for the HMP. The work involved continuous rainfall-runoff modeling for test watersheds, with the results being fed to almost three hundred hydraulic and sediment transport models to test channel vulnerability to stormwater. Based on these results we were able to test potential flow control standards for the HMP.

Dry Creek Dam Removal, Napa, 2006. For Napa County RCD. Project Director. PWA conducted field surveying, constructed a hydraulic model and developed a conceptual design for the removal of a low diversion dam on Dry Creek. A key part of the project was to assess the potential for the dam removal to allow downstream channel erosion from an incised reach to propagate upstream. PWA's design involved replacing the dam with a boulder step-pool to prevent this from happening.

York Creek Flood Study, Napa Co., CA, 2008**.** For Beringer Winery/California Land Stewardship Institute. Project Director on a flood study to develop ways of reducing the flood risk for a winery located on York Creek.

Napa River Restoration Design, 2003-05**.** For Rutherford Dust Society. Project Manager. PWA conducted a geomorphic assessment of 4 miles of the Napa River and developed a conceptual design to address habitat restoration and bank erosion. The target species included Chinook salmon and Steelhead trout. A key component was working with a diverse private landowner group to achieve consensus on the project approach. PWA is currently working with the California Land Stewardship Trust and the Yountville landowners group to complete the next 9 miles of creek restoration design.

Newhall Ranch Geomorphic Assessment and Natural Channel Design, Los Angeles County, CA. 2006-2009. For Newhall Land and Farming Company. Dr. Collison is the lead geomorphologist and channel designer on this project, which involves assessing existing channel geomorphic conditions and developing design plans for five creeks to mitigate for the effects of hydrograph modification following development. The creeks have to combine flood control, mitigation needs and aesthetic conditions in this high visibility setting adjacent to the Santa Clara River. The design approach has to comply with LA County DPM and LA RWQCB standards as well as regulatory agencies such as LA COE and CDF&G. The project involves channel geomorphic assessment, hydraulic studies, sediment transport modeling and channel design.

Carroll Canyon Creek (Los Peñasquitos Creek Watershed) Channel Design, San Diego County, CA. 2006-09**.** For Vulcan Materials. Dr. Collison is the project manager and geomorphology lead for the design of a restored channel through what is currently a gravel mine. The geomorphic approach was to conduct historic research on the setting and channel form, identify watershed factors that had changed (sediment and water regime) and develop conceptual approaches for a new channel that would be in equilibrium with the changed watershed.

San Clemente Dam Removal Feasibility Study & Conceptual Design, Monterey, 2007-08. Project Manager and Lead Geomorphologist. For California Coastal Conservancy. PWA developed a conceptual restoration design for a channel to bypass the San Clemente Dam with the aim of allowing steelhead migration and natural sediment transport. The design was tested for geomorphic stability, sediment transport characteristics and fish passage by developing a detailed hydraulic model and running continuous flow data for a six year period to assess performance in a wide range of flow conditions.

Pájaro River Riparian Corridor Restoration, Santa Clara Co., CA, 2006-08. For The Nature Conservancy. Project Manager. PWA has developed a restoration plan for a 4 mile riparian corridor and creek restoration of the Pájaro River near Gilroy. A key component has been to enhance an existing steelhead migration corridor and to enhance riparian and channel habitat while preventing flooding in the surrounding areas.

Jacques Gulch Channel Restoration, Santa Clara County, CA, 2006-08. For SCVWD. Project Manager and Geomorphologist. PWA conducted a geomorphic assessment and developed design drawings to remove mercury-laden mine tailings and restore a natural channel.

Chorro Creek Long Term Restoration and Management Plan, **San Luis Obispo County**, 2004-2009. For California Dept. of Fish & Game and the Morro Bay National Estuary Program. Project Manager and geomorphology lead. PWA is developing a plan to restore the creek and floodplain, and to trap sediment that would otherwise pass into Morro Bay Estuary. As well as managing the project Dr. Collison is leading the channel assessment and restoration conceptual design components, which involve floodplain regrading, in-stream habitat structures and bank stabilization.

River and Floodplain Restoration in Grizzly Slough, Sacramento Co., CA, 2004-2005 For DWR/CALFED. Lead geomorphologist. DWR is seeking to reconnect and restore a portion of floodplain in the confluence of the Cosumnes and Mokelumne Rivers, to recreate natural levee and tidal slough habitat and enhance floodplain physical and biological processes. We have established the historic and current geomorphology of the site, and are using one and two-dimensional hydraulic and sediment transport models to evaluate levee breach scenarios.

Restoration of Las Flores Creek, Malibu, 2004. For the City of Malibu. Lead geomorphologists. Las Flores Canyon is a steep coastal canyon that drains to the Pacific Ocean near Malibu. It has been impacted by fires, floods and a large landslide that moved the channel across the valley floor. PWA developed a restoration plan to stabilize the creek and reduce erosion of the landslide toe by the creek. The plan involved a hydraulic and geomorphic study of the canyon, and a preliminary restoration design.

Restoration of Tallac and Taylor Watershed and Wetlands, Lake Tahoe, CA, 2003. For US Forest Service Lake Tahoe Basin Management Unit. Geomorphology Lead. The geomorphic, hydrologic and ecologic functions of this important wetland are believed to be impaired due to disturbance in the watershed. Dr. Collison led the watershed geomorphic assessment to assess existing conditions and historic function of the wetland and wider watershed, leading to a restoration design.

Sacramento River National Wildlife Refuge Floodplain Channel Restoration, 2003. For DWR and The Nature Conservancy. Lead geomorphologist. PWA assessed the historic geomorphic change of the floodplain, and carried out hydraulic and sediment transport modeling leading to a conceptual design to restore historic floodplain back channels. The channels will restore river-floodplain interactions along the Sacramento River, as well as relieving flooding in an adjacent State Park.

