Appendix C

Biological Resources Documentation

C.1 Sand Analysis

Effects of the proposed Thousand Palms flood control structures on the supply of sand-sized sediment to the aeolian sand transport system

Draft Final Report Prepared for
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Introduction

The purpose of the studies described in this report is to assess the effects of the proposed flood control structures in the vicinity of Thousand Palms, California on the supply and delivery of sand-sized sediment to the aeolian sand transport system that feeds the dunes and sand sheets that occur in the Coachella Valley Preserve (CVP) and Coachella Valley National Wildlife Refuge (CVNWR).

The proposed flood control structures have the potential to alter the delivery of sand-sized material to the sand dunes in the Coachella Valley Preserve (CVP) and Coachella Valley National Wildlife Refuge (CVNWR) by: (1) physically blocking natural sand transport pathways by water or wind; (2) changing the transport capacity of flood waters so as to change the volume of sand-sized sediment transported by water; and (3) affecting the location(s) of areas where this sediment is deposited, for subsequent entrainment and transport by wind. The physical blocking and immediate effect of the proposed flood control structures on wind transport of sand is addressed in the Phase II, Task 1 report. This report focuses on the broader impact of the proposed flood control structures on sand supply from alluvial sources and its redistribution by wind.

Study Area

The study area (Figures 1,2) is located south of the Indio Hills, CA and encompasses coalescing alluvial fans and areas of sand dunes that lie to the southeast. There are two major alluvial fan systems: (1) the Gravel Pit Wash fan, which lies to the north of the community of Thousand Palms; and (2) the Thousand Palms Canyon Wash fan, which lies east of Thousand Palms. Between these two alluvial fans are several smaller fans. Sediment is deposited on the alluvial fan surface and at the toe of the fans, where northwesterly winds transport sand-sized material to the dune area.

The aeolian sand deposition area largely lies within the CVP and CVNWR and comprises areas of dunes and sand sheets that cover a total area of 5.62 sq. miles. Within this, there are areas of active (mobile, un-vegetated or sparsely vegetated) dunes with an area of 0.9 sq. miles, surrounded by extensive partially vegetated sand sheets. Upwind (NW) of the main dune area is an area of partly vegetated sand sheets interspersed with areas of alluvial deposits (ponded silts and small channels) that extends to the toe of the Indio Hills alluvial fans in the vicinity of

Ramon Road. The dunes are extending to the southeast at rates of 11 – 20 m per year.

The zone that connects the alluvial fan and aeolian sand depositional area was designated as the "wind corridor" by Simons, Li, and Associates (SLA, 1997) – Figure 1. As wind action is not confined to this zone, it is more appropriate to designate the area that extends NW to SE from the toe of the alluvial fans to the dune area as the "sand transport corridor". The sand transport corridor is defined by the presence of sand sheets, coppice dunes (nebkhas), and areas of mobile dunes. In existing conditions, it is confined to the south by development (e.g. Classic Club Golf Course), the interstate highway and railroad corridor and to the southeast by the Sun City development. In historic conditions, the sand transport corridor likely extended to the south as far as the Morongo Wash. The northern margins of the sand transport corridor are defined by the toe of the alluvial fans – the Thousand Palms Canyon Fan to the NE and the Indio Hills fans to the NW.   Average width of the sand transport corridor is 5000 feet (1500 m) and the total length is 7.8 miles (13 km) in existing conditions.

Figure 1: Study area in existing conditions.

The proposed flood control structures in the project area comprise four reaches (Figure 2). Reach 1 is located on the upper-mid section of the Indio Hills alluvial fan, north of the city of Thousand Palms and extends in a SE - ESE (138 – 108°) direction for approximately 12600 feet. Reach 2 is located east of the developed area of

Thousand Palms and extends in a SE (138°) direction for approximately 2000'. Reach 3 is located southeast of Thousand Palms and extends in a SE (131°) direction for about 9200' before approximately following the SW boundary of the Coachella Valley Preserve and entering the Classic Club Golf Course. Reach 4 runs from the southern boundary of the Classic Club Golf Course along the southern boundary of the Coachella Valley Preserve at Avenue 38 for approximately 8000' to Washington Street where it joins existing flood control structures.

