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Geomorphic Assessment of Sand Transport for the Modified Project (Palen Solar Electric Generating System)

Draft Final Report Prepared for
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ASPEN ENVIRONMENTAL GROUP

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Table of Contents

Summary

This report documents the effect of the Palen Solar Electricity Generating System (PSEGS), also known as the Modified Project, on sand transport patterns, using the based on the Philip Williams and Associates (PWA) sand transport model results.

The main effect of the Modified Project on sand transport is to create a zone of reduced sand movement up to 1000 feet wide along the northeastern and eastern boundaries, affecting primarily sand transport zones II and III. The Modified Project affects a total of 1581 acres of which 421 acres are indirect effects, primarily in sand transport zone II.

Modeling of the effects of the Modified Project on sand transport in the Palen Valley indicates that the Project has an increased level of predicted effects on sand transport, compared to the Applicant's Reconfigured Alternatives 2 and 3. This is because the project footprint extends further east into the sand transport corridor, compared to the Applicant's Reconfigured Alternatives 2 and 3. Quantification of effects on sand transport indicate that 348 acres of zone II will be affected, compared to 130 and 79 acres, for Alternatives 2 and 3 respectively. In addition, the qualitative effect on sand transport is predicted to be much more significant, because the modeling indicates that 135 acres or 38.6% of the reduction in sand transport is predicted to be at a high level (75-100%). Compared to the Alternatives 2 and 3, the Modified Project indirectly affects an additional 39 and 51 acres respectively at the 25-50% reduction level, 56 and 85 acres at the 50-75% level and 124 and 134 acres at the 75-100% level.

Sand transport reduction modeling indicates that the Modified Project heliostat array is predicted to have a very significant effect on sand transport such that sand transport will be reduced by 93% at 1738 feet into the array. This suggests that the array will be highly effective at reducing sand transport and that any sand entering the array will be deposited within a zone up 1800 feet from the edge of the array.

The PWA sand transport model has significant limitations in its abilities to predict where erosion and deposition of sand may occur. Such information is valuable for site design and implementation of any sand control measures that may be needed. It is also valuable for assessing the impacts of infrastructure on habitat for flora and fauna. We recommend that a new model be developed, based on existing peer reviewed cellular automaton models.

Given the limitations of the PWA model and the fact that there is no way to evaluate if it does in fact reproduce the probable effects of any project on sand transport, we recommend that a program of sand transport monitoring be designed and implemented on site to detect changes in sand transport and associated changes in dune morphology and habitat suitability. Such a monitoring program would provide valuable information for siting of other facilities in sandy areas.

Given the widespread extent of sand transport corridors in the Mojave Desert and the very general way in which they have been mapped, we recommend a program that will identify and map these corridors, to provide an assessment of the levels of sand transport experienced (as indicated by landforms and vegetation cover), so that future siting decisions may be informed by reliable information

1. Introduction

This report describes work undertaken by DRI in support of the geomorphic assessment of sand transport in the vicinity of the Palen Solar Electric Generating System (PSEGS), also known as the Modified Project. The work performed included: (1) Modeling of the effect of the Modified Project on sand transport patterns using the model developed by Phillip Williams & Associates Ltd. (PWA), following assessment of the model assumptions and parameters; (2) Assessment of the effects of the Modified Project on sand transport and deposition patterns based on PWA model results – including a comparison of effects of Approved Project's Reconfigured Alt 2 and Alt 3 and Modified Project; and (3) Assessment of the effects of Modified Project using sand transport reduction modeling.

2. Geomorphic setting

The Modified Project is situated on the southern side of the Palen Valley, which lies astride a sand transport corridor referred to as the Clark's Pass sand transport pathway (Muhs et al., 2003), which extends from Dale Lake in the west to the Colorado River valley near Blythe (Fig. 1). The Palen Valley area comprises a local sediment sink for this corridor, which consists of areas of sparely vegetated to largely unvegetated sand sheets, low dunes, and more active (migrating) dunes of crescentic and locally parabolic form. Kenny (2010) identified and described three zones of sand transport conditions: Zone I, which lies mainly on the northern side of the valley and comprises actively migrating low crescentic dunes; Zone II, which is characterized by low hummocky dunes with a sparse vegetation cover; and Zone III, located on the distal parts of alluvial fans and consists of thin sand sheets and small dunes (nebkhas), often anchored around creosote bushes.

3. The PWA Sand Transport Model

The sand transport model used to evaluate the effects of the Approved Project's Reconfigured Alt 2 and Alt 3 is described in Collison et al. (2010). The model is very simple in concept and execution and moves sand from cell to cell in a pattern based on the percentage of potential sand movement from different directions. The simulation runs in MATLAB, but requires use of a GIS (e.g. ArcGIS 10) to visualize the output and to generate input files for the project footprint.

3.1 Model domain

The model domain is a grid of 250 x 250 cells, each with dimensions of 250 feet on a side. The domain is anchored at the SW corner at the following location using Stateplane coordinates: Easting 6851802;Northing 2158691 feet.

3.2 Input files

Input files are required for: (1) the distribution of sand across the project area. The distribution is assumed to be uniform; (2) the variation of wind direction (if any) across the project area; and (3) the project footprint. The project footprint is generated by converting the project outline polygon to a raster and exporting this file as a .csv file for use in the simulation. The project footprint is superimposed on the grid as a raster so that the intersection of cells with the outline generates a value of 99.

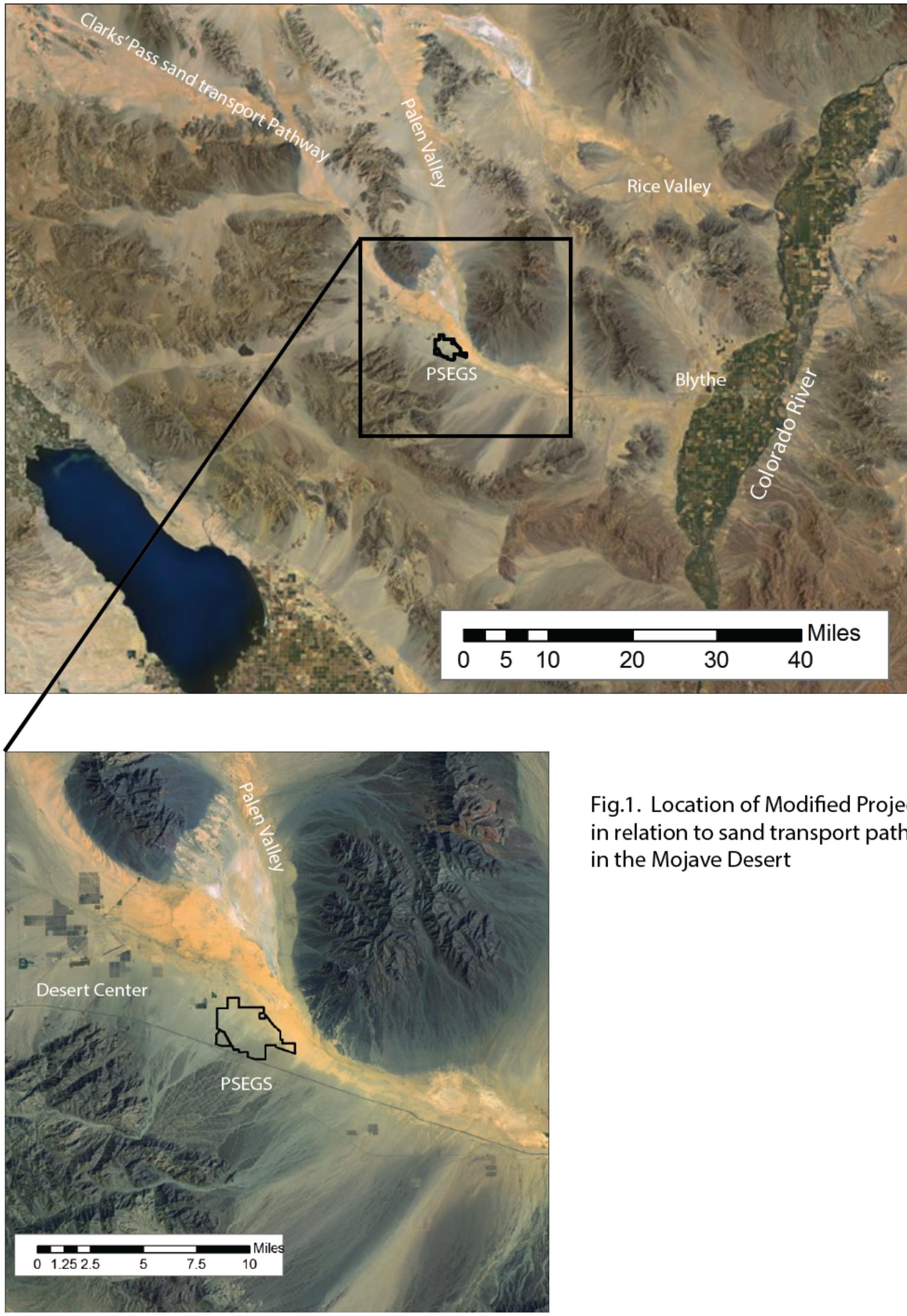


Fig.1. Location of Modified Project (PSEGS) in relation to sand transport pathways in the Mojave Desert

3.3 Output files

The simulation produces a raster (.asc) file that shows the proportion of sand (flux) reduction in each cell on a scale from 0 – no change in sand flux to 1 – no sand transport occurring. The output is binned into classes that represent 0-25%, 25-50%, 50-75% and 75-100% sand flux reduction.

3.4 Simulation procedures

The direction of sand movement in the model domain is based on a moving "window" in which sand is transferred from cell to cell depending on the proportion of potential sand flux occurring in each of eight directions. The PWA model assumes one or more primary direction(s) of sand movement with subsidiary movement termed "diffusion". The model assumes that the project boundary is impermeable to sand movement, which therefore ceases at the project boundary.

