TECHNICAL MEMORANDUM

MODELING OF POSSIBLE AEOLIAN SAND SOURCES FOR KEELER DUNE FIELD, OWENS VALLEY, CALIFORNIA

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Background

On November 16, 2012, the Great Basin Unified Air Pollution Control District (District) issued a final report regarding the historic origin and development of the Keeler Dunes.[1] The District performed seven separate research studies in cooperation with several external consultants to evaluate the historic development of the Keeler Dune field (located east of the Owens Lake playa, north of the town of Keeler), and to study the possible origin of the material (sand) present in the current dune field. The report concludes that (p.iii) "*The results of the investigations taken together clearly show that the landscape within the Keeler Dunes has changed dramatically in the last century and that the current active emissive Keeler Dunes developed after the historic desiccation of Owens Lake.*" Furthermore, regarding the origin of the sand in the current active dune field, the report states that the investigations (p.iii) "*conclusively indicate that the current active and emissive dune deposits are not natural but instead are the result of disruption of the natural hydrologic environment in the Owens Valley due to water diversion activities.*"

The Los Angeles Department of Water and Power (LADWP) has provided review comments to the District's report and its supporting analysis (including an earlier draft version of the documents[2]), and has pointed out multiple shortfalls of the technical arguments presented in the report. The sand motion modeling described in this technical memorandum was conducted to provide an alternative assessment of sand sources contributing to the Keeler Dunes.

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[1] Great Basin Unified Air Pollution Control District, 2012. Final Staff Report On the Origin and Development of the Keeler Dunes. November 16, 2012.

[2] Great Basin Unified Air Pollution Control District, 2012. Preliminary Staff Report On the Origin and Development of the Keeler Dunes. September 7, 2012.

Methods

Overview of Approach

The approach followed in this analysis is based on the characterization of sand motion in areas that could serve, or have served historically, as sources of windblown sand material for the Keeler Dune field. Sources considered were located on the (dry) Owens Lake playa, as well as off-lake (i.e., not located on the Owens Lake playa). The latter includes historic shoreline dunes, which originated from periodic desiccation of the lake (long before any water diversion by LADWP), as well as alluvial fans located between the historic shoreline and the Inyo Mountains east of the dunes. The geographic domain of interest was segregated into multiple areas (polygons) with similar soil, surface, and vegetative conditions (see "Site Characterization").

Next, for each polygon the potential sand motion was evaluated using the Single-event Wind Erosion Evaluation Program (SWEEP). Each polygon was given a unique relationship between the potential sand flux and wind speed (see "Sand Motion Potential"). These relationships were then incorporated into a sand motion model, combining the polygons identified in the first step, their associated sand motion potential, and modeled wind fields for the domain of interest. The wind fields quantify the hourly 10-meter wind speed and direction within the modeling domain over a five-year period. By linking the spatially and temporally differentiated sand motion potential and wind fields, the overall potential of sand from each polygon to reach the Keeler Dunes could be evaluated. Several different modeling scenarios, with varying assumptions, were considered, providing a spectrum of possible outcomes.

Site Characterization

Procedure

An initial delineation of potential sand source areas surrounding the Keeler Dunes and spanning up to the Owens River Delta was performed prior to field work using a range of historical aerial photography, and other data and knowledge about soil, surface, and vegetative characteristics in these areas. The initial delineation consisted of 22 polygons (Figure 1). Each of these areas was visited and verified in the field from October 22–24, 2012, with the objective to obtain soil, surface, and vegetative data necessary to populate the SWEEP model. Each of the source areas (polygons) was visited to assess the characteristics listed in Table 1. Based on field observations, boundaries between polygons were adjusted, or new polygons were created to better describe and encompass variation in the surfaces. Mapping was done on an approximate 1:10,000 level scale, based on the model configuration and input needs (see "Sand Motion Modeling").