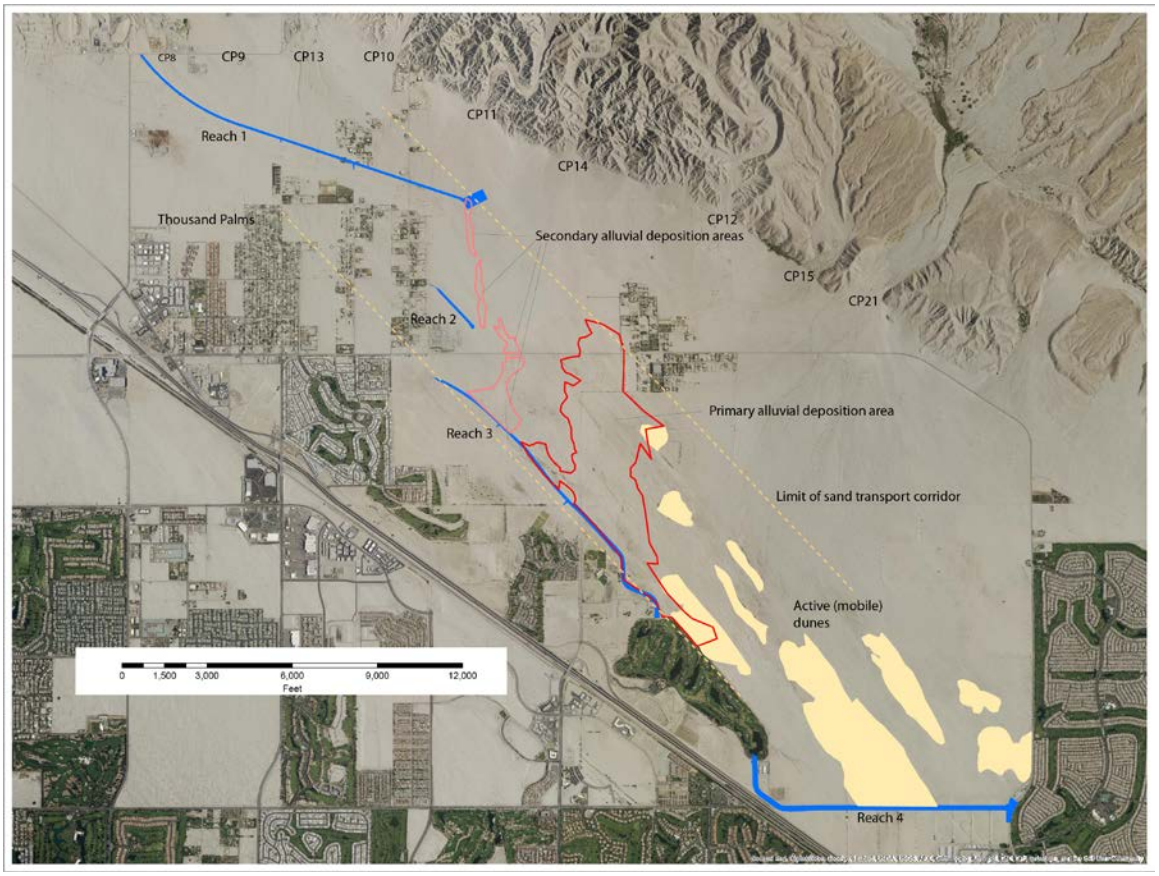

Figure 2: Study area in Project Conditions

Sediment supply

Sediment supply in this context is defined as the production of sediment of a size suitable for wind transport (Kocurek and Lancaster, 1999). The primary source of sediment for wind transport is the series of small washes than drain the Indio Hills, which are comprised of deformed sandstone and fanglomerate of Pleistocene age (Keller et al., 1982). In addition, the Thousand Palms Canyon drainage potentially supplies sand to the sand transport corridor and the CVP and CVNWR area.

Following Griffiths et al. (2002) the fluvial system in the Coachella Valley is comprised of ephemeral channels that deliver sediment from high relief, steeply sloping catchments in the mountains to coalescing alluvial fans (bajadas) downslope from the mountain front. The majority of sediment transport takes place during short-duration (flash) floods that occur after heavy rains in the mountain areas. Significant flood events that affected the study area have been recognized from historical reports and observations and aerial photographs. Major events occurred in January 1916; September 24, 1939; October 22, 1974; September 10 and 11, 1977; and March 1, 1991 (NHC, 2013).

