# Sand Transport and Dust Reduction Measures within and near the ODSVRA to Reduce 24-hour Average $PM_{10}$ Concentrations at the CDF Ambient Air Quality Monitoring Station in San Luis Obispo County, CA

**J.A. Gillies[*] and V. Etyemezian[**], Division of Atmospheric Sciences, Desert Research Institute, Reno[*] and Las Vegas[**], NV**

**C. Dugan, TRA Environmental Sciences, Inc., Menlo Park, CA**

**Prepared for California State Parks, OHMVR Division, Sacramento, CA**

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**Draft Proposal:**

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The Off-Highway Motor Vehicle Recreation (OHMVR) Division of California State Parks, the California Air Resources Control Board, and the San Luis Obispo (SLO) County Air Pollution Control District (APCD) have identified reducing the number of days that exceed the U.S. EPA's 24-hour average $PM_{10}$ National Ambient Air Quality Standard (NAAQS) at the SLO County APCD's CDF ambient air monitoring station as a priority action for Spring 2014. This proposal provides the initial context and outline for such priority action and will be refined as Spring 2014 approaches.

## Proposed Action and Schedule

The OHMVR Division proposes a phased approach to dust control in Spring 2014. Beginning April 1, 2014, the OHMVR Division would commence with the first of up to three 30-acre dust control projects in regions identified given the background information and dust control considerations summarized herein. These regions are identified as Region 1, 2, and 3, respectively (see Figure 1). Initially, the OHMVR Division would proceed with 30-acres of dust control in Region 1. If this initial dust control project does not demonstrably reduce $PM_{10}$ concentrations to levels below the standard at CDF , the OHMVR Division would proceed with a second, 30-acre treatment in Region 2, and then a third, 30-acre treatment in Region 3 (if necessary). This phased approach would enable the OHMVR Division to ascertain the incremental effect of specific dust control measures on the CDF site, which will aid in future dust control efforts.

Dust control Region 1 is generally located in the northern portion of the Oceano Dunes SVRA open riding and camping area (the La Grande tract area). The OHMVR Division anticipates the dust control area would likely be in-line with or east of existing vegetation islands (e.g., between South BBQ flats and Heather vegetation islands, if feasible). The OHMVR Division would design the dust control treatment to provide required dust control effectiveness while supporting use of the treatment area for OHV training or other limited OHV activity. Dust Control Region 2 is generally located east of the Oceano Dunes SVRA open riding and camping area, in the Oceano Dunes SVRA buffer area (this land is leased from Phillips 66). Dust control Region 3 is also located east of the Oceano Dunes SVRA open riding and camping area, but on private lands. The OHMVR Division would require authorization from private landowners to proceed with dust control on these areas.

Each dust control project would use artificial dust control materials to achieve a sand transport control of a minimum of 50 percent. The means to achieve the sand flux reduction and the range of dust control that accompanies this reduction in sand flux will be described later in the proposal. Dust control measures would remain in place until June 30, 2014. The OHMVR Division would monitor wind speed, wind direction, sand flux, and $PM_{10}$ concentrations (with an E-BAM) upwind and downwind of each control project.

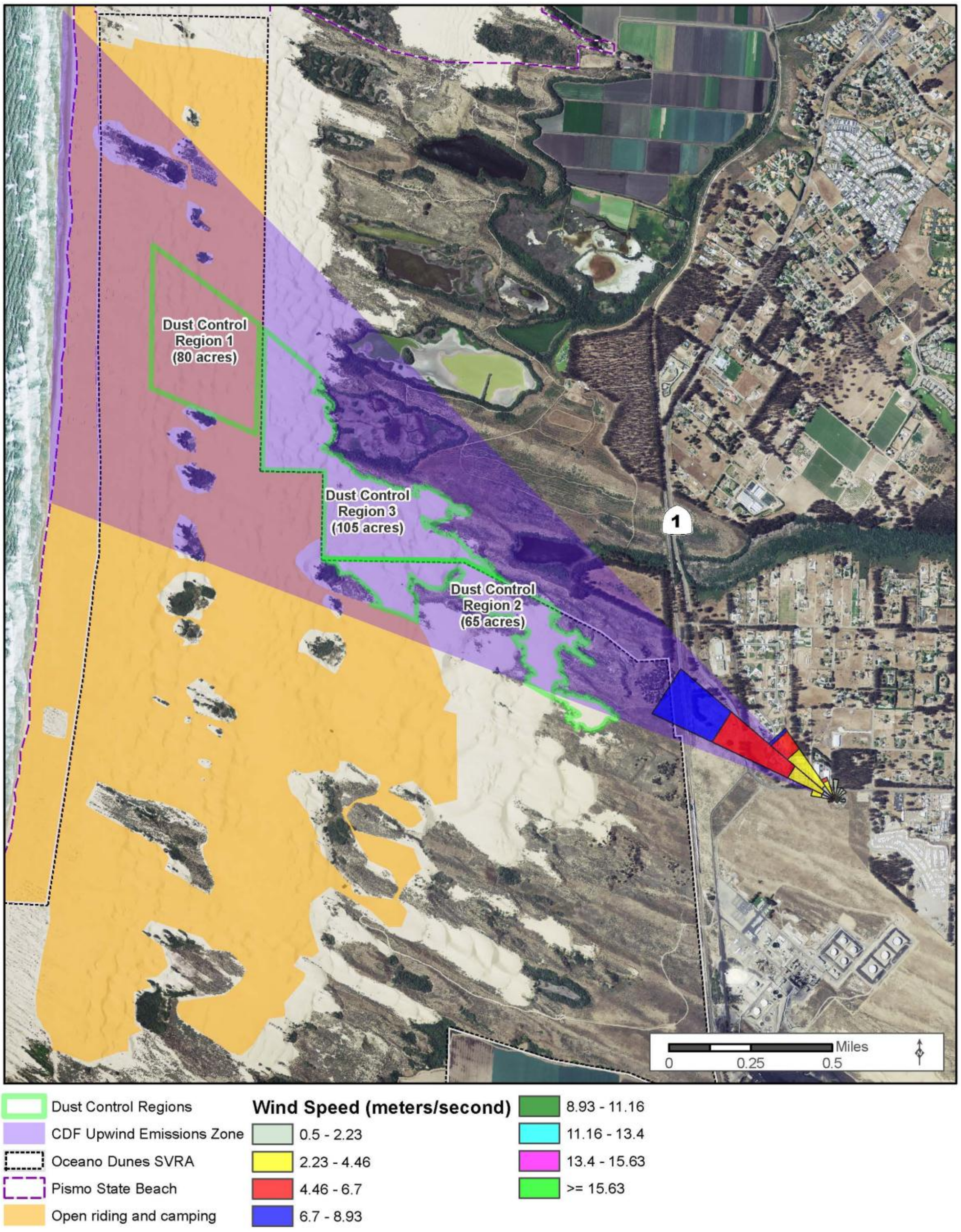

**Figure 1** Proposed 2014 Dust Control Regions

*Oceano Dunes SVRA Draft Dust Control Proposal*

TRA ENVIRONMENTAL SCIENCES, Inc.