Design of a Step-Pool Channel for Lincoln Creek, Auburn, CA. For City of Auburn. Lead geomorphologist. As part of a plan to daylight a culverted creek in a new city park, PWA designed a step-pool channel for a steep valley in the Sierra foothills. The project involved identifying suitable channel and material dimensions and ensuring that the resulting design would be stable, ecologically beneficial and appropriate to the land use and setting.

Designing a Fish Rearing Channel, Skagit River, WA, 2003. For City of Mt Vernon. PWA designed a back channel to provide fish rearing habitat and reduce stranding risk in Edgewater Park, Mt Vernon. We used a 2D hydraulic and sediment transport model to optimize our design, ensure the channel was stable and create the best hydraulic conditions for salmonids.

Redwood Creek Restoration, Marin, 2003. For NPS/GGNRA. Geomorphologist. Assessed the final field installation of large woody debris restoration structures and made field modifications in final location.

Southern California Coastal Watershed Research Project (SCCWRP) Hydromod Project 2007 – present. Dr. Collison is a member of the Technical Advisory Group for the Hydromod project that SCCWRP is conducting. The work will provide background research and help develop assessment tools for the HMPs that are taking place in Southern California.

Contra Costa County HydroModification Program, 2004-06. For Contra Costa County. Geomorphology lead. Developed the decision support tools and procedures to be **used** in the County's HMP plan for assessing stream vulnerability to hydrograph modification. The procedures developed in this project will form the basis for future permit applications in the county.

Winter Creek Channel Stabilization, Berkeley, CA, 2006-07. For UC Berkeley. Lead Geomorphologist. Winter Creek is a steep headwaters stream in the Berkeley Hills. In the last three years it has undergone rapid downcutting, leading to bank erosion and the loss of rare specimens in the UC Berkeley Botanical Gardens. PWA has developed a plan to stabilize and restore the creek. The plan involved estimating an equilibrium channel gradient for the changed watershed conditions and designing a series of rock step-pool structures to gain elevation between the graded reaches.

Assessing the Bank Stability and Calculating Setback Requirements for the South Fork Coquille River, OR. 2005. For Clearwater BioStudies Ltd. Lead geomorphologist. The S.F. Coquille has been straightened and is gradually reverting to a more sinuous course. In order to predict the impact that this will have on bank erosion PWA used a combination of bank stability modeling and erosion modeling. To estimate the required setback that would be needed to accommodate river evolution we developed a sine generated meander model. The results were used to develop a river management plan.

Poggi Canyon, Chula Vista, CA. 2004-05. For City of Chula Vista. Geomorphic assessment and design of a series of step-pools to retrofit a channel undergoing erosion from hydrograph modification impacts.

Geomorphic Assessment of Corte Madera Creek, Town of Portola, CA, ongoing. For Town of Portola. Lead geomorphologist. Corte Madera creek is an urban stream for much of its length, and has been extensively patched by ad-hoc stabilization efforts undertaken by individual property owners. The Town of Portola hired PWA to assess the larger scale pattern of geomorphic channel evolution, and to devise more environmentally-friendly and sustainable stabilization strategies. We assessed six miles of creek to identify channel conditions, stabilization efforts and the trajectory and evolution of the system. We then developed and wrote a series of stabilization plans for landowners in different parts of the system, so that owners can use better methods when they next undertake a creek project. We are in the process of setting up a series of 'Creek walks' to educate and inform the people of Portola about the creek and how they can be good stewards.

Putah Creek Dam and Sedimentation Management Project, Solano County Water Agency, 2004. Lead geomorphologist. The operation of Lake Solano is hampered by a high tailwater effect downstream, caused by sediment deposition and vegetative growth. PWA was hired to develop potential remedies. Our historic assessment showed that the main cause was a transition from an ephemeral river with high flushing flows that suppressed channel vegetation growth. We have developed a series of conceptual alternatives including dam removal that will address the sediment and hydraulic problem in an environmentally sustainable way.

Watershed Stewardship Initiative, Santa Clara, CA, 2003-05. For SCVWD. Project manager and technical lead for geomorphology and hydrology component. PWA is the lead on the geomorphology and hydrology components of this project to assess all 18 watersheds between the Guadalupe River and San Francisquito Creek, and to develop more detailed stewardship plans for two watersheds. We used a combination of GIS and field survey methods to rapidly and economically evaluate all 18 watersheds, and developed a selection system to identify the best candidates for more detailed analysis and stewardship. We then carried out more detailed geomorphic assessments on 8 miles of Stevens and Calabazas Creeks. Finally we carried out a fish barrier assessment and developed conceptual plans to overcome barriers on Stevens Creek. The work has involved working closely with the client and a large stakeholder group to develop the most appropriate watershed and creek analysis tools to meet the District's policies.

Brown Ranch Habitat Mitigation, Contra Costa County, CA. 2006-07. For H.T. Harvey & Associates. Project Manager. Brown Ranch is currently a cattle ranch, but has been identifies as a potential mitigation area for a development in Contra Costa. PWA conducted a hydrologic and geomorphic assessment and developed preliminary design plans for six wetlands and ponds for California Tiger Salamander and California Red Legged Frogs. The project involved conducting water balances to identify whether small drainages could support wet conditions during the required periods for the species in question.

Selected Journal Articles

Simon, A. and Collison, A.J.C 2002. Quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability. *Earth Surface Processes And Landforms*., 27(5), 527-546

Simon, A, and Collison, AJC. (2001) Pore pressure effects on the detachment of cohesive streambeds: seepage forces and matric suction. *Earth Surface Processes and Landforms*. 26, 1421–1442

Collison, AJC. (2001): The cycle of gully head retreat: slope unloading and fissure flow as controls on gully head failure. *Hydrological Processes*, 15(1), 3-13.