The majority of sand-sized material is transported by stream flow as wash load, with a sediment concentration of 40% or less by weight (NHC, 2013). During flood events, sediment is entrained from hill slopes and channels in the headwaters of the catchments and transported in channels that pass through the bajadas. In extreme flood events, the water flow exceeds the capacity of the channels, and spreads out on the bajada surface, where sediment is deposited as discontinuous floodplain deposits. Sediment that passes through the bajada in the channelized flows is deposited on low-angle depositional areas at the toe of the bajada and on the valley floor. Most of the sediment transported as wash load is of small gravel to sand size, with a minor silt and clay component (Griffiths et al., 2002).

Several estimates of sediment yield from the Indio Hills and Thousand Palms Canyon have been made. Simons and Li & Associates (SLA) identified six drainage basins in the Indio Hills from US Army Corps of Engineers (USACE) hydrologic studies (Bechtel, 1997) and provided estimates of sediment yields and water discharge. Northwest Hydraulic Consultants (2004) provided a new estimate of sediment yields based on new hydrologic and hydraulic modeling. In 2013, Northwest Hydraulic Consultants updated their hydrologic and hydraulic modeling to use revised estimates of 100-year flood rainfall water depth from the NOAA Atlas 14. Parsons Brinckerhoff (PB 2013) developed an integrated model for alluvial sediment loading and transport. This analysis uses the PB (2013) dataset as it is the most recent available.

Nine watersheds contribute sediment to the Thousand Palms area. From west to east they are designated as CP8, 9, 13, 10, 11, 14, 12, 15, and 21, based on the USACE (2000) nomenclature (Figures 1 and 2). PB (2013) calculated sediment yields at the fan apex using Los Angeles District Corps of Engineers (LADCOE) methods, which were developed specifically for Southern California (Gatwood et al., 2000). Sediment yields are estimated using a multiple regression approach with precipitation, catchment relief and area, fire being the main independent variables and adjusted for local conditions. The PB model was forced using the maximum 1-hour precipitation or the 100-year runoff.

Estimated sediment yields from the PB modeling are given in Table 1.1. Total sediment yield from the watersheds is 601 acre-feet (741,322 cubic meters). The sediment yield results show that the majority (96%) of sediment contributed to the project area comes from two catchments: CP13 (Gravel Pit Wash) and CP21 (Thousand Palms Canyon wash).

Table 1.1: Sediment yield at fan apex (from PB 2013, Table 3)

Catchment		Area sq miles	Acre feet 100-yr debris yield	Acre feet 100-yr flow volume	Cubic meters 100-yr debris yield	Cubic meters 100-yr flow volume
CP8	Edom Hill	1.39	4.8	108.2	5921	133463
CP9		0.64	2.8	47.8	3454	58960
CP10		0.84	4	62.7	4934	77339
CP11		0.85	3.5	62.1	4317	76599
CP12		0.92	4.5	76	5551	93745
CP13	Gravel Pit Wash	7.33	45.5	574.1	56123	708142
CP14		0.87	3.9	82.5	4811	101762
CP15		1.24	6.5	111	8018	136916
CP21A	TPC	82.7	525.5	6190.7	648195	7636116

Table 1.2 Sediment reaching Project area

	acre feet Reach 1	Reach 2	Reach 3	2-3 area	Reach 4
CP8	4.8				
CP9	0.8				
CP10	1.1				
CP11	0.8				
CP12			1		
CP13	7.7				
CP14				0.2	
CP15			0.2		
CP21A			13.9		6.2
Total	15.2		15.1		0
	cubic meters				
CP8	1233				
CP9	987				
CP10	1357				
CP11	987				
CP12			1233		
CP13	9498				
CP14				247	
CP15			247		
CP21A			17145		0
Total	14062		18626		0