**Pertinent Background Information**

The CDF site is located at 2391 Willow Road, Arroyo Grande, CA 93420 (Fig. 1). The site began operation in 2010 and is operated by the SLO County APCD (Air Quality System ID 06-079-2007). Since it began operation, the CDF site has recorded a 24-hour average $PM_{10}$ concentration above the U.S. EPA's PM10 NAAQS of 150 micrograms per cubic meter (µg $m^{-3}$) six times. Table 1 summarizes these events.

**Table 1 Days When CDF Recorded 24-Hour Average $PM_{10}$ above the NAAQS (150 µg $m^{-3}$)**

| Day | 24-Hour Average $PM_{10}$ Concentration µg $m^{-3}$ |
|---|---|
| May 23, 2012 | 186 |
| May 24, 2012 | 167 |
| June 8, 2012 | 163 |
| April 8, 2013 | 158 |
| May 22, 2013 | 169 |
| September 25, 2013 | 162 |

Source: CARB Air Quality and Meteorological Information System

The 24-hour averages recorded at CDF were between 8 and 36.5 µg $m^{-3}$ above the NAAQS[1]. Half of the days that exceeded the NAAQS occurred in May (three out of six); nearly 85% (five out of six) occurred from April to June. As shown in Equations 1 and 2, the average 24-hour average for the six days listed in Table 1 is approximately 168 µg $m^{-3}$, or 12% higher than the NAAQS.

$$\frac{(186.5+167.1+163.9+158.0+169.2+162.2)}{6} = 168\ \mu g\ m^{-3} \qquad (1)$$

$$\frac{167.8}{150} = 1.1 \qquad (2)$$

Preliminary resultant wind data available for CDF from CARB's Air Quality and Meteorological Information System (AQMIS) indicates prevailing winds at CDF during these days were generally from the west-north-west and north-west, centered around 300° 40 percent of the time and 315° 17 percent of the time (Fig. 1). This prevailing wind pattern is generally consistent with data from the CDF site for periods when hourly concentrations exceed 50 µg $m^{-3}$ (Fig. 2; DRI 2013). During these periods, the prevailing winds pass over approximately 750 acres of open sand under the control of the OHMVR Division (approximately 600 acres) and private land owners (approximately 150 acres).

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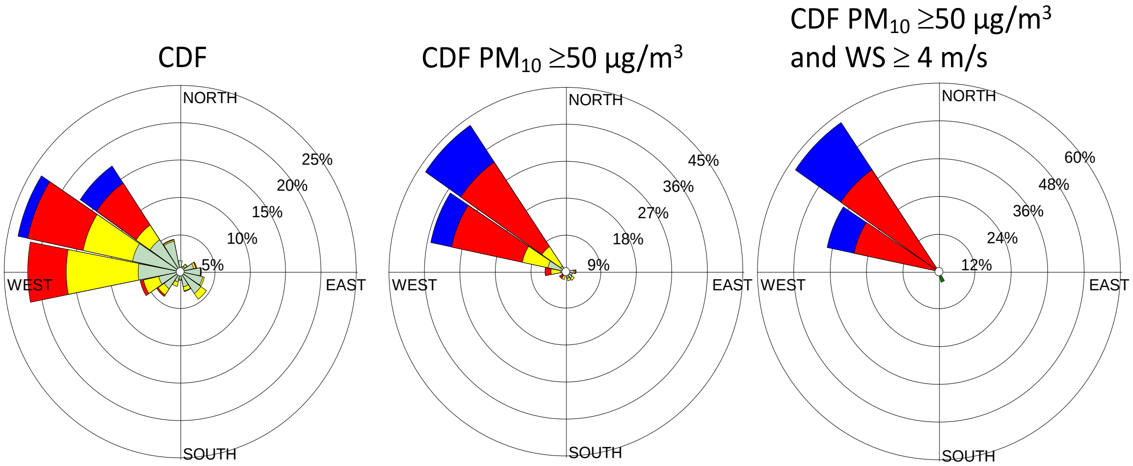
[1] The U.S. EPA PM10 standard is attained when the number of days per calendar year with a 24-hour average concentration above 150 µg/$m^3$ is less than or equal to one. 40 CFR, Part 50, Appendix K defines the term "exceedance" to mean a daily value that is above the 24-hour standard after rounding to the nearest 10 µg $m^{-3}$. For the purposes of this proposal, however, it is assumed the target 24-hour concentration to be achieved at CDF is 150 µg $m^{-3}$.



CDF

CDF $PM_{10} \geq 50$ µg/m$^3$

CDF $PM_{10} \geq 50$ µg/m$^3$ and WS ≥ 4 m/s

**Figure 2**. CDF wind pattern and wind patterns related to $PM_{10}$ and defined wind speed.

## Dust Control Considerations and Effects on Ambient Concentrations at CDF

For the purposes of determining where to attempt action that has the highest potential to successfully control dust such that 24-hour average $PM_{10}$ concentrations at the CDF site remain below 150 µg m$^{-3}$, it is important to note that each individual acre of open sand does not contribute equally to the ambient $PM_{10}$ concentration measured at CDF for several reasons.

First, the area must be exposed to winds capable of initiating and sustaining the sand transport process. If all other factors are equal, areas exposed to stronger, more frequent winds generate more $PM_{10}$ than areas exposed to weaker, less frequent winds. Figure 2 indicates there was a pronounced directional component to the wind on the six days CDF exceeded the $PM_{10}$ NAAQS (winds were from approximately 292° to 307°, with little variation (on the order of 10°) during the windiest periods). Thus, this upwind area should be the focus of Spring 2014 dust control actions.