Figure 1. Original Field Survey Polygons and Surface Sampling Locations

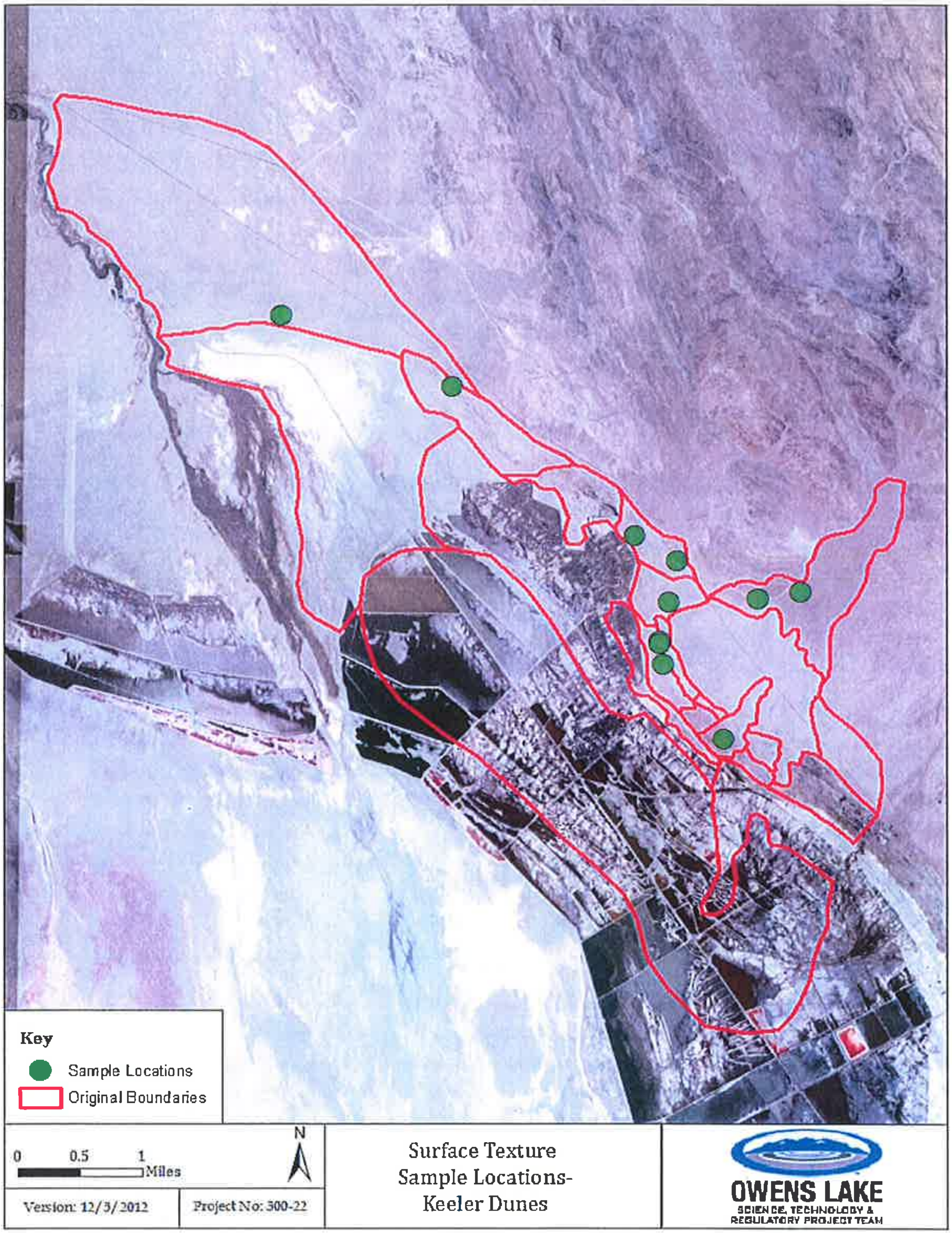


Table 1. Field Attributes Collected

Attribute	Units
Layer Thickness	mm
Sand	%
Silt	%
Clay	%
Fine Gravel	%
Coarse Sand	%
Medium Sand	%
Fine Sand	%
Very Fine Sand	%
Water Dispersed Clay	-
Dry Bulk Density	Mg/m^3
1/3 Bar Bulk Density	Mg/m^3
Geometric Mean Diameter	mm
Geo Standard Deviation	-
Max Aggregate Size	mm
Min Aggregate Size	mm
Aggregate Density	Mg/m^3
Aggregate Stability	J/kg
Crust Thickness	mm
Crust Density	Mg/m^3
Crust Stability	J/kg
Crust Surface Fraction	m^2/m^2
Loose Material	Kg/m^2
Fraction Loose Material	m^2/m^2
Initial Water Content	Kg/Kg
Saturated Water Content	Kg/Kg
Field Capacity Water Content	Kg/Kg
Wilting Point Water Content	Kg/Kg
0.1 Bar on Sand	Kg/Kg
Soil CB Value	Kg/Kg
Air Entry Potential	cm/sec
Saturated Hydraulic Conductivity	cm/sec

Table 1. Field Attributes Collected (continued)

Attribute	Units
Random Surface Roughness	mm
Albedo	%
Organic Matter	%
Soil pH	-
$CaCO_3$ Equivalent	-
Cation Exchange Capacity	-
Ridge Orientation	Degrees
Ridge Height	mm
Ridge Spacing	mm
Ridge Width	mm
Random Roughness of Ridge	mm
Vegetation Height	cm
Vegetation Canopy Diameter (North/South)	cm
Vegetation Canopy Diameter (East/West)	cm
Average Shrub Spacing	feet
Shrub Layout	-
Estimated Living Vegetation Cover	%
Shrub Density	Plants/acre
Plant Vertical Porosity	%
Plant Horizontal Porosity	%
Plant Vigor	Poor to High Vigor

Within each polygon, surfaces and landscape features were characterized at a representative location. Surface features were measured and recorded, pictures of the area were taken, selected surface samples were collected (Figure 1), and GPS locations for surface samples were recorded. Average vegetation characteristics were also evaluated, both quantitatively and qualitatively. Surface samples were sent to IAS Laboratories in Phoenix, AZ. In some polygons with existing data, existing soil/surface information was used to populate particle size and surface parameters. In addition to surface characteristics, significant impediments or sinks were noted where landscape features existed that would impede sand motion. These mostly consisted of large gullies, berms, or dense vegetative stands.

Post Fields Collection Procedures

Field data were compiled and analyzed for similarities, and any polygons that were very similar were merged to reduce unnecessary complexity. After field characterization, there were approximately 27 delineated polygons. Through merging polygons with highly similar characteristics, the final number of polygons characterized for SWEEP input parameters was 37 (Figure 2). Attributes were populated for each polygon, using surrogate data from similar areas as needed.