Hydrologic and sediment modeling by NHC (2004, 2013) and Shvidchenko et al., 2006) provides a clear picture of the distribution of floodwaters on the fans and the valley floor, verified by comparing the modeled water flow paths with those depicted on aerial photographs taken immediately after the 1977 flood event. In existing conditions, water and sediment from the western-most watersheds (CP8, 9, 13) is directed down-fan through the community of Thousand Palms towards the Morongo Wash. Water and sediment from watersheds CP10, 11, 12, 14, and 15 is directed south or southwest towards the upwind part of the sand transport corridor in the area of Ramon Road. A distributary channel of the Thousand Palms fan also routes water and sediment southwest to this area, although model results suggest that much of the flow on this fan is directed to the south and southeast, where it enters the dune area. Based on the above, and supplemented by geomorphic mapping (Figure 2), the area south of Ramon Road is designated as the primary sand deposition area for the onward transport of sand to the dune area by wind. This area covers approximately 0.75 sq. miles (1,942,491 m^2).

PB (2013) routed sediment from the fan apex to the project area in existing and project conditions using an integrated hydrological and sediment model and the Laursen (Copeland) routine to simulate flood flows into the area. Because water flow is attenuated and/or spread out on the fan surface, where sediment is deposited, the amount of sediment reaching the distal parts of the alluvial fan is a fraction of that at the fan apex (Table 1.2). The ratio between the sediment yield at the fan apex and the sediment transported to any point down stream (the non-dimensional sediment flux) decreases exponentially with distance from the fan apex (Figure 3).

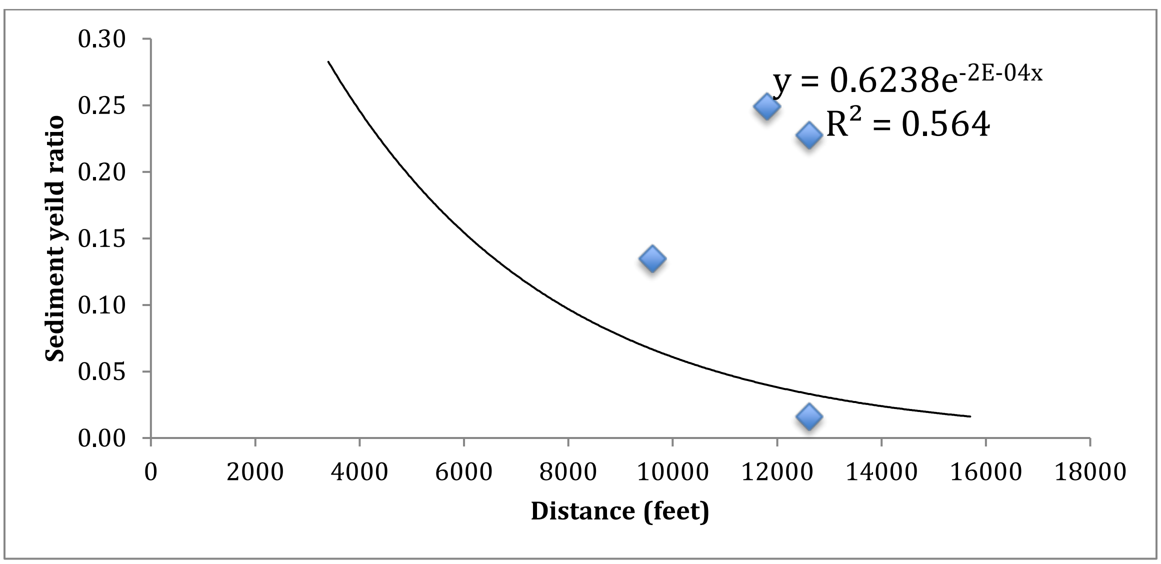

Figure 3: relationship between distance downslope and ratio between sediment yield at fan apex (CP) and sediment loading at any point. Data from PB (2013).

Existing conditions

The data from the PB (2013) modeling indicates that between 15.10 and 7.40 acre-feet (18626 to 9128 cubic meters) of sediment is transported to the primary deposition area in a flood event, based on the estimate of sediment reaching Reach 3 of the proposed project (PB Table 3). The range reflects the amount of sediment contributed from the Thousand Palms Canyon Wash depending on the assumed sediment routing on this fan. Assuming all of this sediment is deposited in the depositional zone, this sets an upper limit on the sediment supply to the wind transport system.