Second, if all other factors are equal (e.g., wind speed, particle size distribution), then areas with higher emission potential would contribute more $PM_{10}$ than areas with lower emission potential. Preliminary data indicate sand transport may be initiated at lower wind speeds in the northern portion of the Oceano Dunes SVRA open riding and camping area (the La Grande tract area) likely due to the particle size distribution of the sand (i.e., shift to smaller mean grain diameter), which is located approximately 300° upwind of CDF. This can be taken into consideration as part of the developing suite of information to guide in the prioritization for areas to receive dust control.

Third, if all other factors are equal, areas closer to CDF may contribute more to measured $PM_{10}$ concentrations than areas farther away from CDF. Due to the nature of dispersion in which pollutant concentrations decrease as the pollutant moves downwind or away from its source, the sources areas closest to the CDF site may substantially contribute to ambient $PM_{10}$ concentrations even if they have a lower emission potential that sources farther upwind. Similarly, sources farther away from CDF may require a greater degree of control (i.e., installing more effective controls or controls on more acres) in order to produce a noticeable effect on measured $PM_{10}$ concentrations, even if such sources have a higher emission potential. Finally, it is important to note that if an uncontrolled emitting surface capable of producing ambient concentrations of $PM_{10}$ at CDF greater than 150 µg m$^{-3}$ is present between a dust control project and CDF, then additional controls would be needed to satisfy priority action objectives. The relative effects of emission strength and dispersion to affect source areas closer to or further away from CDF will be discussed and considered as part of this proposal.

There is an important distinction between sand flux an dust emission. Sand flux refers to the amount of sand-sized material (nominally 75 µm and larger) that is transported across a boundary on the ground in a given period of time. It is often quantified using passive collection devices that allow sand grains to enter them and fall into a hopper. The contents of the hopper are later weighed and related to the period of time that corresponds to the sand grain collection. Dust emissions are more directly related to $PM_{10}$ and air quality issues. These are suspendable particles (nominally 0 – 30 µm) that are small enough to leave the ground for extended periods and can be transported distances of hundreds to thousands of meters. In a dune environment, when winds increase above a certain threshold, sand grains begin to roll and bounce along the surface; it is unusual for dust sized particle to be directly suspended by wind to any appreciable degree. When sand grain motion becomes sustained, the ballistic impact of sand returning to the surface serves to eject dust-sized particles into the air, where they can remain entrained for long periods (hours – days). Thus, sand flux and dust emission are very closely linked, but they are not necessarily related linearly.

As described above, prevailing winds generally pass over approximately 750 acres of open sand located upwind of CDF. From Table 1 and Eq. 2 it is known that 24-hour average $PM_{10}$ concentrations were approximately 12% higher, on average, than the $PM_{10}$ NAAQS on days when the NAAQS was exceeded at CDF. Based on accepted theory (Shao, 2000), the relationship between sand flux (Q) and dust emissions (F) is non-linear with sand flux ($F \alpha aQ^b$, with b=3). The maximum expected reduction based on theory will be that dust emission reduces in a non-linear relationship as well. Thus, in theory, if all other factors were equal, a 12% reduction in sand transport in the upwind source area that impacts the CDF site for west-north-west and north-west winds could reduce $PM_{10}$ concentrations measured at CDF by more than 12%, thereby reducing the potential for CDF to record a 24-hour average $PM_{10}$ concentration above the NAAQS on most days; however, the actual non-linear effects of dust control on the CDF site cannot be established with certainty *a priori*. Therefore, a good starting point would be to assume a linear relationship between sand transport and $PM_{10}$ concentrations at CDF, i.e., controlling sand transport on 12% of the upwind sand area could achieve a minimum 12% reduction in $PM_{10}$ concentrations recorded at CDF. This could require up to 90 acres of dust control in Spring 2014. The reduction in dust flux associated with a reduction in sand flux will be described in more detail later in the proposal as well as the assumptions used to estimate this relationship for the ODSVRA.

## Evaluating Sand and Dust Flux Controls for Use at ODSVRA

There are several components that go into an estimate of how much $PM_{10}$ concentrations at CDF may be reduced when specific control measures are applied at some locations upwind of CDF and within the ODSVRA. These pertain broadly to how effective different controls will be under different wind and soil conditions and what the influence of a specific location is on the receptor (CDF in this case). In the former case, estimates of control effectiveness from prior work can be used to determine a range of effectiveness for a given configuration. In the latter case, the effects of atmospheric dispersion on the emissions from a source must be considered. In many ways, this latter component is associated with more uncertainty than our understanding of control effectiveness using surface roughness. We begin by discussing these components separately and then combine this information into several control scenarios that can be assessed for feasibility, desirability, and other factors. Key assumptions are summarized as part of this discussion. Some suggested routes forward are provided in a final section. These are not recommendations for the choice of management practice, but are intended to provide guidelines on how to proceed with the chosen implementation method.

Within the time constraints to implement a control strategy to reduce sand flux and the accompanying dust emissions by Spring 2014, two methods are proposed: sand fences and engineered roughness arrays. This approach, i.e., using roughness to provide control, as opposed to chemical treatment or other techniques that require greater infrastructure or are associated with greater risk, can be relatively quickly implemented, is known to have had at least a temporary impact on reducing sand flux and dust emissions at the Oceano Dunes and elsewhere, is largely reversible, and is reasonably compatible with the OHV riding activities that occur at the ODSVRA.

Although not perfect, there exists an empirical understanding of the impact of increasing the density of the array elements on the reduction of sand flux compared to what they would be in the absence of such elements (Gillies et al., 2006; Gillies and Lancaster, 2013). Some assumptions are needed to arrive at a similar relationship between the density of roughness elements and the reduction in dust emissions – ultimately the purpose of these controls.

In order to gain some understanding of how effective reducing sand flux will reduce the accompanying dust emissions it was necessary to use data obtained from sand dunes at a different location that related sand flux directly to dust emission. Nickling et al. (2000) carried out a series of large-scale field wind tunnel measurements of sand and dust emission at several dune field sites around Owens Lake, CA. The assumption for comparability with the ODSVRA dunes is that the dunes at Owens Lake are similarly $\geq$98% sand (particle diameter 75 µm), with the $PM_{10}$ reservoir lying in the 2% of the mass that is <75 µm. The relationship between dust emission (F) and sand flux (Q) combining two dune areas at Owens Lake as measured by Nickling et al. (2000) is shown in Fig. 3.