Sand Motion Potential

Model Description

Each polygon was evaluated for potential sand motion as a function of wind speed using the SWEEP. This program is part of the Wind Erosion Prediction System[3] (WEPS), developed by the Natural Resources Conservation Service (NRCS). WEPS replaces the predominately empirical Wind Erosion Equation as a prediction tool for those who plan soil conservation systems, conduct environmental planning, or assess offsite impacts caused by wind erosion. The development of WEPS was based on agricultural applications, and, as such, accommodates inputs for soil parameters, surface roughness, vegetation cover, and meteorology (wind speed and direction, precipitation). Outside of the agricultural arena, SWEEP has been successfully applied on the Owens playa to evaluate sand motion on playa soils and the effectiveness of various measures to reduce sand motion on the playa.

Modeling Steps

For each of the 27 polygons (Table 2) the soil and surface information was converted to a SWEEP input file. Initial runs with SWEEP were performed to verify the threshold wind velocity (i.e., hourly average wind speed at a 10-meter height at which sand begins to move over a surface) and the estimated sand flux as a function hourly wind speed (assuming no vegetation present). These threshold and sand flux values were then compared to sand flux versus wind speed relationships observed on the Owens Lake playa and in the Keeler Dune area. If needed, the soil and/or surface input parameters were adjusted to yield sand flux versus wind speed relationships comparable to those observed.

In the next step the vegetation data for each of the polygons were processed to yield the input parameters required by SWEEP, specifically, vegetation height (m), LAI (m^2/m^2), and vegetation spacing (m). The final SWEEP inputs consisted of best estimates of these parameters based on (not in order of priority): 1) on-the-ground measurements, 2) on-the-ground general visual observations, 3) representative photographs of each vegetated polygon, and 4) vegetation cover estimates based on remote sensing. Next, new relationships between sand flux and wind speed were developed for those polygons that had vegetation present.

[3] http://www.weru.ksu.edu/nrcs/wepsnrcs.html (last accessed 12/7/12; Version June 2012)