However, in existing conditions, a proportion of the sediment load is transported beyond the deposition area, so that the quantity of deposited sediment can be represented by the difference between the sediment load entering the depositional area and that reaching the location of Reach 3. The input sediment load is calculated from the relationship show in Figure 3. Based on these estimates, in existing conditions between 12.2 and 24.6 acre feet (15048 to 30367 cubic meters) is deposited within the primary depositional area for onward transport by the wind, assuming that PB Scenario A applies. This is equivalent to a layer of sediment 2 to 3 inches (5 – 8 cm) thick over the whole depositional area.

Additional sediment may be supplied for wind transport to the dune area from CP13 (Gravel Pit Wash) as well as CP8, 9, 10 in the area north (upslope) of Thousand Palms, but the aeolian sand transport pathway is blocked by development along Sierra del Sol, Desert Moon Drive, and Via Las Palmas.

Project Conditions

Table 2 shows the sediment budget under Project conditions, based on the PB modeling. The flood control structures on Reach 1 are designed to intercept water and sediment from watersheds CP8, 9, 10, 11, and 13, and divert it along the structure towards the east. As much as 9.2 acre-feet (11348 cubic meters) of sediment is trapped along this Reach, but 6.0 acre-feet of sediment (7401 cubic meters) exits the reach and is transported down fan towards Reach 2. Reach 2 is a zone of sediment deposition, as 6.9 acre-feet of sediment enters the reach and 4.4 acre-feet exits the reach. Approximately 50% of this sediment volume is deposited in the area between Reach 2 and 3, which is the northwestern part of the primary sand deposition area. In Scenario A, Reach 3 also receives substantial sediment input from CP 21 (77 acre-feet), resulting in deposition of sediment along this reach; but minimal amounts (0.8 acre-feet) of sediment under Scenario B.

Based on analysis of the PB (2013) sediment model output, it can be concluded that under Project conditions, an additional 2.2 acre-feet (2714 cubic meters) of sediment will be contributed to the primary deposition area from the washes north of Thousand Palms that are intercepted by Reach 1. This may be augmented by sediment transported by wind along Reach 1 following flood events.

Table 2: Sediment budget under Project conditions. Data from PB (2013).

	Inflow from upstream	Inflow from tributary watersheds	Sediment outflow	Net deposition (erosion)
Reach 1	0	15.2	6	9.2
Reach 1 -2	6	0.1	6.9	-0.8
Reach 2	6.9	0	4.4	2.5
Reach 2 - 3	4.4	0	2.2	2.2
Reach 3 A	2.2	78.2	35.1	45.3
Reach 3 B	2.2	0.8	3	0
In ST corridor				3.9
Reach 1	0	18749	7401	11348
Reach 1 -2	7401	123	8511	-987
Reach 2	8511	0	5427	3084
Reach 2 - 3	5427	0	2714	2714
Reach 3 A	2714	96458	43295	55877
Reach 3 B	2714	987	3700	0

Wind transport of sediment from deposition areas towards dune areas in the sand transport corridor.

Rates and volumes of sand transport by wind

There are no measurements of rates and volumes of sand transport by wind in the vicinity of the Project area. Rates of sand transport by wind have therefore to be estimated from wind data and compared to rates measured or estimated elsewhere in the Coachella Valley.

Short-term (several months) measurements of sand transport were made in the Whitewater River flood plain by Sharp (1964;1980) and analyzed by Williams and Lee (1995). Rates range from 0.26 to 4.4 kg/m/sec x 10^6 (1.0 to 6.5 pounds/foot/second x 10^{-6}). Weaver (1979) estimated rates of sand transport from CALTRANS sand removal records and predicted rates in the range of 1 to 5 cubic yards/foot/year (1.5 to 7.5 tons/foot/year or 2.5 to 12.54 m^3/m/year) for the area of Thousand Palms.

Potential sand transport rates may be calculated from wind speed and direction data using empirical equations for sand transport as a function of wind speed above the threshold for transport. Rates calculated in this way by SLA (1997) range between 3.52 and 10.52 tons/foot/year (7.25 to 21.72 m^3/m/year) using the Bagnold formula and 5.8 to 22.3 tons/foot/year (11.97 to 46.03 m^3/m/year) using the SLA procedure. The source of the wind data used by SLA in their calculations is not clear. This study utilized wind data from the CIMIS (California Irrigation Management System) stations at Cathedral City and Indio; and the ICAO weather station at Palm Springs Regional Airport. All data were downloaded from the California Climate Data Archive website (http://www.calclim.dri.edu).