Collison, AJC, Wade, SD, Griffiths, J. & Dehn, M. (2000): Modelling the impact of predicted climate change on landslide frequency and magnitude in SE England. *Engineering Geology*, 55(3), 205-218.

Collison, AJC, and Anderson, MG (1996): Using a combined slope hydrology and stability model to identify suitable conditions for landslide prevention by vegetation cover in the humid tropics. *Earth Surface Processes And Landforms*, 21, 737-747.

Collison, AJC, Anderson, MG & Lloyd, DM. (1995): The impact of vegetation on slope stability in a humid tropical environment - a modelling approach. *Proceedings of the Institute of Civil Engineers*: *Water, Maritime and Energy*, 112, 168-175.

Brooks, SM, Anderson, MG & Collison, AJC (1995): Modelling the role of climate, vegetation and pedogenesis in shallow translational hillslope failures. *Earth Surface Processes and Landforms*, 20, 231-242.

Chapters in books

Collison, A., Pollen, N. and Simon, A. 2005. The effects of riparian buffer strips on streambank stability: root reinforcement, soil strength and growth rates. In: Zobel, R.W. (Ed.) Roots And Soil Management : Interactions Between Roots And the Soil, Soil Science Society of America.

Pollen, N., Simon, A., Collison, A. 2004. Advances in Assessing the Mechanical and Hydrologic Effects of Riparian Vegetation on Streambank Stability. In: Bennett, S.J., Simon, A., Editors. Riparian Vegetation and Fluvial Geomorphology. American Geophysical Union, Washington, Dc. P. 125-140.

Collison, A. and Griffiths, J. 2004. Modelling Slope Instability. In: Wainwright, J. and Mulligan, M. (Eds.) Environmental Modelling: finding simplicity in complexity. Wiley: 197-210.

Collison, AJC. (1996): Unsaturated strength and preferential flow as controls on gully head development. In: Brooks, SM. & Anderson, MG. (Eds.): *Advances in Hillslope Processes*. Wiley: 753-770.

Brooks, SM, and Collison, AJC. (1996): The significance of soil profile differentiation to hydrological response and slope instability: a modelling approach. In: Brooks, S.M. & Anderson, M.G. (Eds.): *Advances in Hillslope Processes*. Wiley: 471-486.

Sara M. Keeler

Employment History

California Energy Commission

Planner II, Staff Biologist *12/2009 to present*

As a staff biologist with the Energy Commission, Ms. Keeler analyzes the biological resource components of energy facilities siting applications to assess resource impacts, develop mitigation, and to evaluate compliance with applicable local, state, and federal laws, ordinances, regulations, and standards. This requires working closely with biological resource protection and management agencies, subject matter experts, and Energy Commission consultants as well as with other Energy Commission staff to provide the best available information is included in staff analyses.

California Department of Transportation, District 3

Associate Environmental Planner/Environmental *11/2007 to 12/2009*

Ms. Keeler's primary duties with Caltrans were to coordinate and complete environmental documents to satisfy CEQA, NEPA, regional, and permitting requirements, and act as the Project Biologist on various transportation-related projects in California.

Entrix, Inc.

Senior Staff Scientist/Staff Scientist *01/2005 to 11/2007*

While with the environmental consulting firm Entrix, Inc., Ms. Keeler specialized in California wildlife and floristics studies. She worked throughout California including in the Lake Tahoe Basin, Great Basin, Central Valley, Sierra Nevada, in coastal California, and desert areas. Projects while at Entrix included biological resource field studies such as habitat assessments, protocol-level surveys for special-status plants and animals, wetland delineations, and riparian surveys; project, task, and budget management; and writing biological resources sections of a variety of documents including documents to satisfy NEPA and CEQA requirements, environmental assessments, and existing conditions reports.

USDA, Forest Service, Pacific Southwest Research Station

Biological Sciences Technician *05/2001 to 09/2002*

Ms. Keeler conducted breeding bird surveys and vegetation inventories and assessments on a breeding bird survey crew in the Sierra Nevada. This included conducting surveys using a variety of techniques including tree-climbing (ascenders, 3-point climbing, Swedish ladders), auditory surveys, and vegetation sampling.

EDUCATION

Biological Sciences (Evolution and Ecology) *B.S (High Honors)*
University of California, Davis *June 2004*

Susan Sanders Biological Consulting

12213 Half Moon Way
Nevada City, California 95959
Phone: (530) 477-7415 Fax: (530) 477-7580
ssanders55@comcast.net

RESUME OF SUSAN SANDERS

EDUCATION

Ph.D.	Zoology	University of California, Davis (1983)
M.A.	Zoology	University of California, Davis (1979)
B.A.	Zoology	University of California, Berkeley (1976)

PROFESSIONAL AFFILIATIONS/CERTIFICATIONS

Wildlife Society, Sacramento-Shasta Chapter
Sierra Nevada Willow Flycatcher Working Group
Certified by California Unified Certification Program as DBE/WBE firm (UCP # 25204)

CONTINUING EDUCATION (UC Davis, University Extension)

Threatened and Endangered Reptiles and Amphibians of Northern California
Wetlands Regulations, Impacts, and Mitigation
Endangered Species: Resources, Law, and Potential Solutions
Resolving Endangered Species Conflicts: Practical Approaches to Problem Solving

REGULATORY COMPLIANCE EXPERTISE in coordination with state, federal, and local agencies in the environmental review process for projects regulated by the California Environmental Quality Act, National Environmental Policy Act, Federal and State Endangered Species Acts, National Fish & Wildlife Coordination Act, Clean Water Act, and California Coastal Act. Also experienced in providing technical support and agency coordination for license and permit applications.