Figure 2. Final Modeling Boundaries

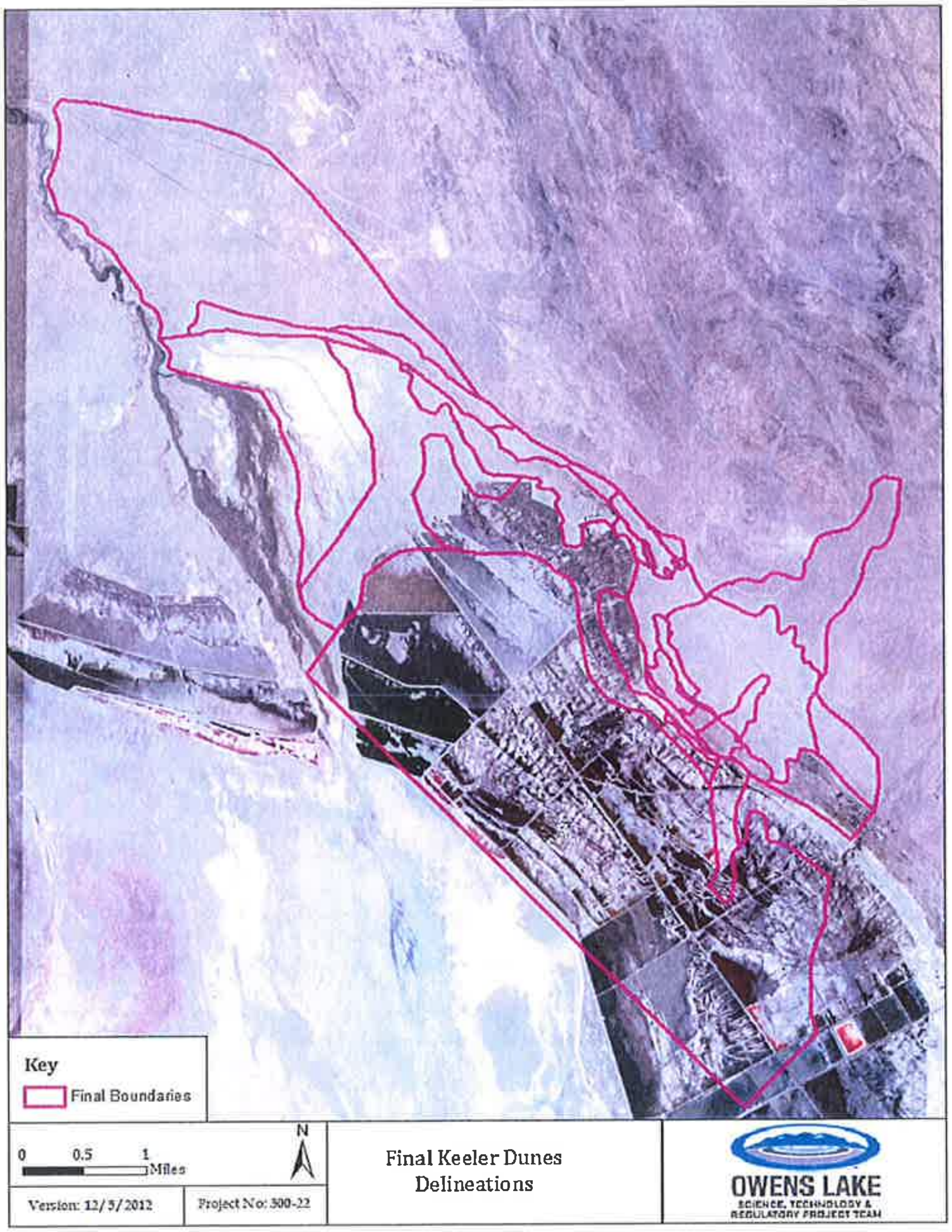


Table 2. Description of Polygons in Modeling Domain

Polygon	Description	Season Factor	Vegetation	Sand Flux
1	Lizard Tail Mesa	No	Low	Yes
2	Northern Lizard Tail Shoreline	No	High	No
3	Delta Playa (resistant crust)	Yes	Negligible	No
4	Southern Lizard Tail Shoreline (like #2)	No	High	Yes
5	North Swansea Shoreline	No	Medium	Marginal
6	Lizard Tail Playa	**Yes**	Negligible	No
7	North Swansea Bench	No	High	Marginal
8	East Playa	**Yes**	Negligible	Yes
10	Swansea Dunes	No	Low	Yes
11	Swansea Shoreline	No	Medium	Yes
12	Upper Swansea Dunes	No	Medium	Marginal
13	Keeler Dune Alluvial (North & South)	**Yes**	Low	Yes
14	North Sand Sheet	**Yes**	Negligible	Yes
15	Keeler Shoreline Saltgrass Meadow	No	Medium	No
16	Keeler Shore Dunes	No	High	Marginal
17	Keeler Dunes	No	Low	Yes
18	Upper Alluvial	No	Low	No
19	Keeler Dune – Vegetated Strip	No	Medium	Yes
20	Keel Shoreline - Old Outflow	No	Medium	Marginal
21	Keeler Dune – Vegetated Dunes	No	Medium	Marginal
24	Keeler Shoreline - Dense Vegetation	No	High	No
26	South Alluvial - Dense Vegetation	No	High	No
28	South Keeler Upper Mesa	No	Low	Yes
29	South Keeler Upper Shoreline	No	High	No
31	Swansea Dunes Sand Alleys	No	Negligible	Yes
32	South Shoreline Playa (like #8)	**Yes**	Negligible	Yes

In the final step the output data from SWEEP were characterized in the form of a 3-parameter sigmoidal curve (non-linear) regression yielding a mathematical relationship between wind speed and potential sand flux for all polygons that had sand motion under wind speed conditions up to 28 m/s. The mathematical curves took the following general equation:

$$SF = \frac{a}{\left(1 + \exp(-(WS - X_0)/b\right)}$$

where *SF* is the estimated hourly horizontal sand flux (kg/m), and *WS* the hourly average wind speed (m/s), and *a*, *b*, and X_0 parameters determined from the regression curve. The parameters for each of these equations were implemented in the next modeling step (see "Sand Motion Modeling"). Example curves are shown in Figures 3 and 4.

Modeling Refinements

Two additional refinements were added to the sand motion model. First a seasonality factor was applied to those polygons consisting of salt crusts. The seasonality was added to reflect the observation that salt crusts on the Owens Lake playa tend to harden up in the summer time and become less emissive (or alternatively non-emissive) relative to the winter and spring. To reflect this seasonality, for a subset of polygons (Table 2) summertime sand fluxes estimated using the SWEEP-based sand motion relationship were divided by a factor of two. This scaling factor was based on a statistical comparison of sand fluxes of all playa-based sand motion monitoring sites on the north sand sheet between the dust season (November through May) and non-dust season (all other months) over the 2000-2001 period (July 2000 through June 2001).

A second refinement consisted of the application of a factor quantifying the probability that playa surfaces are emissive under given wind speed conditions. If the sand flux versus wind speed curves would be implemented for every hour at that wind speed, one would have to assume that for every hour out of the year with a given wind speed above the sand motion, the play would be emissive. However, through the District's extensive sand flux monitoring network, this is known not to be the case.

To account for the frequency that a surface is actually emissive under a specific wind speed, a probability that sand motion occurred at a given wind speed was derived over all sand motion monitoring sites on the north sand sheet from July 2000 and June 2001 (pre-dust control). For example, at a 12 m/s wind speed, for only 20 percent of the hours, significant sand motion was observed, whereas at an 18 m/s wind speed, about 90 percent of the hours showed significant sand motion. The probability of showing sand motion under a specific wind speed was regressed using the same mathematical relationship as between sand flux and wind speed (see above) and applied in the sand motion modeling to the curves for each polygon.

Figure 3. Comparison of Modeled and Observed Sand Fluxes on Two Playa Polygons

Shown are observed playa sand fluxes (gray circles), and two SWEEP-based sand flux curves.