To use this relationship at ODSVRA required some knowledge of the range of sand flux for a range of wind speeds. The data from Gillies and Lancaster (2013) provide sand trap measurements for 15 transport events at the ODSVRA during the Pilot Study of 2011 (Lancaster et al., 2011). The critical measurements are those made upwind of the roughness array. These single height (0.15 m) measurements of sand mass collected in the BSNE style traps (Fryrear, 1986) for known durations of transport events are converted to sand flux by applying the normalized flux versus normalized height measurements for a sand surface reported by Gillies et al. (2013). The estimates of sand flux for the ODSVRA Pilot project data are very similar to the sand fluxes generated in the wind tunnel testing of Nickling et al. (2000) providing good confidence that they are realistic and allow application of the Owens Lake F vs. Q relationship (Fig 3) to estimate dust emissions at the ODSVRA as a function of sand flux.

With a means to generate estimates of dust emission (F) as a function of sand flux (Q) will allow for estimation of the effectiveness of different engineered roughness elements and sand fences to reduce dust emissions. To bound the potential for engineered roughness and sand fences to control sand flux

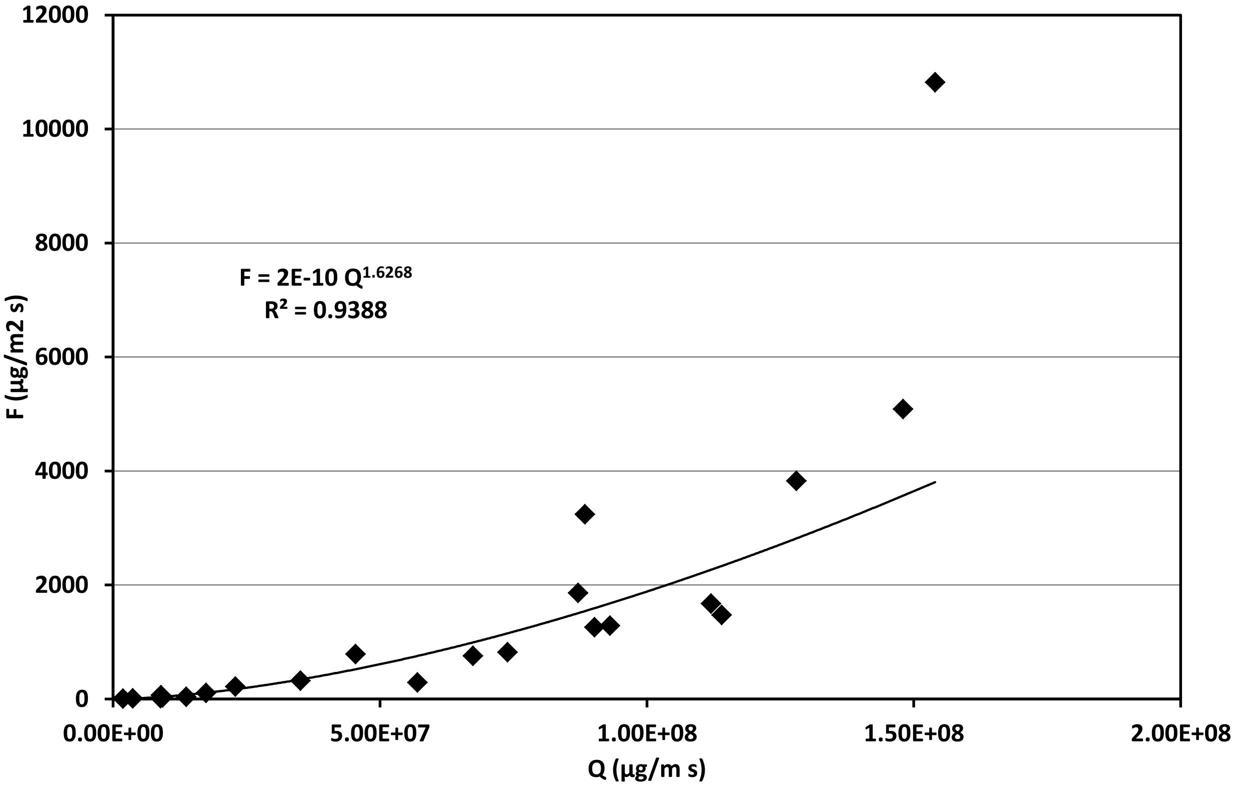


**Figure 3**. Wind tunnel derived relationship for dust emission and sand flux at sand dunes above the historic shoreline of Owens Lake, CA (after Nickling et al., 2000).

and reduce dust emissions three scenarios are used: 1) for a percent reduction in sand flux there is an equivalent reduction in dust emission, 2) the emission of dust as a function of sand flux is represented by the relationship shown in Fig. 3, and 3) the emission of dust scales as flux of sand raised to the third power (Shao, 2000).

## Sand Fencing to Reduce Dust Emissions

In order to evaluate how sand fencing influences dust emission we make use of the relationship of Mulhearn and Bradley (1983) that shows the reduction in shear velocity in the lee of a porous (50%) fence can be defined by the Eq.:

$$\frac{u_{*lee}}{u_*} = 0.201 \ln(NDD) + 0.429 \qquad (3)$$

where $u_{*lee}$ = the shear velocity at positions downwind of the fence, $u_*$= the shear velocity without the fence present, and NDD = normalized downwind distance (distance downwind of fence/fence height). For a threshold shear velocity we assume the typical value for fine sand of 0.3 m $s^{-1}$ ($u_{10m}$=7.8 m $s^{-1}$). Eq. 3 indicates that $u_{*lee}$ will return to the value of $u_*$ at NDD≈15. For a 4 foot high sand fence this will be at 60 ft. (18.3 m). The effectiveness of sand fences to reduce sand flux for fences placed at 6H, 8H, 10H, and 15H can be evaluated based on how far past the fence the shear velocity reaches threshold and the mean shear stress in the zone that extends to the point of full recovery (i.e., $u_{*lee}/u_*=1$). We assume here that sand flux scales as a function of $u_{*lee}$ and $u_*$ based on the data of Nickling et al. (2000) (Fig. 4).