3.5 Model parameters

The critical parameter in the PWA model is the distribution of potential sand movement from different directional sectors, which determines how and where the impact of the project will occur. Collison et al. (2010) based their modeling on the sand transport vectors (wind ripple and dune orientations) observed in the field by Kenney (2010); and analysis of the potential sand transport regime at Blythe Airport. They based their model on 70% of sand transport taking place from the N and NW directions, with 30% taking place equally from the other 6 sectors.

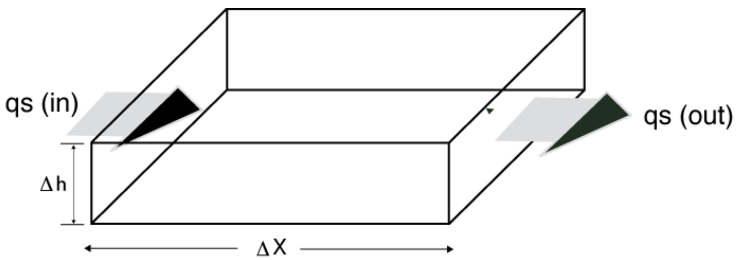
4. Evaluation of the PWA model

Several cellular automaton models for sand transport are described in the literature (e.g. Nield and Baas, 2008a; Werner and Kocurek, 1997). Unlike the PWA model, they all move slabs of sand around in a streamwise or lateral direction determined by the chosen wind regime and a probability of erosion or deposition in a given cell. These models have been shown to be able to reproduce dune landscapes in a realistic fashion.

The PWA model differs from these and other cellular automaton sand transport models (Baas and Nield, 2007; Barchyn and Hugenholtz, 2012; Werner, 1995) in that it does not provide for erosion and/or deposition of sand and therefore does not provide information on how spatial variations in sand transport may affect landforms and associated cultural and biological resources. In addition, the model does not incorporate a time dimension. As described, sand is moved from one cell to another over one time interval only – in this case a year. All other sand transport models incorporate multiple time steps so that the distribution of sand evolves over a realistic time period (multiple years) and areas of net erosion and deposition can be identified. There is no feedback between the cells in the PWA model. In reality, sand moved from point A to point B may be transferred back to point A, or to other cells depending on the wind direction. No account is taken in the PWA model that sand may be deposited or eroded in a differential manner and pile up to form dunes, or be scoured from other areas.

As discussed below, sand transport rates and patterns are strongly influenced by the presence of vegetation, which acts as a roughness element, to protect the surface directly as well as to extract momentum from the wind (Lancaster and Baas, 1998; Wolfe and Nickling, 1993). The PWA assumes that there is no vegetation and that sand transport rates are entirely dependent on wind speed and direction.

The model therefore predicts the spatial pattern of the degree to which *potential* sand transport is changed by obstacles, but it does not provide for the effect such changes may have on the erosion and/or deposition of sand, which are governed by principles of conservation of sediment mass or volume (Middleton and Southard, 1984) (Fig. 2).



$$dh/dt = -dq/dx$$

Fig. 2: Principal of sediment continuity.

Changes in surface elevation are the product of spatial changes in transport rates and temporal changes in sediment concentration such that:

$$dh/dt = -(dqs/dx + dC/dt) \quad (1)$$

where h is the elevation of the deposition surface, t is time, qs is the spatially averaged bulk volumetric sediment transport rate, x is the distance along the transport pathway, and C is the concentration of sediment in transport. The transport rate (qs) consists of two components: that due to bedform migration (bedform transport, qb) and that which is throughgoing (qt) as a result of saltation 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 bedforms.

It follows therefore that zones of accelerating flow (increasing sand transport rates) are areas of erosion, whereas zones of decelerating flow (decreasing sand transport rates) are characterized by deposition.

5. Application of the PWA model to evaluate sand transport patterns resulting from the Modified Project

As discussed above, a critical parameter in the PWA model is the distribution of potential sand movement from different directional sectors, which determines how and where the impact of the project will occur. Accurate and appropriate determination of this distribution is therefore very important.

5. 1 Wind regime of the Palen Area

The wind regime of the Mojave Desert is discussed by Laity (1987). The primary factor controlling wind flow is the position and strength of the Pacific high-pressure cell. During the spring and summer months, there is a thermal low in the interior of the desert, while the Pacific high is strong, resulting in prevailing westerly winds, with some southerly flow from the Gulf of California. In autumn and winter, the pressure gradient is weaker, resulting in lower wind speeds, except when frontal systems pass through or near the area. The western Mojave is dominated by westerly winds, whereas the eastern Mojave (where the project is located) shows more variable winds. In all areas of the Mojave, the direction of winds is strongly controlled by the topography, so that winds are funneled parallel to valley axes; this includes a prominent north-south element to the winds in the Colorado River Valley and immediately adjacent areas. Unfortunately, there is no record of wind speed and direction for the immediate area of the PSEGS. The nearest record is from Blythe Airport located approximately 30 miles ESE of the site of the PSEGS. Another record exists for the Rice Valley (38 miles NE of the PSEGS site) – see Fig. 1.

We calculated the potential sand transport (also known as Drift Potential – DP) using the approach of Fryberger (1979), modified for use with wind speeds measured in meters per second by Bullard (1997). We assumed a threshold wind speed at a height of 10 m of 7 m/sec., following Lancaster and Helm (2000). The input wind data was the record of hourly wind speed (meters/second) and direction (16 directional bins) for the period January 1, 2001 – December 31, 2012, obtained from the Western Regional Climate Center http://raws.dri.edu/cgi-bin/rawMAIN.pl?

For Blythe, there is a clearly bimodal sand-moving wind regime with DP from two main directional sectors (N-NNW – 34.37% of annual total DP; and SSE-WSW – 59.75% of annual DP (Fig. 3). Seasonally, the northerly sector dominates in the winter months, whereas the southwest sector dominates in the spring and summer. The strongest winds and a significant proportion of annual potential sand transport (DP) occur in the spring (March – May), accounting for 42% of annual DP (Fig. 4). Importantly, winds in this period are dominantly from the SSW-WSW sector, giving rise to sand transport towards the northeast at this time of year. The annual total drift potential (DP) is 19.37 VU (vector units); the resultant vector of sand transport is 8.08 VU towards 78.5° (ENE).

In the Rice Valley, away from the direct influence of the Colorado River Valley, and in a broad open valley, potential sand transport occurs from three sectors: N-NNE – 51.4%; S-SW – 17.3%, and WNW-W - 25.7% (Fig. 5). As at Blythe, winds are strongest in the spring, accounting for 39% of annual DP. Summer southerly winds are weak, and account for only 5% of annual DP. Winter months (November – February) are characterized by north winds. The annual total drift potential (DP) is 20.75 VU (vector units); the resultant vector of sand transport is 7.81 VU towards 101.2° (ESE).

Based on the modified classification of wind regimes in Bullard (1997), the wind regimes at both locations are "low energy", with an annual DP <27 VU. This is approximately equivalent to a total annual sand transport of 2.5 $m^3 m^{-1} yr^{-1}$, or 26.92 cubic feet per foot width per year. It is therefore reasonable to expect that the Palen area experiences similarly low rates of sand transport.

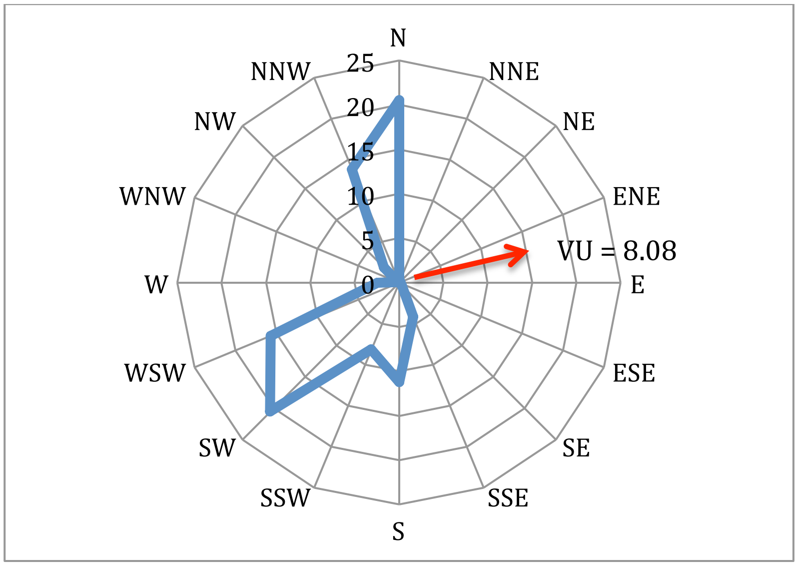
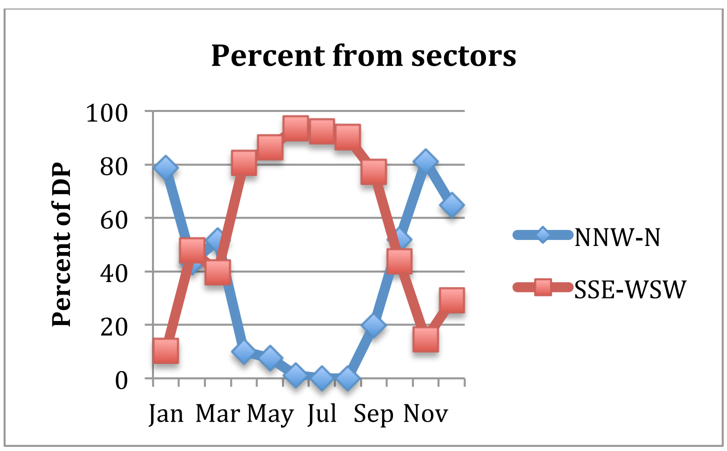


Fig. 3. Sand rose diagram showing percentage of annual total drift potential (DP) generated by winds from different directions at Blythe. Red arrow indicates resultant (vector) transport direction.