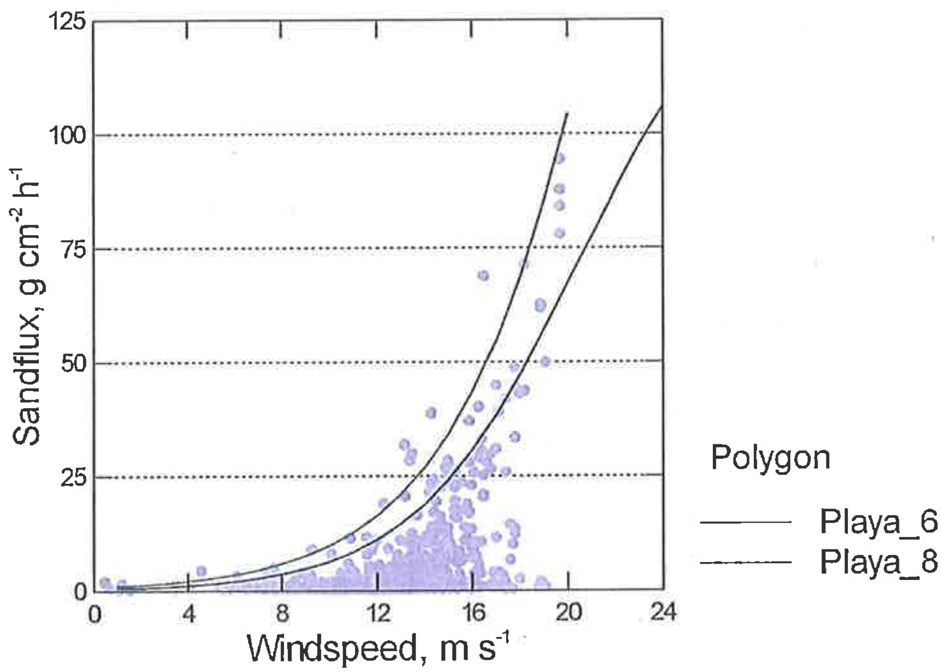
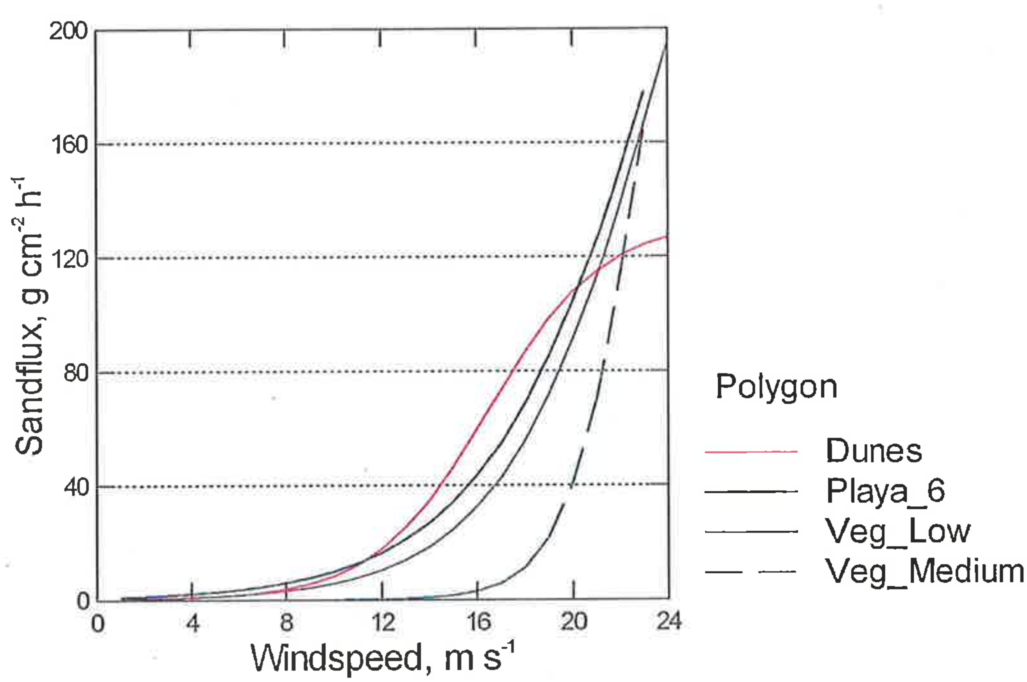


Figure 4. Examples of Sand Flux Differentiation by Surface Type

Shown are (example) sand flux dependencies of wind speed (x-axis), surface type (solid curves), and vegetation density (brown, solid curve vs. green, dashed curve).



Sand Motion Modeling

Modeling Domain

Figure 5 shows the sand flux modeling domain used for this analysis. The domain is 15-kilometers by 5-kilometers, rotated 45 degrees from the north in order to more efficiently sample active sand areas of the lake. This rotation also aligns the long axis of the domain to the predominate northerly wind direction. A 125-meter grid spacing was used for this grid.

Wind Field Extraction

Five years (7/1/2006-6/30/2012) of CALMET wind field data from the Great Basin's Dust ID program were used for this analysis. CALMET was reconfigured and re-run to generate wind fields on a 250-meter resolution grid in the northeast quadrant of the Owens Lake area surrounding the modeling domain as shown in Figure 5. The lowest level CALMET winds (10 m) were extracted for each hour and node. All nodes in or adjacent to the model domain were rotated 45 degrees, with a corresponding addition of 45 degrees to the wind direction. The rotated wind data were then imported to a MATLAB programming environment for the actual modeling. The x- and y- unit vectors were calculated for each hour. Then the wind speed and unit directional vectors were interpolated to the 125-meter sand modeling domain. An example wind field after processing is shown in Figure 6 for a large westerly event on March 30, 2010, hour 12.