Assuming the ODSVRA sand surface is exposed to a $u_*$ range from 0.3 m $s^{-1}$ to 0.8 m $s^{-1}$ ($u_{10m}$=7.8 m $s^{-1}$ to 20.8 m $s^{-1}$) the amount of sand flux reduction for the four fence spacings and the accompanying dust emission is summarized in Fig. 5. This figure shows that over this assumed wind speed range, a sand fence array (perpendicular to the sand transporting wind) with a downwind spacing of 6H will reduce dust emission between 79% and 99% due to the associated reduction in sand flux and accounting for the area behind the fence that does not exceed threshold. For a 15H fence array, the predicted dust emission reduction is between 63% and 91%. The relationships presented in Fig. 5 suggest that a fence spacing of less than 10H provides little additional benefit considering the increase in resources required. For example, reducing the fence spacing from 15H to 8H improves the dust control effectiveness for an equivalent area from between 60 %– 90 % to between 80 % - 99% (or improves by 1.1- 1.25 times) depending on the assumptions used, but it would require twice the material. We recommend here that an array of sand fences to be placed into the 30 acres designated for control have a maximum spacing of 15H. This analysis does not take into account that there may be a synergistic effect associated with multiple rows of fencing due to un-accounted for aerodynamic effects (shear stress partitioning) similar to those associated with bluff-body roughness effects on wind (Gillies et al., 2007) that may increase the effectiveness to an even greater degree.

To treat one (square) acre (63.61 m × 63.61 m) would require four lengths of fence 63.61 m (208.71 ft) spaced 18.3 m (60.04 ft) apart. 30 acres would require 7633.8 m (25,045.3 ft) of fencing. This may need to be adjusted based on the actual height dimension of the fence.