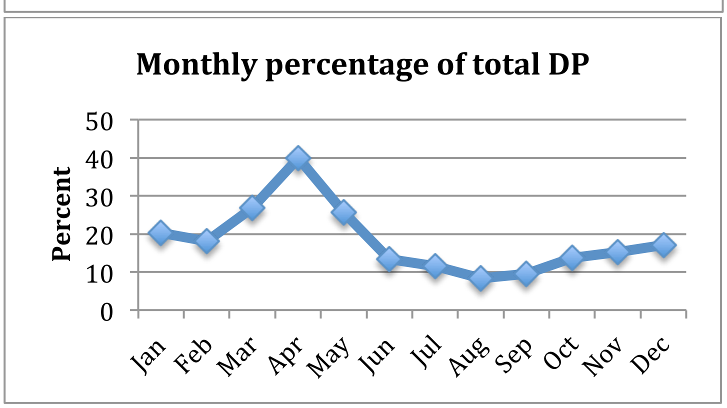


Fig. 4. Seasonal changes in Drift Potential (DP) at Blythe. Pattern at Rice Valley is similar.

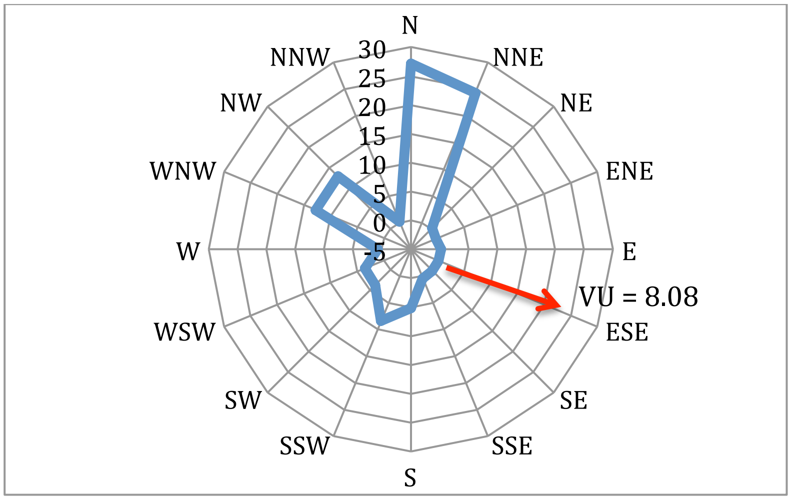


Fig. 5. Sand rose diagram showing percentage of annual drift potential (DP) generated by winds from different directions at Rice Valley. Red arrow indicates resultant (vector) transport direction.

Mapping of dune morphology and dune trends in the immediate area of the PSEGS, using Google Earth, indicates that most dunes in the area are of crescentic form and oriented transverse to winds from the NNW-NW, with a crest strike of 050 – 070°, as result of strong topographic steering of wind directions. Parabolic dunes (Fig. 6A) also occur, especially in the area immediately adjacent to the project. Both these dune types occur in areas where the winds are from one main directional sector, with a range of less than 30°. Dune forming winds are therefore similar to the observations made by Kenney (2010), and it appears that NNW-NW is the dominant wind direction in the project area, as a result of topographic funneling of winds in the Palen Valley. Examination of dune morphology on images acquired at different times of year, using the historical images function on Google Earth, suggests that SE to SW winds also occur in summer and result in reversed dune lee face orientation (Fig.6B).

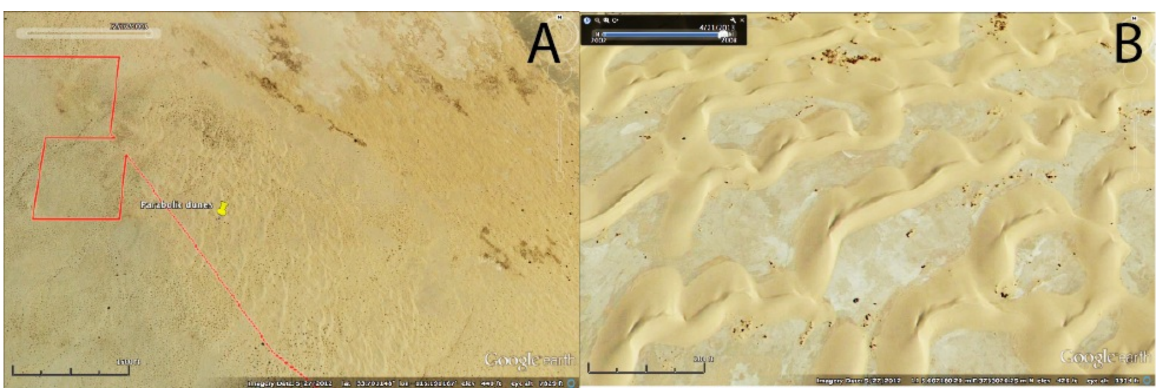


Fig. 6. A - Parabolic dunes in area adjacent to Modified Project (outline in red) Image date – 5-27-12. B – crescentic dunes with reversed crest lines (5-27-2012).

Combining information from dune trends with observed wind regimes in the area allows compilation of a synthetic annual sand-moving wind regime for the Palen area as an input to the simulation model. In order to obtain a realistic distribution of winds from different directions, possible combinations of different proportions of potential sand flux from different directions were tested using the Gross Bedform Normal Transport (GBNT) approach. This model states that aeolian bedforms (dunes, wind ripples) are aligned to maximize sediment transport normal to their crests (Rubin and Hunter, 1987). Its applicability to dunes in a variety of environments has been verified and tested by comparing the predicted GBNT orientation with measured dune trends (e.g.(Lancaster, 1991; Sridhar et al., 2006). Using the program Trend (Rubin and Ikeda, 1990), we simulated the wind regime that satisfies the gross-bedform-normal rule by iterating until the simulated GBNT dune trend matched the observed dune trend and thereby determined the most likely combination of winds that produced the dune trends observed in the Palen area.

In this scheme (Table 1) 85% of the sand is distributed to the southeast and south (mainly by winter north winds and spring winds from the NW); and 14% to the E, NE, and N. The proportion of sand moving to the southeast and south is higher than in the PWA modeling (Collison et al., 2010), 95% against 65% in the PWA model, which assigns an even distribution of sand to all other directions, which is not consistent with the wind regimes observed in the region.

NW = 0.6	N = 5	NE = 4
W = 0.2	0	E = 5
SW = 0.2	S = 40	SE = 40

Table 1. Percentage of sand movement towards the eight compass directions represented in moving window of cells in the PWA model. (0) represents center of cell window.

6. Application of the PWA to determine extent and magnitude of effects on sand transport associated with the Modified Project

Despite its limitations, the PWA is the best available and so was used to model effects of the Modified Project on sand transport and to ensure compatibility and comparison with prior studies. The PWA model was implemented and run using the wind regime illustrated above, together with the Modified Project footprint. We did not use the rotation of the winds used in the Collison et al. (2010) report because the effect of wind rotation was determined to be minimal based on a comparison of model runs with rotated and un-rotated winds, using the PWA wind regime as input. All other input parameters (sand distribution, model domain) were kept the same as the Collison et al. (2010) report. We also conducted model runs with the porosity of the project boundary fence set at zero (complete obstruction of the sand flow (e.g. a wall), and porosity values of 10, 25, and 50%. Following assessment and modeling of the effect of the solar array on winds and sand transport (see section 7), we considered the effect of the solar array and fencing to completely obstruct sand transport, and therefore present the results of the modeling to reflect this.

6.1 Effects of the Modified Project on sand transport patterns

The pattern of potential sand flux reduction resulting from the Modified Project is depicted in Figs.7-11 and considers indirect effects as defined by Collison et al. (2010). Direct effects are defined as areas on which the project completely covers the ground; and indirect effects are considered as areas that experience reduced sand transport. In addition to a strong downwind wake of reduced sand transport, the main effect of the Modified Project on sand movement is to create a zone of reduced sand movement up to 1000 feet wide along the northeastern and eastern boundaries, affecting primarily sand transport zones II and III. The effects of the Modified Project are summarized in Table 2.

	Zone I	Zone II	Zone III	Total
Direct Impact		267	893	1160
Indirect Impacts Sand transport reduction				
25-50%		119	9	128
50-75%		95	10	105
75-100%		135	54	189
Total Indirect effects		348	73	

Table 2: Summary of direct and indirect effects of Modified Project on sand transport (units in acres).

The Modified Project will result in direct impacts to sand transport over a total area of 1160 acres, of which 267 acres are in sand transport zone II. This is the area of the Modified Project that will cover this zone. Indirect effects of sand transport reduction in zone III occur over an area 73 acres, of which the majority lie on the northern project boundary and in the private land re-entrant in the project boundary. Zone II indirect effects cover 348 acres, of which 135 acres or 38.6% of the affected area are predicted to experience more than 75% reduction in sand transport; a further 95 acres or 27.2% of the affected area are predicted to experience a 50-75% reduction in sand transport; while the remainder of this area (119 acres) are predicted to experience 25-50% reductions in sand transport. Following Collison et al. (2010), sand transport reduction of <25% are not considered significant.

The local effects on sand transport are described in three areas labeled A-C on Fig. 8. Effects in area A (Fig. 9) are confined to zone III in an area of sparsely vegetated sand sheets and small washes. In area B (Fig. 10), effects on sand transport affect zone II, with the reentrant in the project boundary affecting zone III, comprising vegetated (likely with creosote bushes) thin sand sheets covering distal alluvial fan deposits. The part of zone II which is affected is more extensive in Area B and consists of an area of small parabolic dunes and adjoining sparsely vegetated sand sheets. Because the primary direction of sand transport in this area is sub-parallel to the Modified Project boundary, the area affected by sand transport reductions is 1000 feet or less in width. Strong reductions in sand transport (>75%) are restricted to the area immediately adjacent to the project boundary. Effects in Area C (Fig. 11) are more extensive, and impact zones II and III. Because the project boundary here lies perpendicular to the prevailing sand transport direction, the downwind effect on sand transport is greater, at approximately 4000 feet, and covers a wider area.