TECHNICAL EXPERTISE in surveys for threatened and endangered wildlife species; biological inventories; habitat management plans; raptor surveys; wildlife habitat assessment; mitigation monitoring; expert testimony, constraints analysis; sensitive species research. Prepared Biological Assessments for endangered, threatened, and candidate species, and conducted field surveys and literature reviews for willow flycatchers, tricolored blackbirds, Swainson's hawks, burrowing owls, California spotted owls, San Joaquin kit fox, bald eagles, valley elderberry longhorn beetles, and many other special-status species. Conducted surveys for raptor species of special concern, including white-tailed kite, northern goshawk, and Cooper's hawk.

PROJECT MANAGEMENT EXPERIENCE on large and complex projects, including a two-year survey of 11,000 acres in the Plumas National Forest for a proposed land exchange, involving supervision of eight technical specialists and subconsultants. Responsible for overseeing numerous transportation and revegetation projects and mitigation monitoring programs which involved budget, personnel, and subconsultant management, agency and client coordination, and preparation of technical reports. Managed long-term (five-year) revegetation/mitigation monitoring projects with annual reporting requirements.

CONSULTING EXPERIENCE (1982 - 2010)

CALIFORNIA ENERGY COMMISSION TECHNICAL ASSISTANCE (2005 – 2010)

Siting Work: Reviewed Applications for Certification; prepared Data Adequacy Forms, Data Requests, Preliminary and Final Staff Assessments; participated in PSA Workshops and provided testimony at Evidentiary Hearings; organized and conducted issue resolution workshops and interagency conference calls to resolve complex and controversial biological resource issues; coordinated extensively with local, state and federal agencies, including California Department of Fish and Game, U.S. Fish and Wildlife Service, Regional Water Quality Control Board, U.S. Army Corps of Engineers, and Bureau of Land Management. Projects include:

- **Palen Solar Power Project**, Solar Millennium (09-AFC-07)
- **Blythe Solar Power Project**, Solar Millenium (09-AFC-06)
- **Genesis Solar Power Project**, NextEra (09-AFC-08)
- **Beacon Solar Energy Project** - Beacon Solar LLC (08-AFC-2)
- **Orange Grove Energy** - J Power USA (08-AFC-4)
- **Ivanpah Solar Electric Generating System -**BrightSource (07-AFC-5)
- **MMC Chula Vista Expansion** - MMC Energy Inc. (07-AFC-4)
- **Eastshore Energy Center** - Eastshore Energy, LLC / Tierra Energy (07-AFC-5)
- **Pastoria Phase 2 Expansion Project** - simple cycle addition - Calpine (05-AFC-1)
- **San Francisco Reliability Project** - City of SF (04-AFC-1)

Avian Specialist for Renewable Energy Issues: Since 2005 provided Energy Commission staff with technical expertise as an avian specialist on wildlife interactions with wind turbines and other utility structures. Activities/publications include the following:

- **Wind-Wildlife Guidelines:** Co-authored *California Guidelines for Reducing Impacts to Birds and Bats from Wind Energy Development in California* published by the Energy Commission in September 2007; helped organize and coordinate this statewide effort to develop science-based protocols for pre-and post-construction monitoring methods to assess the effects of wind energy development on birds and bats. Worked closely with siting, PIER, and legal staff from Energy Commission and California Department of Fish and Game; coordinated the efforts of an eight-member Science Advisory Committee, helped organize and conduct public workshops, worked with wind energy developers, non-governmental organizations, and other stakeholders on this collaborative effort. <www.energy.ca.gov/windguidelines/index.>

- **Guidelines Implementation:** Working with CDFG and Energy Commission staff since 2007 on training for and implementation of the *Guidelines*. Conduct monthly interagency conference calls, helped organize and conduct two training workshops for CDFG, worked with CDFG headquarters and regional staff to develop a draft white paper: *Recommended Compensatory Mitigation Approaches for Reducing Unavoidable Impacts to Biological Resources from Wind Energy Development*. Co-author or on-line *Frequently Asked Questions about the Guidelines* <www.dfg.ca.gov/habcon/energy/wind>

- **Renewable Energy Research for PIER:** Prepared: *A Roadmap for PIER Research on Methods to Assess and Mitigate Impacts of Wind Energy Development on Birds and Bats in California* (Sanders and Spiegel 2008). This roadmap summarizes the current state of knowledge on the impacts of wind energy on birds and bats, and describes research that will improve the biological assessment, mitigation, and monitoring of wind energy projects in California. Currently working with PIER staff to oversee disbursement of $2.25 million in grant money to address Terrestrial resources Energy Research (PON

08-003) and to monitor and manage this research. Continuing work to develop an annotated bibliography of publications relating to research on wildlife interactions with wind turbines. </www.energy.ca.gov/publications/search>

LITIGATION SUPPORT/EXPERT WITNESS

El Portal Road Improvement Project. Conducted field surveys and reviewed the Biological Assessment, Environmental Assessment/FONSI for the El Portal Road Improvement Project litigation (Sierra Club *et al. vs*. National Park Service). Prepared declarations and response to defendants opposition briefs, and provided other technical assistance to project attorneys. (Client: Mariposans for Environmentally Responsible Growth and Sierra Club).

Merced River Plan. Conducted field surveys and reviewed the Merced Wild and Scenic River Comprehensive Management Plan and Final Environmental Impact Statement (Sierra Club *et al. vs.* National Park Service). Prepared declarations and response to defendants opposition briefs, and provided other technical assistance to project attorneys. (Client: Friends of Yosemite Valley and Sierra Club).