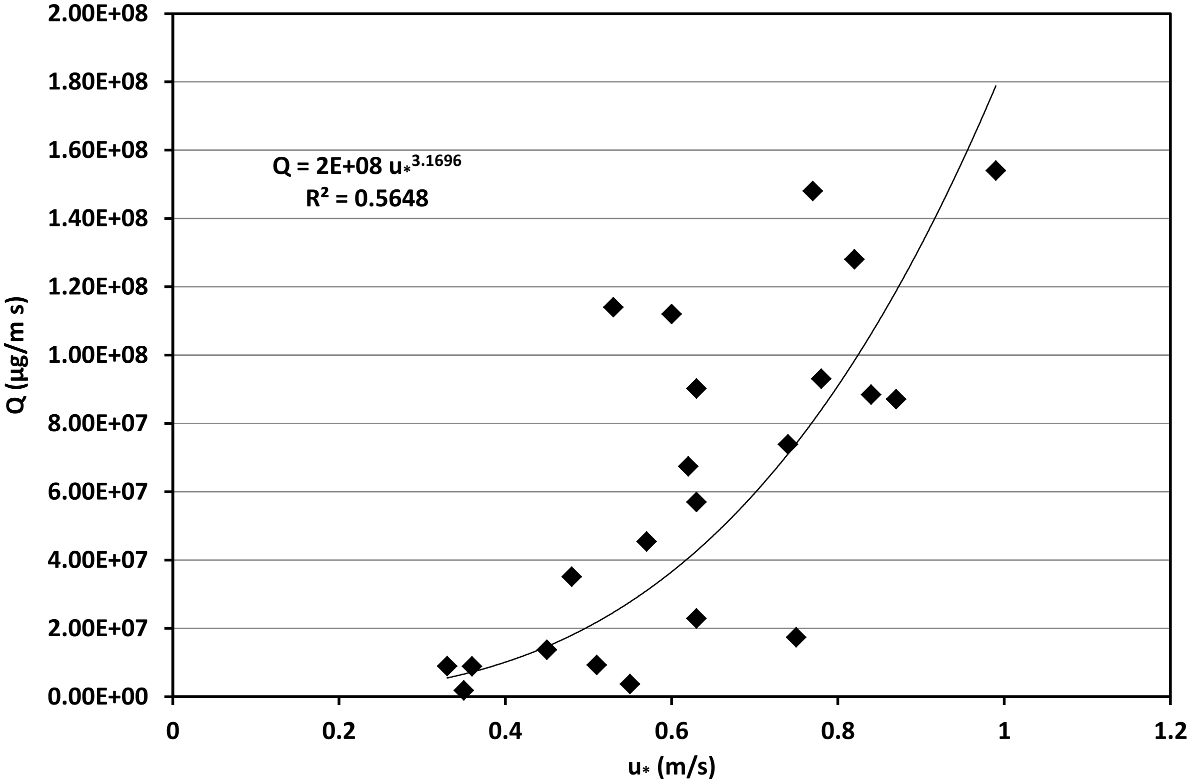


**Figure 4**. Wind tunnel derived relationship for sand flux and $u_*$, Owens Lake CA (after Nickling et al., 2000).

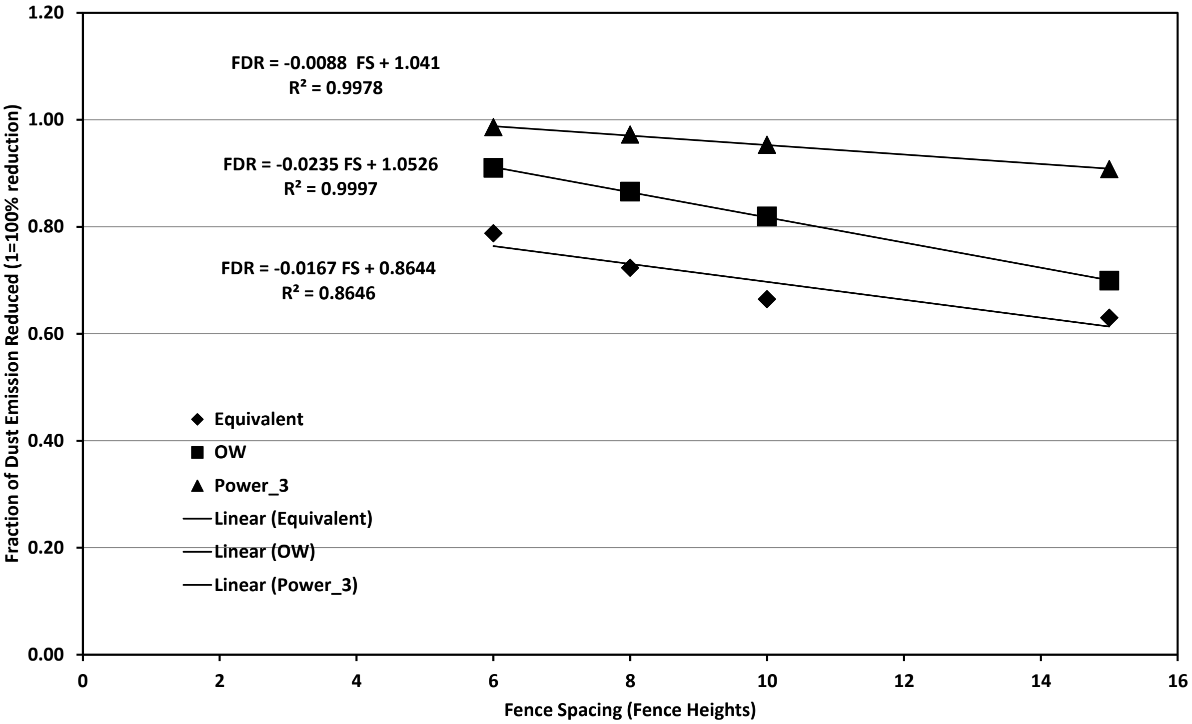


**Figure 5**. Fraction of dust emission reduced by fence spacings of 6H, 8H, 10H, and 15H assuming the three scenarios for the relationship between F and Q.

## Engineered Roughness to Reduce Dust Emissions

The basis for developing a strategy to reduce sand flux and the accompanying reduction in dust emissions is based on the observed relationship between roughness density (λ=# elements×element frontal area/total area containing the elements) and saltation (i.e., sand) flux:

$$NSF = 0.0003 \times \lambda^{-1.894} \qquad (4)$$

which is based on data presented by Gillies and Lancaster (2013) and a new data point for the Keeler Dunes Dust Demonstration project (Gillies et al., in preparation) (Fig. 6). Eq. 4 is used to predict the reduction in sand flux based on the λ of an engineered roughness array for elements approximating the size: 1.12 m long, 0.38 m high, 0.6 m in width (i.e., straw bale dimensions for bales used at the Keeler Dunes Dust Demonstration Project, Keeler, CA, [Gillies et al., in preparation]). The reduction in dust emission that accompanies the reduction in sand flux is estimated using the same three scenarios used for the sand fence effectiveness calculations. The range of expected dust emission reduction as a function of λ is shown in Fig. 7.

We suggest that if engineered roughness is to be used the target sand flux reduction be NSF=0.5, which corresponds to a λ of 0.02. Based on the relationships presented in Fig. 8, the range of accompanying dust emission reduction is estimated to be 50% to 88%. This translates into 189 elements (straw bales) per acre (spaced center-to-center and row-to-row at 4.8 m). For a 30 acre treatment the total number of elements required is 5670. This would need to be adjusted based on the actual dimensions of the available roughness elements.