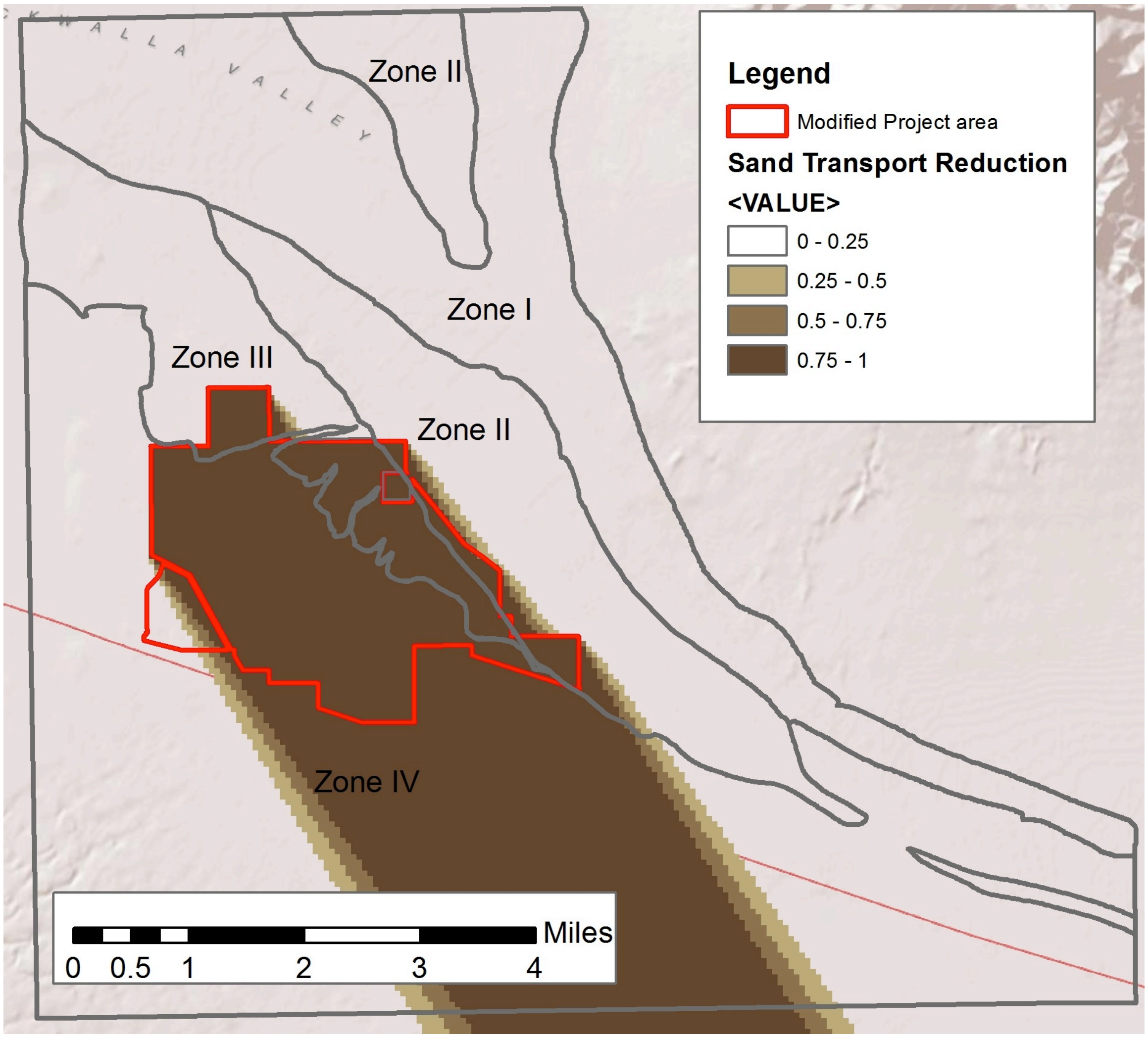


Fig. 7. Overview of sand transport reduction for Modified Project in relation to sand transport zones

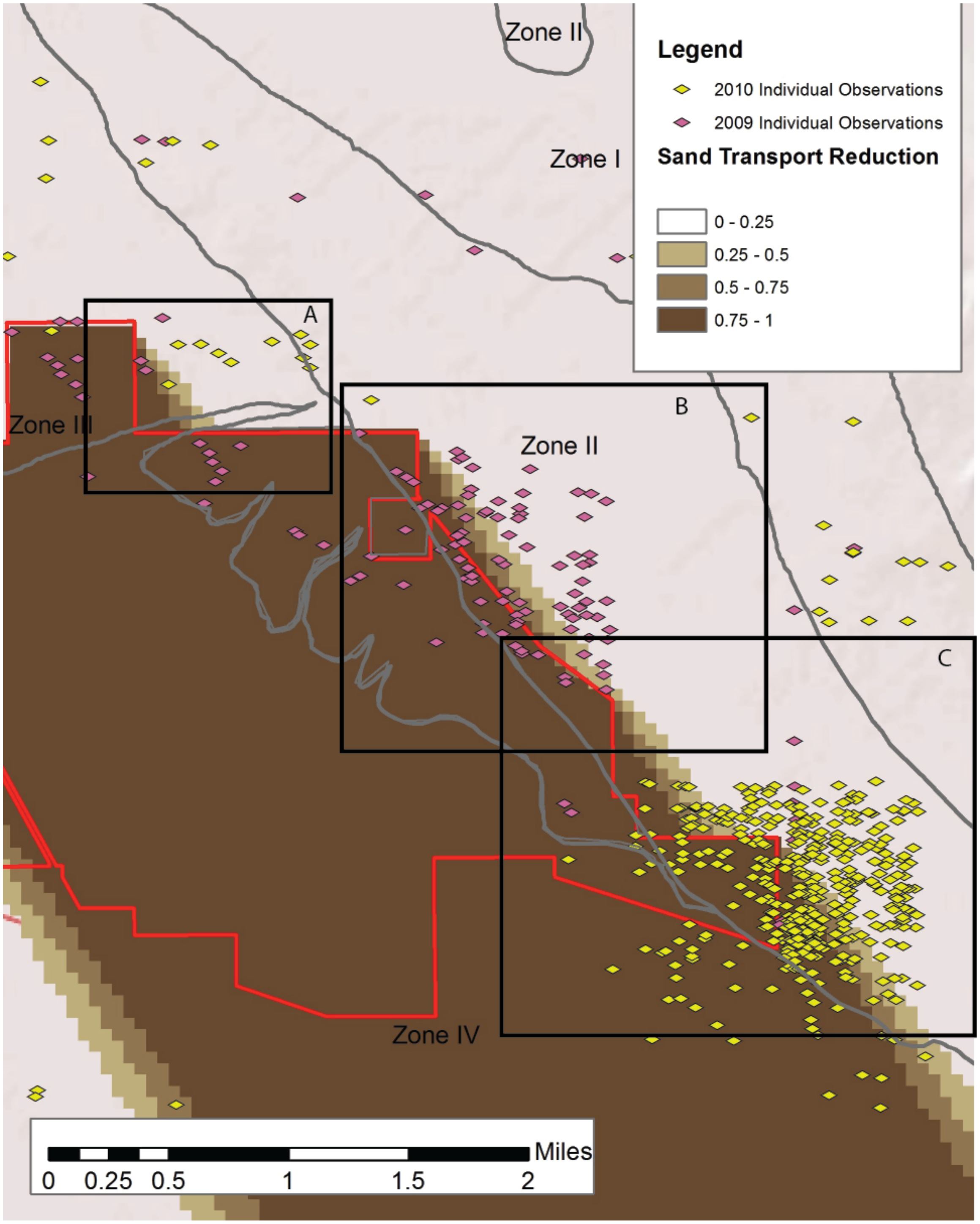


Fig. 8. Close up of pattern of sand transport reduction, with sites of Mojave Fringe Toed Lizard observations included. Areas of Figures 9-11 indicated as A,B,C. Location of Mojave Fringe Toed Lizard observations in 2009 and 2010 indicated by diamonds.