Sand Motion Calculation

For each hour and node, the hourly sand flux was calculated based on the nodes' soil type and wind speed. The base equations were:

$$SFx = SF * P * S * Ux$$

and

$$SFy = SF * P * S * Uy$$

where *SF* is the SWEEP sand flux equation in mass per unit length, *P* is the probability function, *S* is the seasonality parameter, and *Ux* and *Uy* are the unit direction vectors. The net change in sand (Q_i) within the cell is given by:

$$Q_i = \{-abs(SFx) - abs(SFy) + SFx_{adj} + SFy_{adj}\} * W$$

where SFx_{adj} and SFy_{adj} are the incoming sand fluxes from adjacent cells, and *W* is the width of the cell (125 meters). Thus, accumulation occurs when the net sand flux into the cell is greater than the net sand flux out, due to effects like surface, vegetation, and wind gradients.

Figure 5. CALMET and Sand Modeling Domains

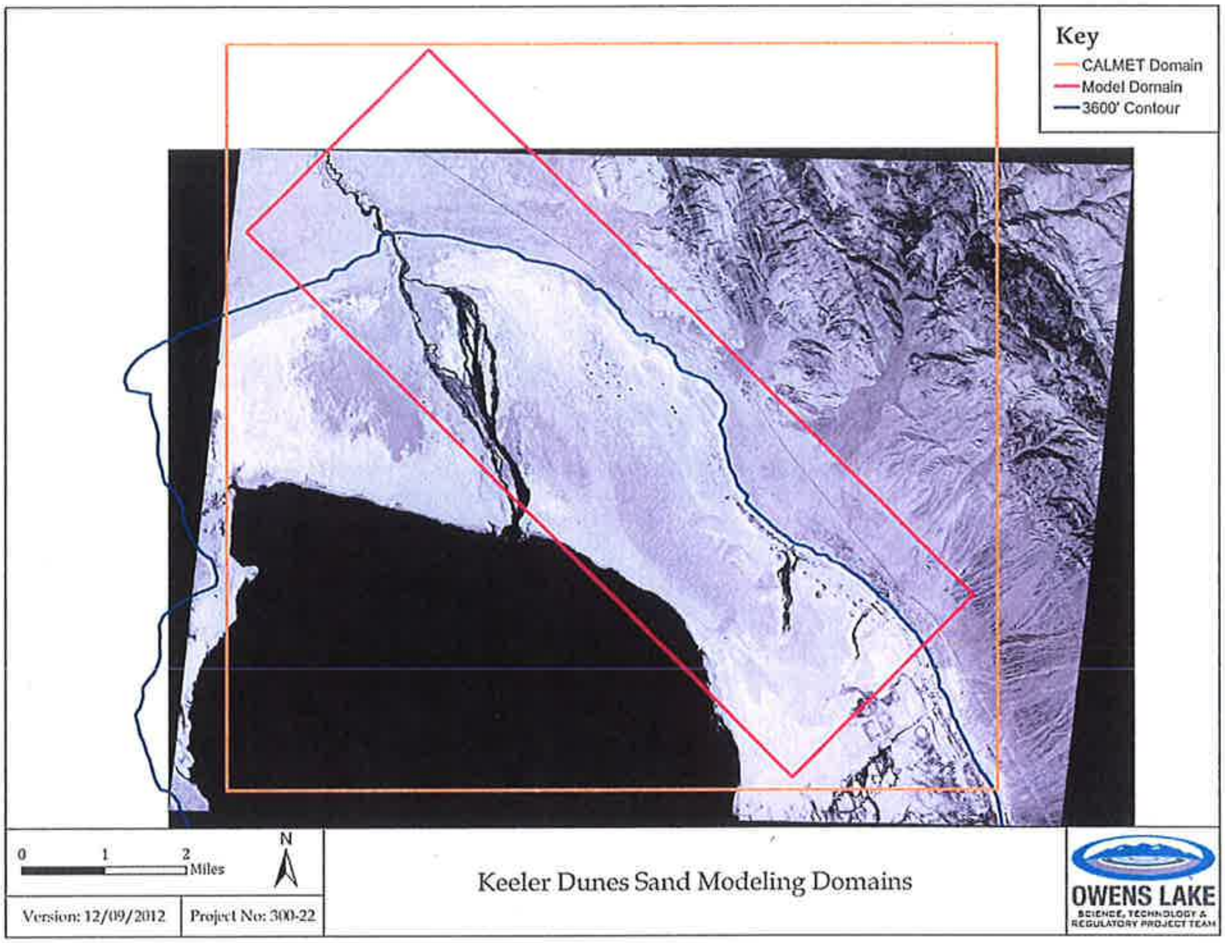
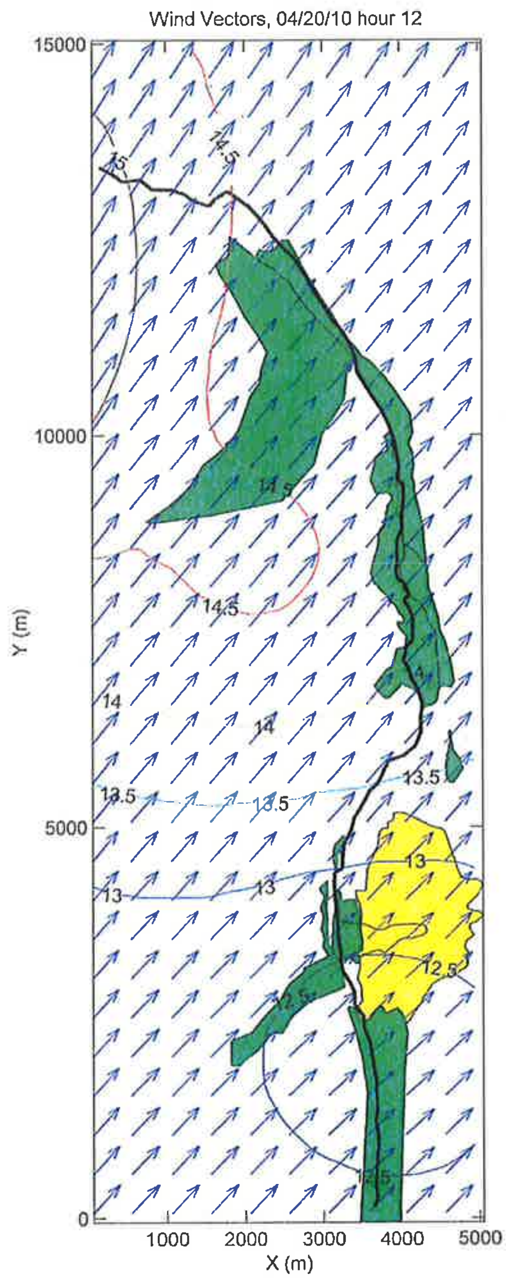