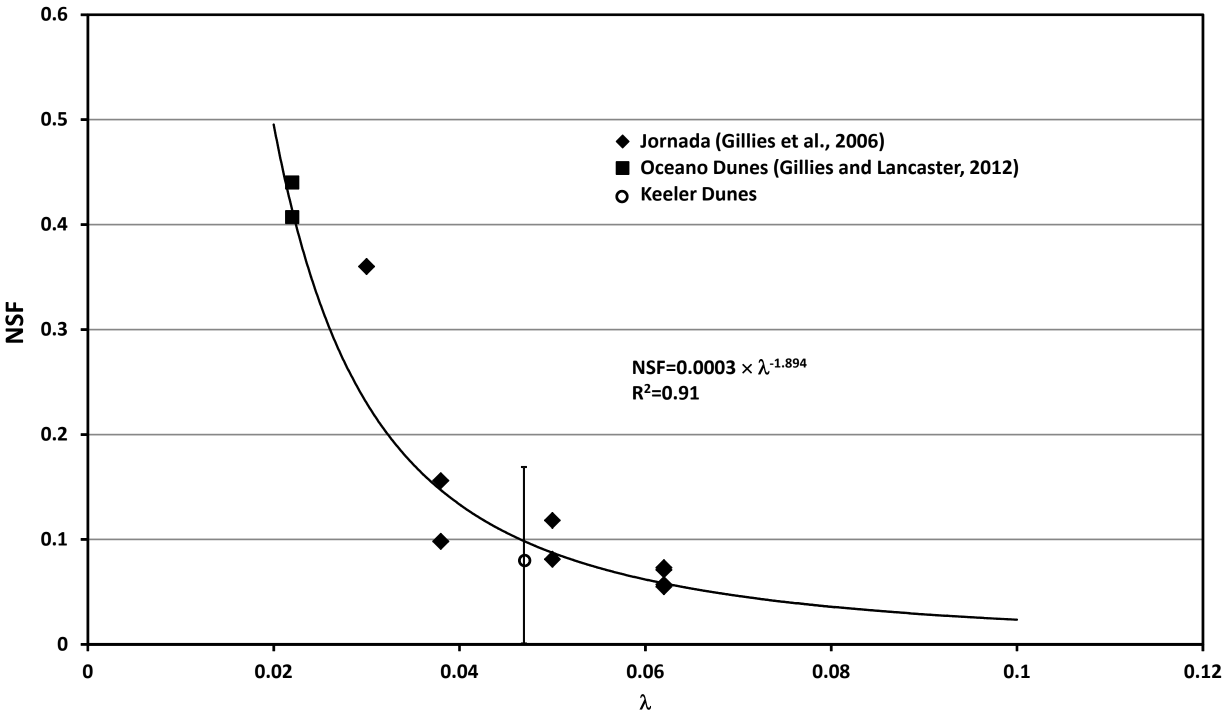


**Figure 6**. Relationship between normalized sand flux and λ (Gillies et al., in preparation).

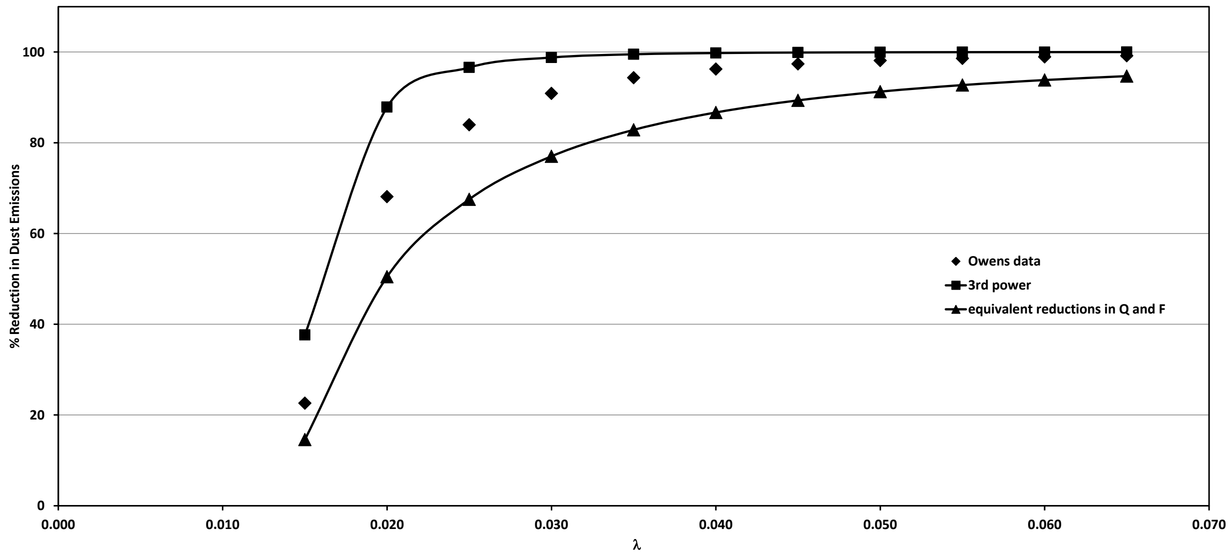


**Figure 7**. Modeled reduction in dust emission as a function of λ assuming the three scenarios for the relationship between F and Q.

## Impact Factor of Controls

The location of controls at the ODSVRA can have a critically important role in the potential for reduction in $PM_{10}$ dust concentrations. This role could be equal to or greater than the magnitude of emissions that are controlled. In the extreme case, 100% control effectiveness could be achieved on an area that is comparatively very prone to dust emissions, but this will hardly register a measureable reduction in dust concentrations at a receptor site because the receptor site will not be substantially influenced by the area that was controlled.

The temporary monitoring effort conducted in spring and summer 2013 indicated that even when examined on an hour by hour basis, on days with high winds, dust concentrations within the ODSVRA all rise in response to high winds at the same time and thus are very highly correlated. This high degree of correlation between monitoring sites at the ODSVRA precluded the possibility of identifying which locations of the ODSVRA exhibit dust concentrations that are most correlated with those measured at CDF. Therefore, concentration data alone cannot be used to infer the contribution of a certain region (e.g., Region 1) to concentrations measured at CDF.

Some information from the temporary monitoring effort can be used to bound the degree of dilution that dust concentrations undergo after exiting the ODSVRA en route to CDF. This relies on examining two cases and comparing estimates of dispersion with results of air quality modeling. In one case, we assume that all of the dust that is measured at CDF originates from the La Grande tract. The relationship between monitoring location T2C (located at the fence-line on the western riding area boundary of La Grande) and CDF indicates that the dust concentrations at CDF on high dust days are 0.21 of those measured at Location T2C. If all of the dust at CDF is from the La Grande tract, then we can roughly state that there is a factor of five dilution over the distance between the end of La Grande and CDF (≈3 km).

Similarly, if we assume that all of the dust at CDF comes from the area near the eastern park border (within Region 2) then a factor of three dilution (comparing T3C to CDF) is accomplished over a distance of ≈1.5 km, if it is assumed that the area within this region is equally emissive everywhere. If it is assumed that this area is only emissive up to T3C then there is factor of three dilution over a distance of ≈2.2 km. AERMOD modeling that was conducted on a preliminary basis suggests that if all areas were equally emissive, the relative contribution from a source area that is 4 km upwind is 40% of a source area that is 2.5 km upwind. This suggests a factor of 2.5 dilution over a distance of 1.5 km.

Rather approximately then, the characteristic distance of decay (d_decay, or distance required for a reduction of approximately 1/3) is ≈2 km. The relative impact of contribution along a direction can be: estimated as:

$$e^{(-d\_source/2)} \qquad (5)$$

where d_source is distance (km) between CDF and a source area. Returning to the three regions, the distance to the mid-point of each region and the estimated relative impact factor are given in Table 2. The third column in the Table can be interpreted as an impact factor in relative terms. The fourth column of Table 2 shows spatially averaged PI-SWERL measured emissions at 3000 RPM. Data available from La Grande were used for that region (1). For Region 2, the emissivity was assumed to be the same as measured west of T3C. This back dune location has been off-limits to riders and shares similar topography with the western “tongue” area. Region 3 is somewhat more difficult to characterize as there are no PI-SWERL tests from that area. To the west of Region 3, lies the Le Grande tract with comparatively high emissions potential (0.90 on a relative scale). However, in the longest east-west fetch region (Transect 3) it appears that emissions potentials dramatically decrease past the point of the

Le Grande tract fence-line (down to a relative value of 0.25). The topography of Region 3 is a mixture of what is seen in Le Grande and what is seen in the back dunes of the tongue. Thus, in the absence of additional information, it is reasonable to assume that the emission potential there can span the range exhibited by the two other regions. This adds substantial uncertainty about the actual impact of controls implemented in Region 3 on concentrations of $PM_{10}$ at CDF.

The final column of Table 2 (product of columns three and four) can be interpreted as an overall, relative impact factor for controls at the three different regions. Recognizing that this analysis is necessarily approximate, if the underlying assumptions are correct (see limitations), then we can state roughly that for an equally-sized area, a comparable level of control in Region 1 provides about 50% more dust reduction than if implemented in Region 2. Similarly, it is possible that controls in Region 3 would have somewhere between 0.5 – 1.5 times the impact of controls in Region 1. The wide range is due to the difficulty in determining if relative emissions in this region are more similar to what they are in the La Grande Tract or if they are more similar to what they are in the western tongue.