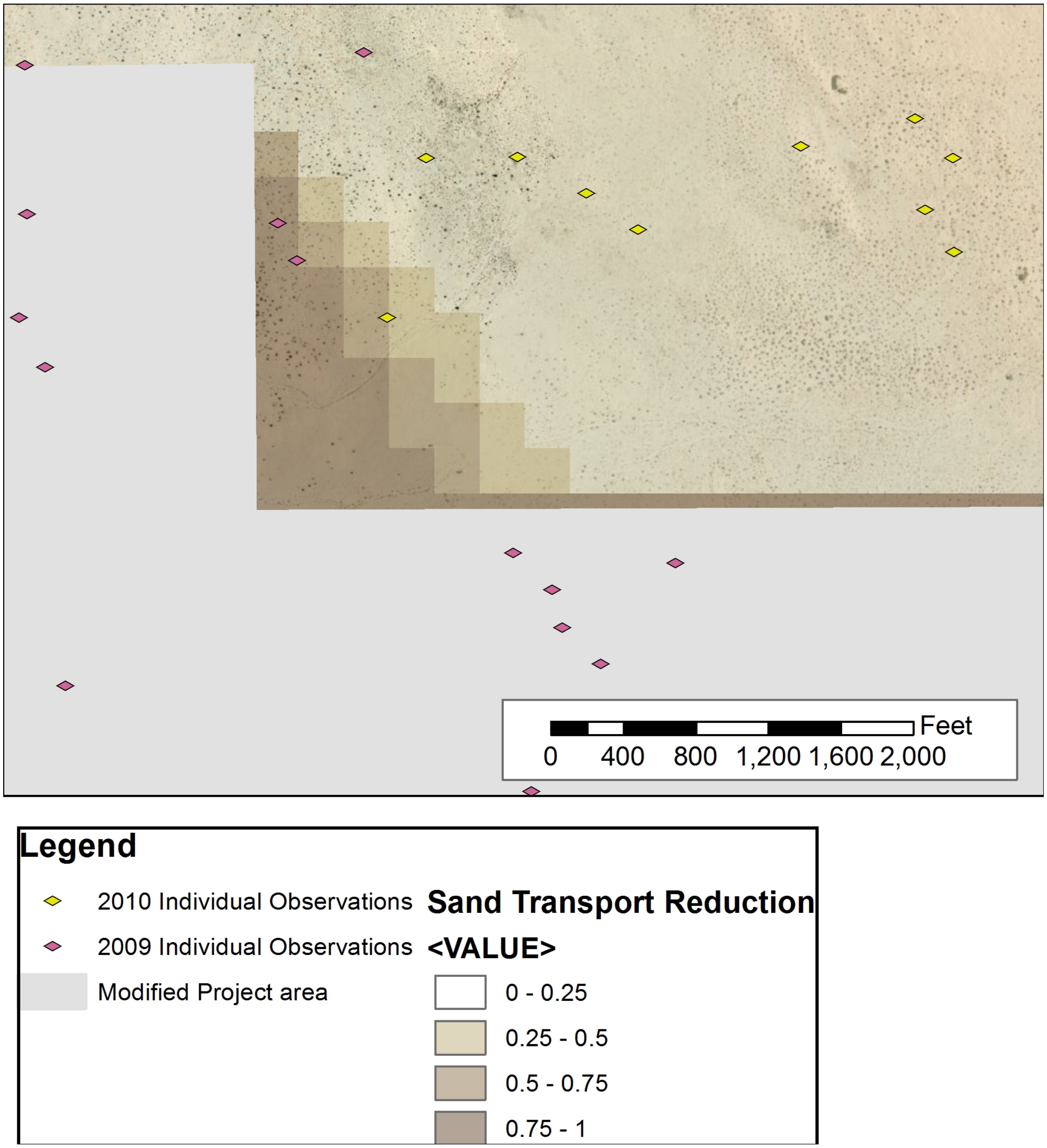


Fig.9. Sand transport reductions in Area A. Location of Mojave Fringe Toed Lizard observations in 2009 and 2010 indicated by diamonds.

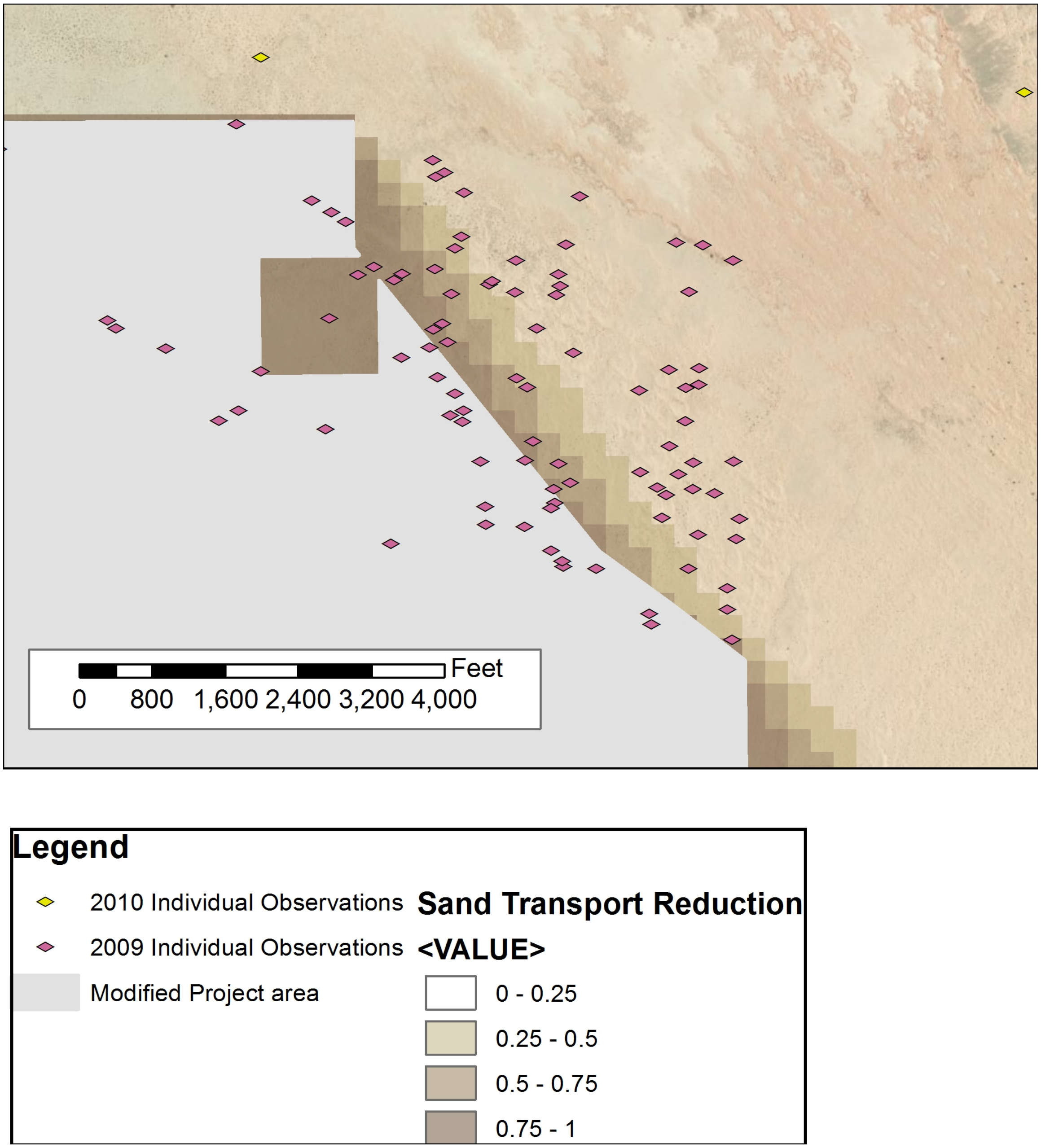


Fig. 10. Sand transport reductions in Area B. Location of Mojave Fringe Toed Lizard observations in 2009 and 2010 indicated by diamonds.

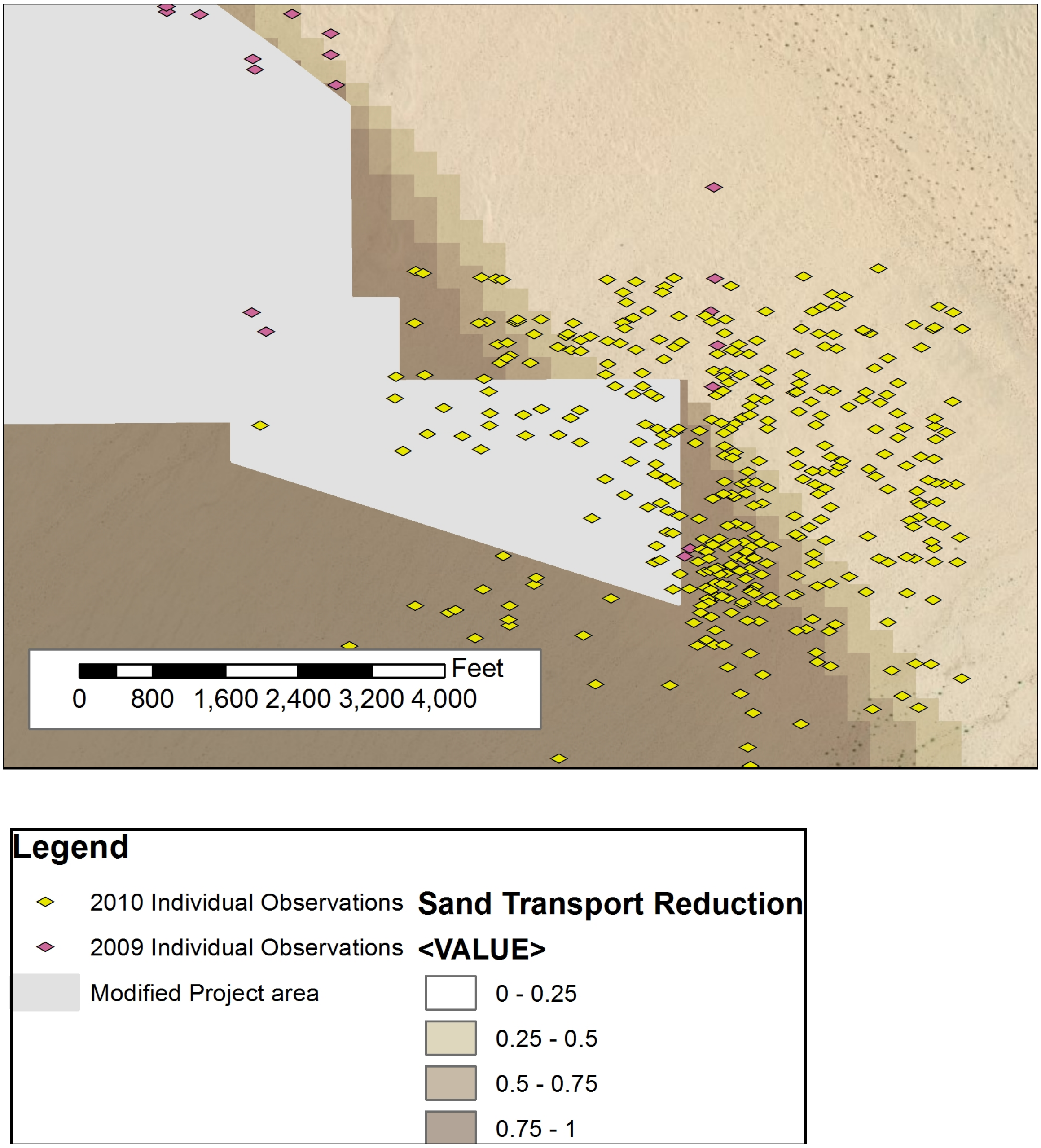


Fig. 11. Sand transport reductions in Area C. Location of Mojave Fringe Toed Lizard observations in 2009 and 2010 indicated by diamonds.