Figure 6. Example Wind Vectors and Wind Speed Contours for a Southerly Wind on April 20, 2010, Hour 12

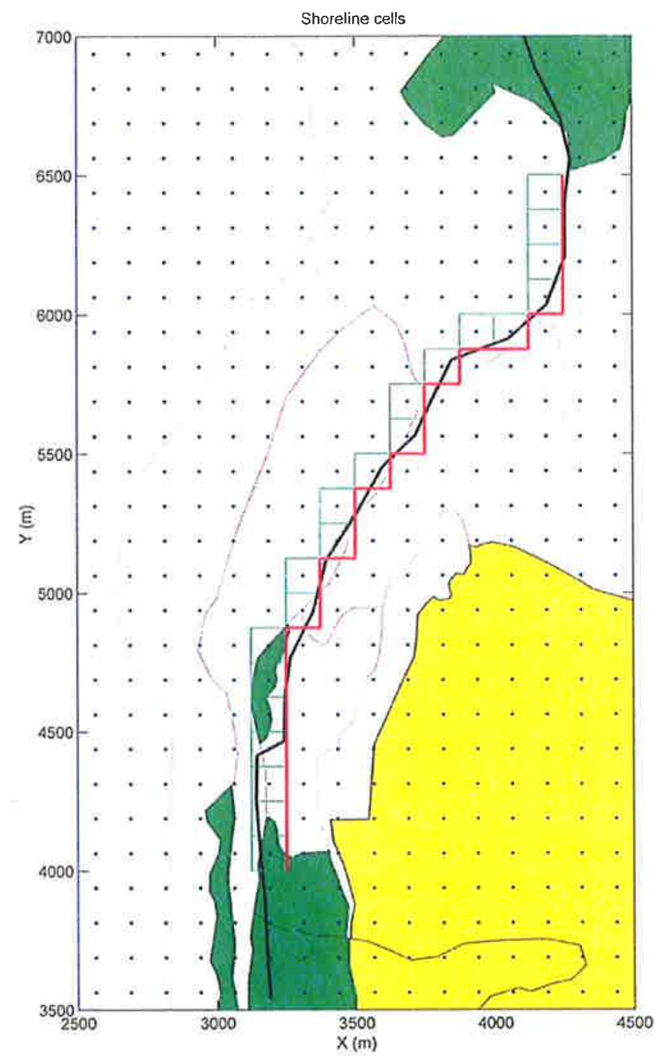
Only every fourth wind vector is shown. Sink areas are in green, Keeler Dunes are in yellow, and the shoreline is the black line. Contour levels are wind speed.



Of particular interest is the amount of sand leaving from the playa and entering into the Keeler Dunes area. Figure 7 shows a series of shoreline cells used to evaluate the sand flux between the lake and the Keeler Dunes area. The fluxes along the red line are tallied to indicate the amount of sand passing between the playa and shore.

Figure 7. Shoreline Cells used to Evaluate Sand Fluxes Between the Playa and Keeler Dunes

Blue points are cell nodes, green boxes are shoreline cells, the red line identifies the faces for determining sand flux between playa and shore, the black line is the shoreline, the green areas are sinks, the magenta lines indicate boundaries of soil types, and the yellow area is the Keeler Dune region.



Results

Wind field modeling indicates that the primary sand-moving wind directions are to the north-northwest and south-southeast. Figure 8 shows the north, south, and net sand flux vectors around the Keeler Dune area overlaid on a 1970 serial photograph. Dune formation on the North Sand Sheet is along this north-northwest wind primary wind direction and not toward Keeler Dunes. Thus, this south-moving sand was likely trapped in the dune structure and not likely to migrate back up to the Keeler Dunes. The figure also indicates that sand entering from the playa to the Keeler Dunes shoreline would likely be coming from the immediate Swansea Bay and alluvial area rather than distant locations (e.g., the Delta area).