Sand transport potential, also termed (sand) drift potential was calculated using the approach of (Fryberger, 1979) as modified by Bullard (1997) for use with wind speeds in meters per second.

$$Q = V^2 (V - V_t)^2 * t$$

Where Q is the sand transport potential in arbitrary units (VU), V is the wind speed, V_t is the threshold wind speed for transport at the height of the wind recorder, and t is the percentage of the time the wind is blowing from a given direction. Values of Q are calculated for each wind speed class and direction and summed to estimate a sand drift potential (DP). A vector sum sand drift potential (RDP) was also calculated. The annual magnitude of sand transport potential returned by the equation as vector units (VU), was converted to a volume per unit width per year using data from Figure 19 in Fryberger (1979) following Bullard (1997).

The sand transport potential (Qp) in cubic meters/meter/year is given by:

$$Qp = 0.0734\ DP(VU)$$

The volumetric sand transport potential was also converted to a mass transport rate using a bulk density of 1.33 tons per cubic meter.

The estimated threshold wind speed for transport was based on prior studies (e.g. Gillies and Lancaster, 2013), which for medium sand indicate a value of 7 m/sec (15.66 mph) at the standard ICAO measurement height of 10 m (32.81 feet).; and 5.8 m/sec at 2 m (6.6 feet) height, which is the height used by CIMIS instrumentation.

Table 3 summarizes the sand transport potential for the stations used. The dominant sand transport direction in all cases is from WNW to NNW (Figure 3) reflecting the strong topographic control on wind direction in the Coachella Valley. As noted by previous studies (e.g. Griffiths et al., 2002; Griffiths et al., 2009), wind strength and therefore sand transport potential decreases eastwards down the Coachella Valley. To estimate sand transport potential in the vicinity of the Project area, a linear decrease in sand transport potential between Cathedral City and Indio was assumed, so that the rate for the Thousand Palms area was estimated as 3.51 m^3/m/year (4.67 tons/m/year). These rates are comparable to those estimated by Weaver (1979), but generally lower than those calculated by SLA (1997).