6.2. Comparison of effects of Modified Project with prior Project configurations

The effects of projects on sand transport patterns can be divided into direct effects, in which the affected area falls within the project footprint, and indirect effects, in which the area lies outside the project footprint and is affected by varying degrees of sand flux reduction. The areas so affected by different project footprint configurations are summarized in Table 3 and Figure 12. The Modified Project affects a total of 1581 acres in zones II and III of which 421 acres are indirect effects, primarily in zone II. It is clear that the Modified Project has a much larger effect on sand transport in zone II compared to the Applicant's Reconfigured Alternatives 2 and 3. This is because the project footprint is larger (at 3794 acres) than the project disturbance area for Reconfigured Alternatives 2 and 3 (3128 and 3164 acres respectively) and, most importantly, extends further east into the sand transport corridor, as shown by Figure 13. In addition, the configuration of the Modified Project boundary includes as 40 acre area of private land in Zone III that is almost completely surrounded by the project and sand transport in this area therefore is affected strongly (at the 75-100% level).

The downwind effects of the Modified Project on Zone II extend for a total distance of approximately 4000 feet, measured parallel to the dominant wind direction. Sand flux reduction at the 75-100% level extends for some 2679 feet. This compares with a total downwind sand flux reduction distance of 3350 feet for Reconfigured Alternative 2 and 3120 feet for Reconfigured Alternative 3. Sand flux reduction at the 75-100% level extends for some 1512 and 710 feet respectively in these alternatives (see Figure 14).

	Zone II Indirect	Zone II Direct	Zone III Indirect	Zone III Direct
Proposed Project	1060	430	53	540
Staff reduced alternative	55	9	237	290
Applicant's Reconfigured Alternative 1	870	520	280	600
Applicant's Reconfigured Alternative 2	130	140	14	540
Applicant's Reconfigured Alternative 3	79	150	16	640
Modified Project	**348**	**267**	**73**	**893**

Table 3: Direct and indirect effects of different project footprints (units in acres).

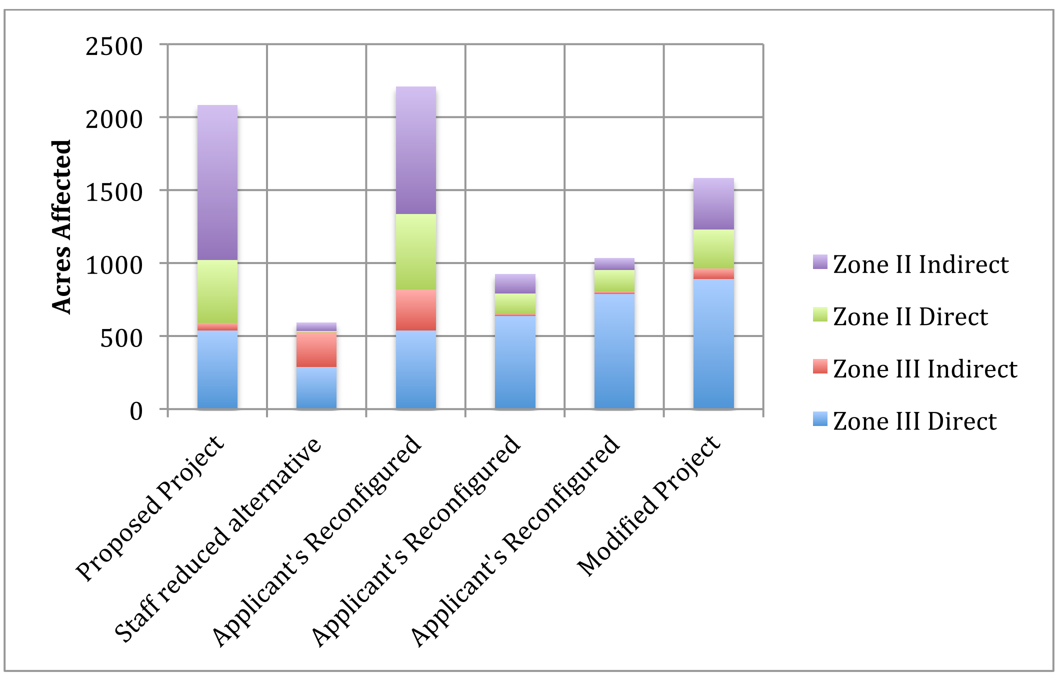


Fig. 12. Comparison of areas affected directly and indirectly in Zones II and III for different project footprints. Data for projects proposed prior to the Modified Project from Collison et al. (2010), Table 2.

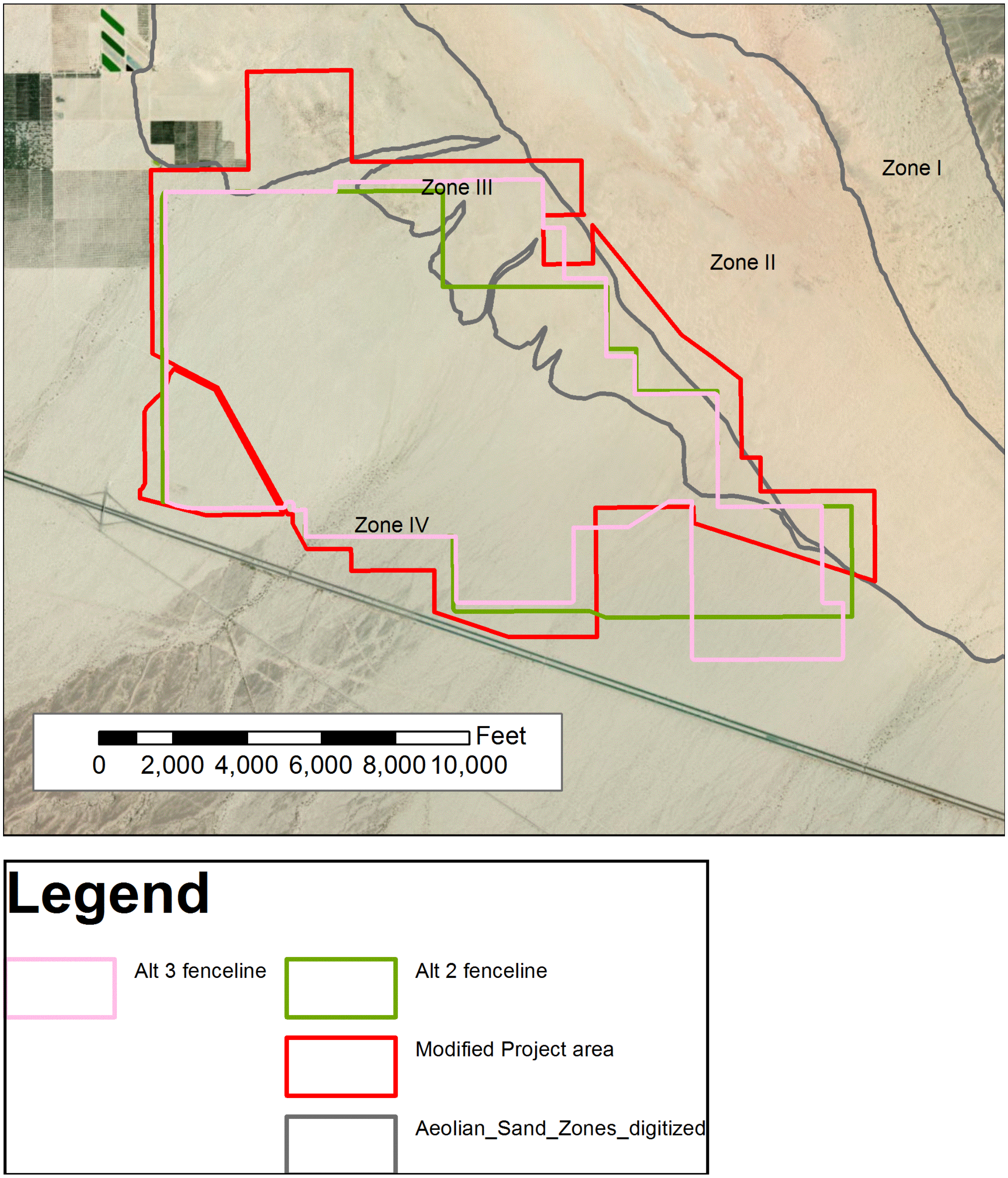


Fig. 13. Comparison of project areas. Note how the Modified Project extends further east in to the Zone II of the sand transport corridor.

In addition to a greater area of indirect impacts on Zone II, the simulation of the effects of the Modified Project on the level of sand transport reduction indicates that 135 acres or 38.6% of the reduction in sand transport is predicted to be at a high level (75-100%). Compared to the Alternatives 2 and 3, the Modified Project indirectly affects an additional

39 and 51 acres respectively at the 25-50% reduction level, 56 and 85 acres at the 50-75% level and 124 and 134 acres at the 75-100% level (Table 4).