Figure 8. North, South, and Net Sand Flux Vectors for the North Sand Sheet and Keeler Dunes Areas

Every fourth vector is shown. The length of the vector indicates the relative magnitude of the sand flux.

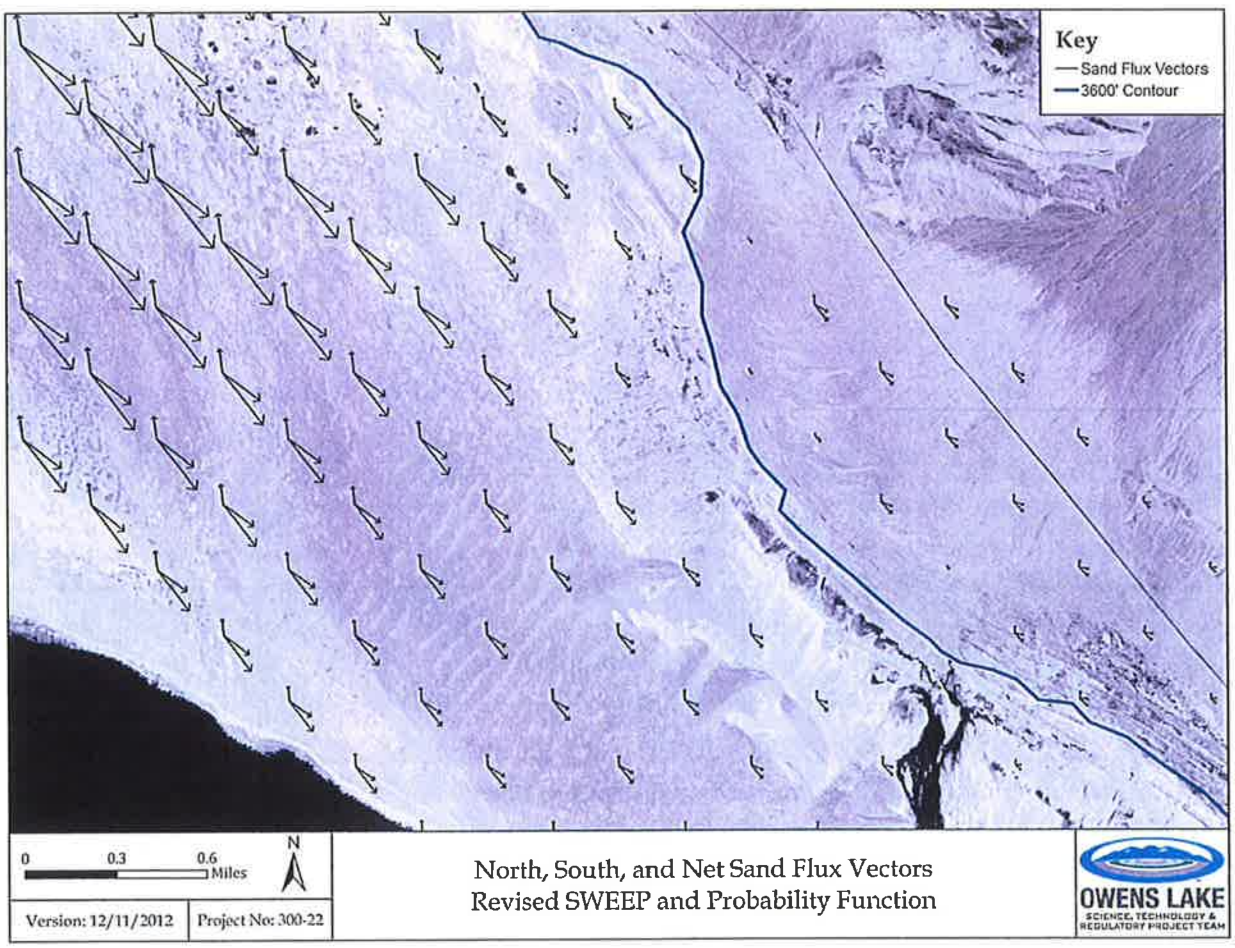


Table 3 shows the sand fluxes leaving the lake from the Keeler Dunes shoreline and the net overall sand flux. The table shows more sand coming from the playa than blowing back from the area above the shoreline. Thus, there would be modest dune accumulation along the shoreline, with highest value in the Swansea area. The District estimates that there was approximately 600,000 m^3 of sand in the Keeler Dunes area. This analysis indicates that the amount of sand entering the dune region from the playa is insufficient to account for the Dune mass, based on the current soil and vegetation conditions.

Table 3. Sand Fluxes at the Keeler Dune Shoreline: Crossing from the Playa, Crossing from the Keeler Dunes Area, and Overall Net

Sand Flux	Average Mass per Shoreline Cell in 5 Years (kg/m)	Average Volume per Shoreline Cell in 5 Years (m^3/m)	Total Volume in 70 Years* (m^3/m)
From Playa	4,207.1	2.6	96,631.4
From KD Area	1,047.6	0.7	24,062.0
Overall Net	3,159.5	2.0	72,569.4

* Volume per cell = Average Mass per cell/(SD *1000), where SD is sand density of 1.6 g/cm^3.

** Total Volume = Volume per cell * number of cells (21) * width of cell (125 m)