Lower American River Instream Flows. Conducted original research and provided declarations on the effects of reduced instream flow to wildlife for the Friends of the American River v. EBMUD, Lower American River. Provided technical assistance to project attorneys, prepared declarations, and provided expert testimony before the State Water Resources Control Board. (Client: Sacramento County and Friends of the American River Parkway).

Putah Creek v. Solano Irrigation District. Litigation support and expert testimony regarding wildlife/fishery impacts of reduced flows in Putah Creek. Provided depositions, declarations, expert witness testimony, and other litigation support (Client: Putah Creek Council).

CEQA/NEPA Documents. Prepared biological resource sections of Environmental Impact Reports/Statements, Initial Studies, and Environmental Assessments for numerous commercial and residential developments, redevelopment projects, transportation projects, dams, and other water projects throughout northern California. Conducted wildlife and plant community surveys, habitat assessments, agency contacts, data analysis and report preparation. Secured 1602 Streambed Alteration Agreements from California Department of Fish and Game, Section 404 Permits from U.S. Army Corps of Engineers, and 401 Permits from Regional Water Quality Control Board. Some representative projects include:

- Pacific Bell Route 101 Fiber Optic Cable, Kern County (PAR Environmental Services, Inc. [PAR]);
- Higgins Corner Marketplace, Nevada County (FHK Development);
- Hinkle Creek Nature Area Biological Inventory/Impact Analysis, Folsom (PAR);
- Willow Flycatcher Surveys, Lake Isabella Project, Kern County (Jones & Stokes);
- Biological Resources Survey, Galilee and TRC Parcels, Roseville, Placer County (PAR);
- Burrowing Owl Impact Analysis/Mitigation Monitoring, Northpointe, Sacramento County (PAR);
- Laguna Creek Interceptor and Sewer Alignment Constraints Study, Sacramento County (PAR);

- Marin Public Safety and Emergency Radio System Project, Marin County (Cord Communication)
- Biological Studies for Endangered Species Compliance, Isabella Dam, Kern County (PAR);
- Granite Quarry, Placerville (The Bedrock Group);
- Pacific-Bell Rocklin Central Dialing Station, Rocklin, Placer County (PAR);
- Whitney Oaks Raptor Surveys, Placer County (Live Oak Enterprises/Pulte Homes);
- Auburn Ranch Subdivision Project, Placer County (Area West Engineers);
- Equestrian Ridge Estates, Placer County (PAR);
- Willow Creek Assessment District Swainson's Hawk Surveys, Sacramento County (PAR);
- Bucks Lake Spotted Owls Surveys, Menasha Corporation, Plumas County (PAR);
- Roseville Water Facilities Project, City of Roseville, Placer County (Geier & Geier Consulting);
- Sugar Bowl Ski Resort Expansion, Placer County (Omni-Means, Engineers/Planners);
- City of Lincoln Waste Water Treatment Plant Expansion, Placer County (City of Lincoln);
- The Heritage at Bickford Ranch, Placer County (Geobotanical Phenomenology);
- South Branch 60 kV Pole Line Project, Roseville, Placer County (PAR);
- Smith-Moulton Pipeline Project, Nevada County (PAR);
- Morada Ranch Annexation, San Joaquin County (Omni-Means);
- Clover Valley Lakes Estates EIR, Placer County (Planning Concepts);
- Turtle Island, Loomis, Placer County (Export International);
- Fort Hunter-Liggett Wildlife Resource Surveys, Monterey County (Jones & Stokes Associates);
- Superconducting Super Collider EIR/EIS, Yolo and Solano Counties (EIP Associates);
- South Lake Tahoe Redevelopment Agency EIR, El Dorado County (Wagstaff & Brady);
- Stanford Ranch EIR, Placer County (Jones & Stokes Associates);
- Northeast Roseville Specific Plan EIR, Placer County, Placer County (Jones & Stokes Associates).
- Teichert/Granite Aggregate Mining Site, Sacramento County (Holliman, Hackard, & Taylor);
- Lower Laguna Drainage Master Plan, Sacramento County (PAR);
- Natomas Ditch Abandonment and Pipeline Construction Project, Sacramento County (PAR);
- Tuolumne River Wildlife Studies for FERC License, Tuolumne County (Holton & Associates);
- Turner Creek Hydroelectric Project, Plumas County (Jones & Stokes Associates);
- Calabazas Creek Flood Control Project, Santa Clara County (Santa Clara Valley Water District).

Transportation Projects. Prepared Caltrans Natural Environment Study Reports, Biological Assessments, Categorical Exemption/Exclusions, Preliminary Environmental Study Forms, and other documentation for bridge replacements, interchange modifications, seismic retrofits, road widenings, emergency storm damage repairs, and other transportation projects in Caltrans Districts 1, 2, 3, 4, 5, 6, and 10. Representative projects include:

- Interstate-80 West El Camino Avenue Interchange Project, City of Sacramento (PAR);
- Route 68 Widening Project, City of Monterey, Monterey County (PAR)
- U.S. 50/Ponderosa/South Shingle Road Interchange Project, El Dorado County, (PAR);
- Auburn Boulevard Improvement Project, Citrus Heights, Sacramento County (PAR);
- Valley Drive Bridge Replacement Project, Nevada County (Nevada County DOTS);
- SR 101/Prado Rd. Interchange Improvement Project, San Luis Obispo County (PAR);
- I-580/Isabel Avenue Interchange Project, Livermore, Alameda County (PAR);
- Gladding Road Bridge Replacement, Coon Creek, Placer County (Planning Concepts);
- Lozanos Road Bridge Replacement, Auburn Ravine, Placer County (PAR);
- Coyote Creek Bridge Replacement Project, Calaveras County (PAR);
- Route 99/Route 120 East Interchange Project, Manteca, San Joaquin County (PAR);
- Route 99/Prado Road Interchange, San Luis Obispo County (PAR);
- Ralston Avenue/Route 101 Interchange, Belmont, San Mateo County (PAR);