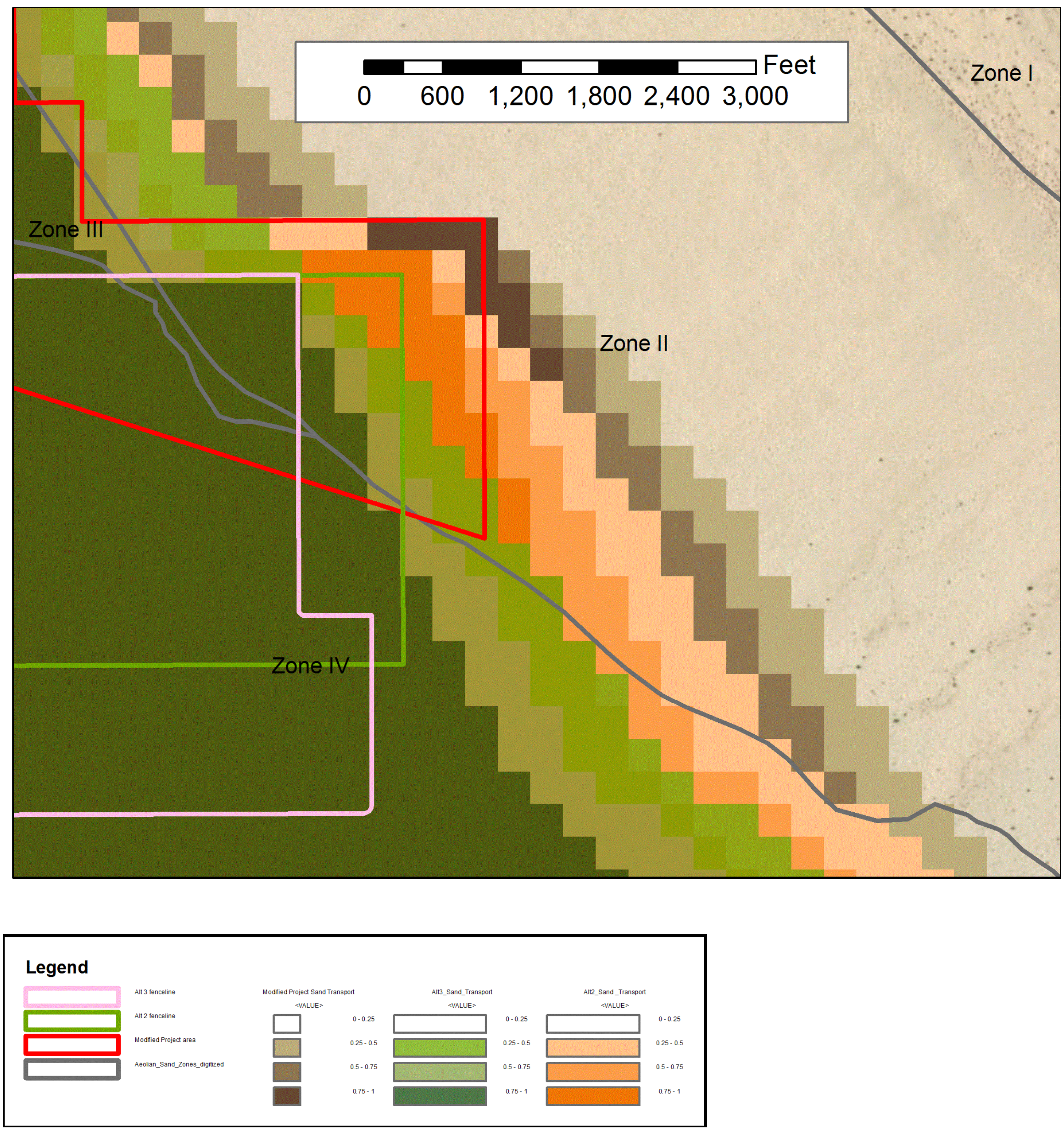


Fig. 14. Comparison of downwind effects in sand transport Zone II of the Modified Project with Reconfigured Alternatives 2 and 3.

	Sand Transport Reduction		
	25-50%	50-75%	75-100%
Applicant's Reconfigured Alternative 2	80	39	11
Applicant's Reconfigured Alternative 3	68	10	1
Modified Project	119	95	135

Table 4: Sand flux reduction predictions in Zone II for selected project alternatives (units in acres).

A index of the total effect (area x level of impact) of the different projects can be developed by multiplying the number of acres affected by the mid-point of the percentage reduction in sand transport (Table 5). This index indicates that the Modified Project has 3.5 – 6.8 times the effect of either of the Applicant's Reconfigured Alternatives.

Impact Ranking	Sand Transport Reduction			
	25-50%	50-75%	75-100%	Total
Applicant's Reconfigured Alternative 2	3000	2438	963	6400
Applicant's Reconfigured Alternative 3	2550	625	88	3263
Modified Project	4466	5919	11777	22161

Table 5: Relative magnitude of the effects of projects on sand transport

7. Assessment of effects of Modified Project using sand transport reduction modeling

The Applicant has stated that the Modified Project will have little or no impact on sand transport and that sand will be free to pass through the solar array (Palen Solar Holdings, LLC's Supplemental Response to CEC staff data request 5, Docket #09-AFC-7C).

Because the Modified Project is surrounded by a chain link fence, with additional desert tortoise fencing, the effects may be different from the approved Project Alternatives 2 and 3 that were surrounded by a wall.

The effect of the solar array on winds and sand transport can best be assessed using models that relate the reduction in sand transport to the aerodynamic roughness created by the solar array.

Roughness elements are known to modulate sand transport by wind. Very sparse roughness can cause increased erosion when the elements are isolated from each other and the individual elements generate a vortex in front and accelerated flow around them (Sutton and McKenna-Neuman, 2008), which enhances wind erosion. At a critical density of roughness, entrainment and transport are suppressed due to momentum absorption by the roughness (Gillette and Stockton, 1986; Raupach et al., 1993; Yang and Shao, 2005). The partitioning of shear stress between the elements and the intervening surface reduces the shear stress on the surface (Gillies et al., 2007; Raupach et al., 1993), thus decreasing sand transport because saltation flux scales as a power function of shear stress (Bagnold, 1941). In addition, interaction of the moving sand with the roughness elements, may also affect the transport efficiency (Bagnold, 1941; Nickling and McKenna Neuman, 1995). (Gillies et al., 2006) and (Gillies and Lancaster, 2013) demonstrated that the size of the roughness element also plays an important role in controlling the effectiveness of the roughness for modulating sand transport, with larger elements of equivalent roughness density (λ) being more effective at reducing sand transport than smaller elements. Roughness density is defined as:

$$\lambda = \frac{element\ breadth \times element\ width \times element\ \#}{total\ area\ containing\ the\ elements}$$

According to Yang and Shao (2005), roughness begins to suppress sand transport when $\lambda \geq 0.012$.

A relationship between (normalized) sand flux and λ for large (≈0.38 m tall) roughness elements was presented by Gillies and Lancaster (2013) (Fig. 15). As this figure shows, the decrease in sand flux with increasing λ is non-linear, and applies to the equilibrium transport condition. The rate of change of sand transport as it enters the roughness also scales as a function of λ. The sand flux decreases at a faster rate with increasing downwind distance as λ increases, which is shown in Fig. 16.

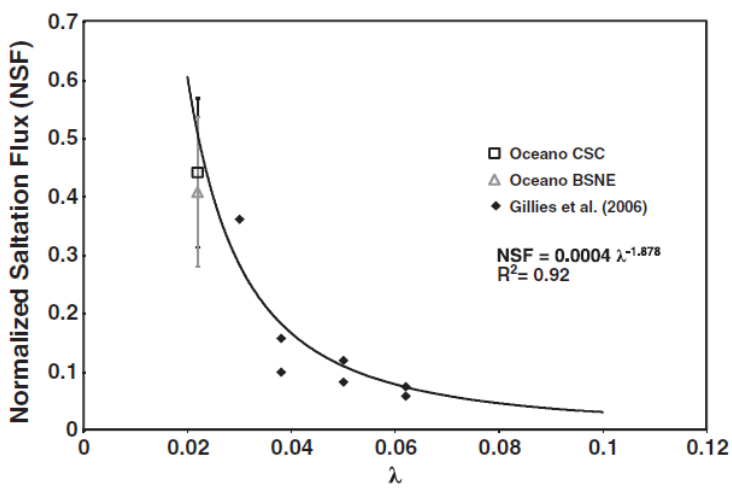


Fig.15. Normalized mean saltation flux (NSF) as a function of λ for the data of Gillies et al. (2006) and Gillies and Lancaster (2013). The regression-derived relationship is for all data combined. Error bars on the Oceano data points represent the standard deviation of the mean (Gillies and Lancaster, 2013).

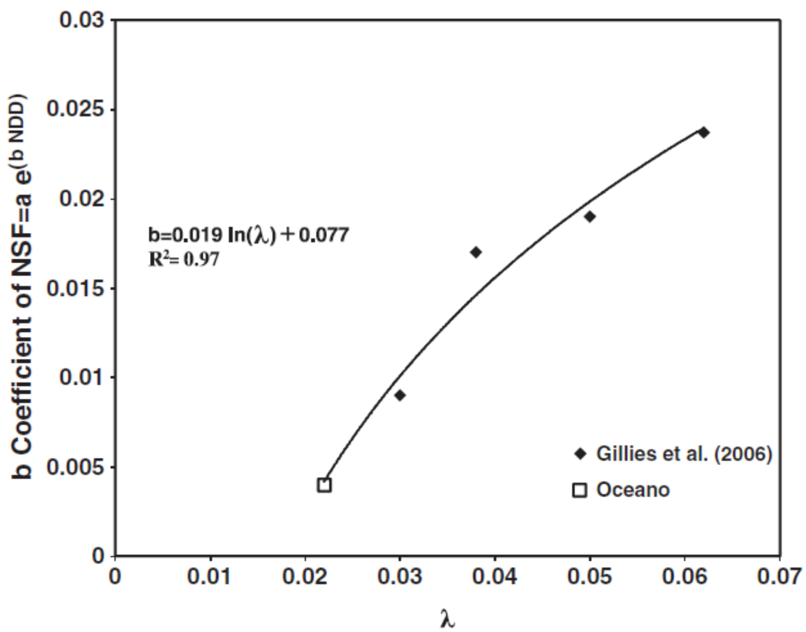


Fig. 16. The relationship between the b coefficient in the NSF = a $e^{(b \times NDD)}$ relationship and λ for the data from Gillies et al. (2006) and Gillies and Lancaster (2013). The regression-derived relationship combines all the data.