**Table 2**. Estimates of the relative impact of $PM_{10}$ emissions from the three identified regions that could receive control measures on $PM_{10}$ measured at CDF.

| Region | d_source (km) | Relative impact using Equation 5 | Relative emissions at $u_* = 0.55$ m/s | Multiplier for control (rel. emission × rel. impact) |
|---|---|---|---|---|
| 1 (La Grande) | 3.8 | 0.15 | 0.90 | 0.13 |
| 2 (area outside of the riding area, furthest east) | 2.0 | 0.38 | 0.25 (assumed same as main tongue region) | 0.09 |
| 3 (East of La Grande, partial tongue) | 3.0 | 0.22 | 0.25-0.90 (assumed range lies between Region 2 [i.e., 0.25] and Region 1 [i.e., 0.90]) | 0.06-0.20 |

## Limitations

There are considerable uncertainties as to the actual performance of the proposed dust control measures for reducing the dust that impacts the CDF site and reduce the 24 hour average $PM_{10}$ concentration to <150 $\mu g\ m^{-3}$. The limitations of the analysis and simple modeling that guided the decisions that form the basis of this proposed control plan are described in this final section.

1. If the arc of likely influence of wind direction is not correctly defined, there is a possibility that controls emplaced will have no measurable results on dust concentrations at CDF. To minimize the likelihood of this happening, it is best to emplace controls along the centerline of the wedge defining the zone of expected influence as shown in Fig. 1.

2. The assumptions used to develop the basis for evaluating potential control effectiveness of modulating sand transport under the influence of sand fencing is based on known physics of how the wind responds to the presence of the fence, but not on measurements of what actually happens to the sand flux.
3. The estimation of effectiveness of sand fencing to reduce sand flux does not consider that large arrays of multiple sand fences create a synergistic effect that is greater than extending the results that have only considered what may happen behind a single fence to a larger fence array.
4. The lack of sand flux measurements made at multiple heights above the surface during sand transport at the ODSVRA required that we estimate the range of sand flux (for a small area of the ODSVRA) by applying a known vertical flux profile for a sand surface to previously acquired single height measurements of sand flux at ODSVRA.
5. A lack of measurements of dust emission as a function of sand flux for the ODSVRA resulted in the need to seek this type of data from other sources. The data used were from sand dunes, but not coastal dunes that are used for off-road vehicle activity, and there may be textural differences in the silt and clay components that strongly influence the dust emissions. The particle size distribution of the sand is also not likely the same as the sand at the ODSVRA. $PM_{10}$ from saltation process is the only source considered, other sources may contribute but these remain un-quantified.
6. To bound the relationship between sand flux and dust emission at ODSVRA we considered two other scenarios that are based on: 1) making a conservative estimate of equivalent dust emission reduction for a reduction in sand flux, and 2) applying the theoretical relationship that dust emission scales as a power function ($3^{rd}$ power) of sand flux. For both the theoretical assumption and the limitation described in point 5, there is also uncertainty associated with the choice of the constant terms used to generate emission estimates, in both cases it was assumed that the Owens Lake Dune data provided acceptable values.
7. We made use of the PI-SWERL data from the recently-completed Spring/Summer 2013 measurements, but extrapolated the results to areas where there is uncertainty in their representativeness, although a few measurements were made in close proximity to the area under consideration for control. Uncertainty for emission potential for Region 2 is likely reasonable (30%) because of similarity of that region to the area adjacent with measured emission potential data. The uncertainty for Region 3 is substantially greater.

**In our opinion the uncertainties associated with the enumerated assumptions are as follows:**

1) **1: error up to 100% (Why? No definitive data to define actual link from source to receptor)**
2) **2-7: error up to a factor of three (Why? Modest or very little data available, and extrapolated data used)**

## Conclusions

Based on the work presented here we offer the following suggestions for moving forward to the implementation phase:

- February 15, 2014 – Identify specific project areas within dust control regions 1, 2, and 3
- March 1, 2014 – Begin baseline wind, sand flux, and $PM_{10}$ monitoring at project areas
- April 1, 2014 – Install dust control project in Region 1
- As necessary – Install dust control project in Region 2
- As necessary – Install dust control project in Region 3

- June 30, 2013 – Remove dust control projects and monitoring equipment

It is suggested that Regions 1 and 2 be targeted first because their comparative impact is better known. Controls in Region 3 may have significant impact or they may provide comparatively little advantage. Region 1 provides the additional advantage that emplacing controls there first would allow assessment of some of the larger assumptions that are made in this analysis, including the very important question of how much winds carrying $PM_{10}$ from Le Grande influence CDF. This is why it is proposed to emplace controls there early on in the dust season.

**Citing controls**

The preceding is a conservative study of control options. Locations have been selected from maps without regard to local topography or setting (i.e., local topography will affect the ease or difficulty of applying controls). It is highly recommended that potential control installation sites be visited and documented for appropriateness as soon as possible.

**Monitoring**

Regardless of whether sand fences or roughness arrays are chosen it is strongly recommended that extensive monitoring accompany the installation of controls. Specifically, it is suggested that sites where proposed controls are to be emplaced should undergo base-line monitoring for sand flux, dust concentrations (upwind and downwind) and basic meteorology. CA Parks already owns the equipment necessary for monitoring, however, additional sand flux measurement instruments (e.g., Sensits or sand traps) will also need to be acquired. This should be implemented following the site selection process (see Citing Controls). This monitoring will allow for the collection of data to quantify the actual effectiveness of the control measures to reduce sand flux, and estimation of the sand flux reduction on $PM_{10}$ concentration (dust emission). The monitoring will provide very useful information to compare with the model estimates developed for this proposal and allow for improving the design of the control measures for subsequent dust control efforts.

**Phased in**

The “design” of the above control strategy hinges on many assumptions that may or may not hold to varying degrees (see Limitations). It is highly recommended that the installation of controls be phased in. A period of baseline monitoring during the windy season should be followed by installation of controls in one region only (say Region 1), several weeks of monitoring should follow before installation of controls in the next region. This will allow for adaptive management of resources if necessary.

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