- Route 1 Improvement Project, Sand City to Seaside, Monterey County, PEAR (PAR);
- Northeast Area Transportation Plan, Constraints Analysis, Sacramento (PAR);
- Wilbur Avenue Overcrossing Project, Antioch, Contra Costa (PAR);
- Alpine Road Storm Damage Repair, San Mateo County (PAR);
- Pescadero Road Storm Damage Repair, San Mateo County (PAR);
- Route 92 Widening, Half Moon Bay, San Mateo County (PAR);
- Route 99/Hammer Lane Interchange Improvements, Stockton, San Joaquin County (PAR);
- Hammer Lane Widening, Stockton, San Joaquin County (PAR);
- La Gonda Way and Paraiso Drive Bridge Seismic Retrofit, Danville, Contra Costa County (PAR);
- Highway 162 Bridge Storm Damage Repair Project, Sacramento River, Glenn County (PAR);
- Norwood Avenue Reconstruction Project, Sacramento County (Planning Center);
- HOV Lane Construction, US 50, Sunrise to El Dorado Blvd., Sacramento/El Dorado Co. (PAR);
- Dry Creek Bridge Replacement Project, Route 99, Butte County (PAR);
- Ladies Canyon Bridge Storm Damage Repair, Sierra County, (PAR);
- Emergency Storm Damage Repair, Routes 49 and 89, Sierra and Nevada Counties, (PAR);
- Emergency Storm Damage Repair Project for: Route 70/89, Feather River Canyon, Route 20, 147, Plumas, Nevada, and Butte Counties, (PAR);
- Interstate 5 - Benjamin Holt/Hammer Lane Interchange project, San Joaquin County (PAR);
- State Route 113/Interstate 5 Connector Study, City of Woodland, Yolo County, California (PAR);
- Frederickson Road Widening, Antioch, Contra Costa County (May Consulting);
- East Lime Kiln Road Reconstruction Project, Nevada County (PAR);
- Lower Sacramento Road and Bridge Widening, Stockton, San Joaquin County (May Consulting);
- Sierra College Boulevard Widening Project, Roseville, Placer County (PAR);
- State Route 50/Folsom Interchange Improvement Project, Sacramento County (PAR);
- Pico Creek Bridge Replacement Project, Route 1, San Luis Obispo County (PAR)
- Burns Creek Bridge Replacement Project, Route 1, Monterey County (PAR);
- Pajaro River Bridge Replacement Project, Monterey and San Luis Obispo Counties (PAR);
- Route 113 Widening/North 1st Street Improvements, Dixon, Solano County (Planning Concepts);
- Bridgeport School Bridge Replacement Project, El Dorado County (PAR);
- State Route 49 Widening, Auburn, Placer County (PAR);
- Claus Road Bridge Widening, Modesto, Stanislaus County (PAR);
- Interstate 80/Enterprise Boulevard Interchange, City of West Sacramento, Yolo County (PAR).

Nevada County Biological Inventories/Habitat Management Plans. Conducted site specific vegetation and wildlife surveys in accordance with Policy 13.2A of the Nevada County General Plan; prepared Management Plans in accordance with Sec. L-II 4.3.3, General Provisions of the July 27, 2000 Zoning Ordinances. Representative projects include:

- Waxman Parcel Biological Inventory, Old Wood Road (Nevada City Engineering)
- Habitat Management Plan for DesJardins Dry Creek Crossing (Cranmer Engineering)
- Gregory Creek Biological Inventory, Truckee (King Engineering)
- Landon Parcel Biological Inventory and Management Plan, Wolf Road (California Survey Company)
- Oslin-Tarkowski Biological Inventory, Peardale (Ms. Jeanette Oslin)
- Jackson Parcel, Purdon Road (Mr.
- Hyatt Property Biological Inventory and Management Plan, Dry Creek (Mr. Mike Hyatt)
- Penn Valley Community Church, Penn Valley (Mr. Keith Brown)
- Chapa-De Health Clinic, Grass Valley (Ms. Elaine. Lieske, Architect)
- Inventory and Management Plan for Agren Pond Project, Penn Valley (Mr. Ray Agren)

- Humboldt Lily Plant Preservation Plan (Sares-Regis Group)
- Moore Property, Chicago Park (American Surveys)
- Callaghan Property, Lake of the Pines (Sylvester Engineering)
- Tracy Property, Duggans Road (Cranmer Engineering)
- Ragsdale Creek Setback Study, Higgins Area (Nevada County Planning Department)
- CDFG 1603 Permit Application, Eskaton Village, Grass Valley (Sares-Regis Group)
- Cedar Ridge Baptist Church Expansion, Cedar Ridge (Cedar Ridge Baptist Church)
- Penn Valley Properties, Penn Valley (Sylvester and Creighton)
- Record Connection Property, Brunswick Basin (Daggett Design)
- Droitcour Property, Wolf Road (Mr. Gerald Stapp)
- Hyepark Estates, near Wolf Road (King Engineering)
- Bartel Property Lake Setback (Nevada City Engineering)
- KLOVE Radio Tower, Banner Mountain (Westower Communications)
- Haas-Menasha Property, Ponderosa Way, Rough and Ready (Cliff McDivitt Surveying)
- Eskaton Village, Grass Valley (Sylvester & Creighton)
- Quist Property, Higgins Corner (Sylvester & Creighton)
- Hobart Mills Industrial Park (Sylvester & Creighton)
- Milhous Ranch, North San Juan (Sylvester & Creighton)
- Extasia Workshop Project, Tyler Foote Crossing Road, San Juan Ridge (Mr. Bruce Boyd, AIA);
- Flynn Property, Retrac Way, Grass Valley (Mr. Martin Flynn);
- McGuire Property, Banner Lava Cap Road, Nevada City (Mr. Kirk McGuire);
- Biological Inventory for 240-acre parcel near Donner Lake (Mr. James Mitchell);
- Brunswick Inn Project, Grass Valley (Sylvester Engineering);
- Lopez Tentative Map, Scott's Flat Road (Sylvester Engineering);
- Sierra Knoll Estates, Higgins Corner (Mr. and Mrs. Steve Joos);
- Smallwood Property, Grass Valley (Mr. Jay Smallwood).
- Harmony Ridge Resort (Sylvester & Creighton)