The Modified Project roughness elements are essentially two-dimensional elements mounted on pedestals. They can change their tilt from straight up and down to an angle that most efficiently directs the solar radiation to the solar tower. The general layout of the elements with respect to the solar tower is circular, but the symmetry is imperfect due to boundary conditions that define the area that contains the elements. The dimensions of the panels are approximately 5.230 m long by 3.395 m wide, and there are 8.5×10^4 of them contained within the 1.447×10^7 m^2 area that defines the array.

The roughness density (λ) of the array is calculated based on the following assumptions: (1) on average one element occupies 170.25 m^2, (2) the thickness of a panel is regarded as infinitely small, (3) the array is uniformly arraigned in a circular configuration around each solar tower, and (4) the frontal area of the pedestal is not considered in the calculation (width dimension is unknown). Of note is that for equivalent tilt angle of the panel (0° to 90°) and approach angle of the wind to the element (0° to 90°), the projected area of the panel is also equivalent.

Because the elements are in a circular array around the tower, for a given wind direction there will be elements that are perpendicular to the wind and parallel to the wind, and the rest will be at some angle to the wind between 0° and 90°. Because of symmetry however, regardless of wind direction the same number of elements will always have the same relationship to the wind between perpendicular and parallel.

An estimate of λ for the Modified Project array is based on a sub-unit of the array that contains 20,736 panels, in a 144 by 144 grid that is 1,879.2 m × 1,879.2 m on either side. The total area is $\approx 3.531 \times 10^6$ m^2. Within this grid for any wind direction, 144 panels would be perpendicular to the wind, 144 would be parallel, while the other 142 groups of 144 units would have wind approach angles increasing approximately 0.63° per group, through the 90°arc between perpendicular and parallel. The projected frontal area of an element is a function of the cosine of the wind approach angle to the length of the element (i.e., 5.23 m). The total projected frontal area of the 20,736 roughness elements for this sub-unit of the array is $\approx 2.340\times10^5$ m^2, which divided by the area of the sub-unit gives a λ of 0.066. The predicted sand flux reduction within the array, after reaching equilibrium at approximately 530 m (1738 feet) into the array, based on the relationship presented in Fig. 14 (i.e., Gillies and Lancaster, 2013) is 93%. This indicates that the Modified Project element array should be highly effective in both arresting sand transport and keeping any flux at very low levels in comparison to sand flux on an un-obstructed surface.

8. Conclusions

Modeling of the effects of the Modified Project on sand transport in the Palen Valley indicates that the Project has an increased level of predicted effects on sand transport, compared to the Applicant's Reconfigured Alternatives 2 and 3. This is because the project footprint extends further east into the sand transport corridor. Quantification of effects on sand transport indicate that 348 acres of zone II will be affected, compared to 130 and 79 acres, for Alternatives 2 and 3 respectively. In addition, the qualitative effect on sand transport is predicted to be much more significant, because the modeling indicates that 135 acres or 38.6% of the reduction in sand transport is predicted to be at a high level (75-100%). Compared to the Alternatives 2 and 3, the Modified Project indirectly affects an additional 39 and 51 acres respectively at the 25-50% reduction level, 56 and 85 acres at the 50-75% level and 124 and 134 acres at the 75-100% level.

The Modified Project heliostat array is predicted to have a very significant effect on sand transport such that sand transport will be reduced by 93% at 1738 feet into the array. This suggests that the array will be highly effective at reducing sand transport and that any sand entering the array will be deposited within a zone up 1800 feet from the edge of the array.

9. Recommendations

9.1 Sand transport modeling

The PWA sand transport model has significant limitations in its abilities to predict where erosion and deposition of sand may occur. Such information is valuable to the Applicant for site design and implementation of any sand control measures that may be needed. It is also valuable for assessing the impacts of infrastructure on habitat for flora and fauna (e.g. , the Mojave Fringe Toed Lizard).

We recommend that a new model be developed, based on existing peer reviewed cellular automaton models (e.g. the Discrete ECogeomorphic Aeolian Landscape (DECAL) - (Nield and Baas, 2008b).

9.2 Monitoring of Project Effects on Sand Transport

Given the limitations of the PWA model and the fact that there is no way to evaluate if it does in fact reproduce the probable effects of any project on sand transport, we recommend that a program of sand transport monitoring be designed and implemented on site to detect changes in sand transport and associated changes in dune morphology and habitat suitability. Such a monitoring program would provide valuable information for siting of other facilities in sandy areas.

9.3 Mapping and identification of sand transport corridors

Given the widespread extent of sand transport corridors in the Mojave Desert and the very general way in which they have been mapped, we recommend a program that will identify and map these corridors, to provide an assessment of the levels of sand transport experienced (as indicated by landforms and vegetation cover), so that future siting decisions may be informed by reliable information.

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References Cited

Baas, A.C.W., Nield, J.M., 2007. Modelling vegetated dune landscapes. Geophysical Research Letters, 34, L06405.

Bagnold, R.A., 1941. The Physics of Blown Sand and Desert Dunes. Chapman and Hall, London.

Barchyn, T.E., Hugenholtz, C.H., 2012. Predicting vegetation-stabilized dune field morphology. Geophysical Research Letters, 39(17), n/a-n/a.

Bullard, J.E., 1997. A note on the use of the "Fryberger method" for evaluating potential sand transport by wind. Journal of Sedimentary Research, 67(3), 499-501.

Collison, A., C. Nilsen, J. Gregory 2010 Biological Resources, Appendix C. Geomorphic Assessment and Sand Transport Impacts Analysis Palen Solar Power Project. Prepared for the California Energy Commission and Aspen Environmental by Philip Williams and Associates, ltd., August 18, 2010.

Fryberger, S.G., 1979. Dune forms and wind regimes. In: E.D. McKee (Ed.), A Study of Global Sand Seas: United States Geological Survey, Professional Paper. U.S.G.S. Professional Paper, pp. 137-140.

Gillette, D.A., Stockton, P.H., 1986. Mass momentum and kinetic energy fluxes of saltating particles. In: W.G. Nickling (Ed.), Aeolian Geomorphology. Allen and Unwin, Boston, London, Sydney, pp. 35-56.

Gillies, J., Nickling, W.G., King, J., 2007. Shear stress partitioning in large patches of roughness in the atmospheric inertial sublayer. Boundary Layer Meteorology, 122, 367-396.

Gillies, J.A., Lancaster, N., 2013. Large roughness element effects on sand transport, Oceano Dunes, California. Earth Surface Processes and Landforms, 38(8), 785-792.

Gillies, J.A., Nickling, W.G., King, J., 2006. Aeolian sediment transport through large patches of roughness in the atmospheric inertial sublayer. Journal of Geophysical Research, 111, F02006.

Kenney, M. 2010. Geomorphology Report of the Aeolian Sand System in the Palen Dry Lake Region, Proposed Palen Solar I Energy Project, Chuckwalla Valley, Riverside County,

California. Draft copy submitted to AECOM Environment, Camarillo, CA., April 16, 2010
Laity, J.E., 1987. Topographic effects on ventifact development, Mojave Desert, California. Physical Geography, 8, 113-132.
Lancaster, N., 1991. The orientation of dunes with respect to sand-transporting winds: a test of Rubin and Hunter's gross bedform-normal rule, NATO Advanced Research Workshop on sand, dust, and soil in their relation to aeolian and littoral processes. University of Aarhus, Sandbjerg, Denmark, pp. 47-49.
Lancaster, N., Baas, A., 1998. Influence of vegetation cover on sand transport by wind: field studies at Owens Lake, California. Earth Surface Processes and Landforms, 23(1), 69-82.
Lancaster, N., Helm, P., 2000. A test of a climatic index of dune mobility using measurements from the southwestern United States. Earth Surface Processes and Landforms, 25(2), 197-208.
Middleton, G.V., Southard, J.B., 1984. Mechanics of Sediment Movement. S.E.P.M., Tulsa, Oklahoma.
Muhs, D.R., Reynolds, R.R., Been, J., Skipp, G., 2003. Eolian sand transport pathways in the southwestern United States: importance of the Colorado River and local sources. Quaternary International, 104, 3-18.
Nickling, W.G., McKenna Neuman, C.K., 1995. Development of deflation lag surfaces. Sedimentology, 42(3), 403-414.
Nield, J., Baas, A.C.W., 2008a. Investigating parbolic and nebkha dune formation using a cellular automaton modelling approach. Earth Surface Processes and Landforms, 33(5), 724-741.
Nield, J.M., Baas, A.C.W., 2008b. The influence of different environmental and climatic conditions on vegetated aeolian dune landscape development and response. Global and Planetary Change, 64(1-2), 76-92.
Raupach, M.R., Gillette, D.A., Leys, J.F., 1993. The effect of roughness elements on wind erosion threshold. Journal of Geophysical Research, 98, 3023-3029.
Rubin, D.M., Hunter, R.E., 1987. Bedform alignment in directionally varying flows. Science, 237, 276-278.
Rubin, D.M., Ikeda, H., 1990. Flume experiments on the alignment of transverse, oblique and longitudinal dunes in directionally varying flows. Sedimentology, 37(4), 673-684.
Sridhar, V., Loope, D.B., Swinehart, J.B., Mason, J.A., Oglesby, R.J., Rowe, C.M., 2006. Large Wind Shift on the Great Plains During the Medieval Warm Period. Science, 313, 345-347.
Sutton, S.L.F., McKenna-Neuman, C., 2008. Variation in bed level shear stress on surfaces sheltered by nonerodible roughness elements. Journal of Geophysical Research: Earth Surface, 113(F3), F03016.
Werner, B.T., 1995. Eolian dunes: computer simulations and attractor interpretation. Geology, 23(12), 1107-1110.
Werner, B.T., Kocurek, G., 1997. Bed-form dynamics: Does the tail wag the dog ? Geology, 25(9), 771-774.
Wolfe, S.A., Nickling, W.G., 1993. The protective role of sparse vegetation in wind erosion. Progress in Physical Geography, 17, 50-68.
Yang, Y., Shao, Y., 2005. Drag Partition and its possible implicatins for dust emission. Water, Air, and Soil Pollution: Focus, 5, 251-259.