Land Exchanges. Prepared Biological Assessments/Evaluations for Forest Service land exchanges in the Plumas National Forest. The largest of these was the 11,000 acre Soper-Wheeler Company land exchange, a two-year project requiring management of eight employees and several subconsultants for surveys of rare plants, California spotted owls, northern goshawks, red-legged frogs, and other sensitive species. Other projects include the Crites Mineral Fraction Land Exchange and the Saunders Land Exchange, Plumas National Forest, (PAR).

Mitigation Monitoring. Supervised the design and ongoing monitoring of wetland and sensitive species mitigation projects, including riparian revegetation, vernal pool creation, and mitigation banking. Some projects involved preparation of a Habitat Mitigation and Monitoring Plan, and long-term monitoring efforts (five years plus), as well as preparation of annual reports, and coordination with US Army Corps of Engineers, US Fish and Wildlife Service, California Department of Fish and Game, California Department of Transportation, and the US Environmental Protection Agency. Projects include:

- Humboldt Lily Mitigation Monitoring, Eskaton Village, Nevada County (Eskaton)
- Dark Horse Mitigation Monitoring, Nevada County (Nevada City Engineering)
- Northpointe, Burrowing Owl Mitigation Monitoring, Sacramento County (PAR)
- Burrowing Owl Mitigation Monitoring, Meadowview, Sacramento County (PAR)
- Wilbur Avenue Overhead Project, Habitat Restoration for Lange's Metalmark Butterfly, Antioch, Contra Costa County, (PAR)
- Swainson's Hawk Nest Monitoring, Garden Highway, Sacramento, Sacramento County (PAR)
- Sierra College Boulevard Riparian Revegetation Monitoring, Roseville, Placer County (PAR);
- Roseville Sanitary Landfill Riparian Revegetation Project, Roseville, Placer County (PAR);

- State Route 99/Calvine Interchange Vernal Pool Vegetation and Fairy Shrimp Mitigation Monitoring, Sacramento County (PAR);
- Potrero Hills Landfill Bird Deterrence Monitoring, Solano County (Global Environmental);
- State Route 50/Folsom Boulevard Improvement Project, Beach Lakes Mitigation Bank (PAR);
- Niblick Bridge Riparian Revegetation and Mitigation Monitoring, San Luis Obispo County (PAR).

TEACHING EXPERIENCE

Lecturer. Biology 10, UCD Zoology Department (1985): Instructor - biology for non-majors.
Lab Coordinator. Zoology 2L, UCD Zoology Department (1983-1984): Trained and supervised teaching assistants, managed introductory zoology laboratories.
Teaching Assistant. UCD Zoology Department (1977-1983): General Zoology, Vertebrate Structure, Introductory Biology.
Outstanding UCD Graduate Teaching Assistant (1983).

PUBLICATIONS

Sanders, S. D. and L. Spiegel. 2008. *A Roadmap for PIER Research on Methods to Assess and Mitigate Impacts of Wind Energy Development on Birds and Bats in California.* Consultant Report, Prepared for the California Energy Commission. CEC-500-2008-076 October 2008

California Energy Commission and California Department of Fish and Game. 2007. *California Guidelines for Reducing Impacts to Birds and Bats from Wind Energy Development.* Commission Final Report. California Energy Commission, Renewables Committee, and Energy Facilities Siting Division, and California Department of Fish and Game, Resources Management and Policy Division. Prepared by D. Anderson, S. Flint, S. Sanders, and D. Sterner. CEC700-2007-008-CMF.September 2007.

Beedy, E. C., S. D. Sanders, and D. A. Bloom. 1991. *Breeding status, distribution, and habitat associations of the tricolored blackbird* (*Agelaius tricolor*), 1850-1989. June 21, 1991. Jones & Stokes Associates (JSA 88-187.) Sacramento, CA. Prepared for USFWS, Sacramento, CA.

Flett, M. A. and S. D. Sanders. 1987. *Ecology of a Sierra Nevada population of Willow Flycatchers*. Western Birds. 18:37-42.

Fowler, C., B. Valentine, S. Sanders, and M. Stafford. 1991. *Habitat Suitability Index Model: Willow Flycatcher* (*Empidonax traillii*). USDA Forest Service, Tahoe National Forest.

Harris, J. D., S. D. Sanders, and M. A. Flett. 1987. Willow Flycatcher surveys in the Sierra Nevada. Western Birds. 18:27-36.

Sanders, S. D. and M. A. Flett. 1989. *The ecology of a Sierra Nevada population of Willow Flycatchers (Empidonax traillii), 1986 and 1987*. California Management Branch Administrative Report No. 89-3, California Department of Fish and Game.

Sanders, S. D. 1983. *Foraging Ecology of a Sierra Nevada population of Douglas Tree Squirrels* (*Tamiasciurus douglasii*). Ph.D. Dissertation, University of California, Davis

BEFORE THE ENERGY RESOURCES CONSERVATION AND DEVELOPMENT COMMISSION OF THE STATE OF CALIFORNIA
1516 NINTH STREET, SACRAMENTO, CA 95814
1-800-822-6228 – WWW.ENERGY.CA.GOV

APPLICATION FOR CERTIFICATION FOR THE *PALEN SOLAR POWER PLANT PROJECT*

Docket No. 09-AFC-7

PROOF OF SERVICE
(Revised 8/27/10)

APPLICANT
Alice Harron
Senior Director of Project Development
*1111 Broadway, 5th Floor
Oakland, CA 94607
harron@solarmillenium.com

*Michael Cressner, Project Development & Permitting
Solar Millennium, LLC
1111 Broadway, 5th Floor
Oakland, CA 94709
cressner@solarmillennium.com

Arrie Bachrach
AECOM Project Manager
1220 Avenida Acaso
Camarillo, CA 93012
arrie.bachrach@aecom.com

Ram Ambatipudi
Chevron Energy Solutions
150 E. Colorado Blvd., Ste. 360
Pasadena, CA 91105
rambatipudi@chevron.com

Co-COUNSEL
Scott Galati, Esq.
Marie Mills
Galati/Blek, LLP
455 Capitol Mall, Suite 350
Sacramento, CA 95814
sgalati@gb-llp.com
mmills@gb-llp.com

Co-COUNSEL
Peter Weiner, Matthew Sanders
Paul, Hastings, Janofsky & Walker LLP
55 2nd Street, Suite 2400-3441
San Francisco, CA 94105
peterweiner@paulhastings.com
matthewsanders@paulhastings.com

INTERVENORS
California Unions for Reliable Energy (CURE)
c/o Tanya A. Gulesserian,
Marc D. Joseph
Jason W. Holder
Adams Broadwell Joseph & Cardozo
601 Gateway Boulevard,
Suite 1000
South San Francisco, CA 94080
tgulesserian@adamsbroadwell.com
jholder@adamsbroadwell.com*

Michael E. Boyd, President
Californians for Renewable Energy (CARE)
5439 Soquel Drive
Soquel, CA 95073-2659
michaelboyd@sbcglobal.net

Alfredo Figueroa
Californians for Renewable Energy (CARE)
424 North Carlton
Blythe, CA 92225
lacunadeaztlan@aol.com

Basin and Range Watch
Kevin Emmerich
Laura Cunningham
P.O. Box 153
Baker, CA 92309
atomictoadranch@netzero.net

Lisa T. Belenky, Senior Attorney
Center for Biological Diversity
351 California St., Suite 600
San Francisco, CA 94104
lbelenky@biologicaldiversity.org
Ileene Anderson
Public Lands Desert Director
Center for Biological Diversity
PMB 447, 8033 Sunset Boulevard
Los Angeles, CA 90046
ianderson@biologicaldiversity.org

INTERESTED AGENCIES
California ISO
e-recipient@caiso.com

Holly L. Roberts, Project Manager
Bureau of Land Management
Palm Springs-South Coast Field Office
1201 Bird Center Drive
Palm Springs, CA 92262
CAPSSolarBlythe@blm.gov

ENERGY COMMISSION
ROBERT WEISENMILLER
Commissioner and Presiding Member
rweisenm@energy.state.ca.us

KAREN DOUGLAS
Chairman and Associate Member
kldougla@energy.state.ca.us

Raoul Renaud
Hearing Officer
rrenaud@energy.state.ca.us

Alan Solomon
Siting Project Manager
asolomon@energy.state.ca.us

Lisa DeCarlo
Staff Counsel
ldecarlo@energy.state.ca.us

Jennifer Jennings
Public Adviser's Office
e-mail service preferred
publicadviser@energy.state.ca.us

*indicates change

DECLARATION OF SERVICE

I, Teraja` Golston, declare that on October 22 ,2010, I served and filed copies of the attached (09-AFC-7) Palen Solar – CEC Staff Rebuttal Testimony – Alternatives and Biological Resources, dated October 22, 2010. The original document, filed with the Docket Unit, is accompanied by a copy of the most recent Proof of Service list, located on the web page for this project at:
[http://www.energy.ca.gov/sitingcases/solar_millennium_palen]

The documents have been sent to both the other parties in this proceeding (as shown on the Proof of Service list) and to the Commission's Docket Unit, in the following manner:

(*Check all that Apply*)

FOR SERVICE TO ALL OTHER PARTIES:

__x__ sent electronically to all email addresses on the Proof of Service list;

_____ by personal delivery;

__x__ by delivering on this date, for mailing with the United States Postal Service with first-class postage thereon fully prepaid, to the name and address of the person served, for mailing that same day in the ordinary course of business; that the envelope was sealed and placed for collection and mailing on that date to those addresses NOT marked "email preferred."

AND

FOR FILING WITH THE ENERGY COMMISSION:

__x__ sending an original paper copy and one electronic copy, mailed and emailed respectively, to the address below (*preferred method*);

OR

_____ depositing in the mail an original and 12 paper copies, as follows:

CALIFORNIA ENERGY COMMISSION
Attn: Docket No. 09-AFC-7
1516 Ninth Street, MS-4
Sacramento, CA 95814-5512
docket@energy.state.ca.us

I declare under penalty of perjury that the foregoing is true and correct, that I am employed in the county where this mailing occurred, and that I am over the age of 18 years and not a party to the proceeding.

Original Signature in Dockets
Teraja` Golston