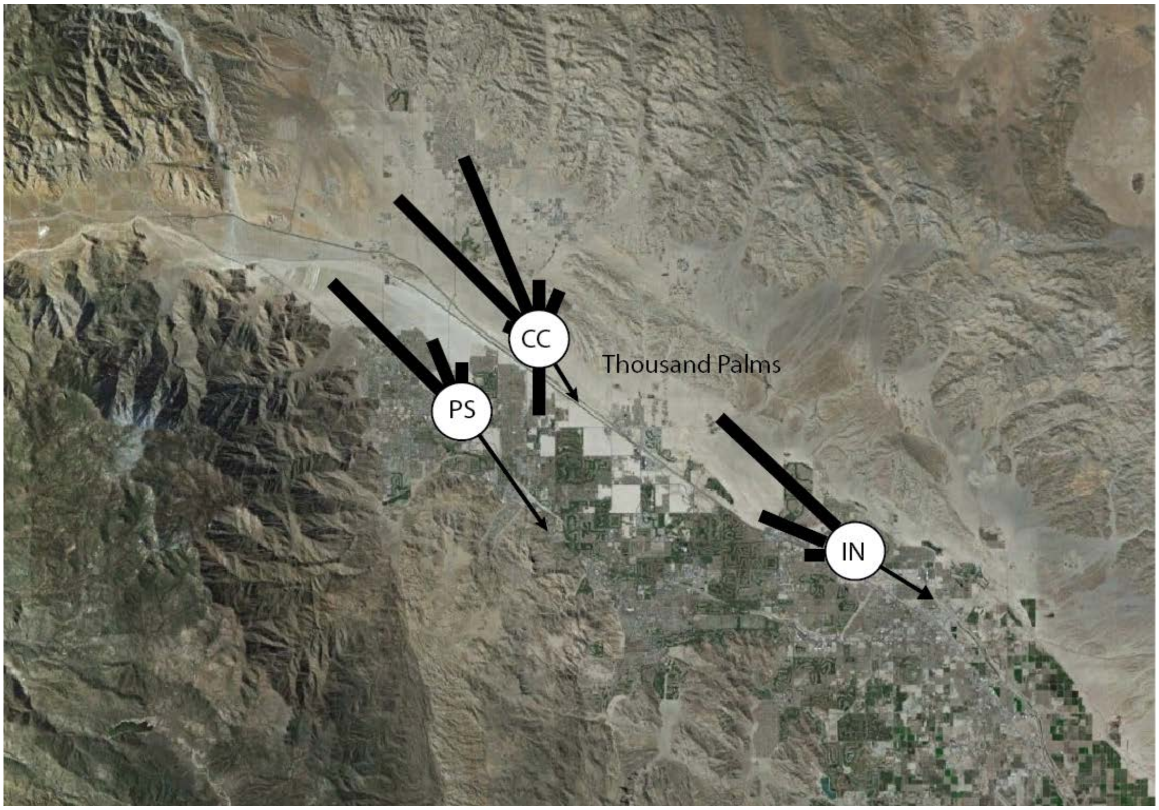

Figure 3: Sand roses for the Coachella Valley area. Length of rose arms is proportional to the percentage of annual potential sand transport *from* that direction. Arrow indicates resultant (vector sum) sand transport direction.

Table 3: Summary of sand transport potential

	DP (VU)	DP (cubic meters/m/yr)	RDP (VU)	RDP (cubic meters/m/yr)	Resultant direction (°)
Palm Springs Regional Airport	125	9.15	104	7.65	145
Cathedral City CIMIS	54	3.96	37	2.72	143
Indio CIMIS	45	3.3	41	2.99	126

Linkages between alluvial and aeolian sand transport systems

Given a width of 1700 m (5577 feet) for the sand transport corridor, and an annual sand transport potential of 3.51 $m^3/m/year$, a total of 5967 m^3 (7805 cubic yards) or 7936 tons could be transported from the primary fluvial deposition zone towards the dune area. This rate is significantly less than the 28,600 tons estimated by SLA (1997; Table 3.2). Both estimates assume that sand is uniformly available across the transport corridor.

As discussed above, deposition of alluvial sediment in the primary depositional area results in a layer of material 2 – 3 inches (5-8 cm) thick. Following Griffiths et al., 2002) the rate of sediment removal from the deposition area is estimated as:

$$Q_e = A^{0.5} . q_r$$

Where Q_e is the rate of removal, A is the area of entrainment, and q_r is the volumetric sand transport rate.

The time required to remove all of the sediment (T_{ed}) is defined as:

$$T_{ed} = V/Q_e$$

In existing conditions, all sediment deposited in the deposition zone (16 - 24.6 acre-feet (19736- 30367 cubic meters) could be removed in a period of 36 to 74 months at a rate of 3.51 $m^3/m/yr$.

In Project conditions, with a delivery of an additional 2.2 acre-feet (2714 m^3) of sand-sized sediment to the deposition area, all sediment could be removed in a period of 43 to 81 months.

The above estimates provide a approximation of the timescales required to redistribute material deposited by a 100-year flood event. They confirm that the aeolian sand transport system is supply limited, as proposed by prior studies, e.g. Lancaster et al. (1993), SLA (1996), and Griffiths et al. (2002) and that there is ample wind energy available to transport any and all sand supplied by the alluvial fan system.

Conclusions

Analysis of alluvial and wind sediment transport data indicates that the proposed flood control structures will have a positive effect on sand supply to the dunes and sand sheets that occur in the Coachella Valley Preserve (CVP) and Coachella Valley National Wildlife Refuge (CVNWR). The Project will increase sand supply by 9 – 14%, mainly as a result of the diversion of water and sediment to the east and southeast to the primary sand deposition area by the levee and channel of Reach 1.

Flood control structures in Reaches 2, 3, and 4, will have little or no effect on wind transport of sand, because they lie outside or downwind of the sand transport corridor. Additional sand may also be added to the system by clearing of sand deposited along the flood control structures.

The aeolian sand transport system is currently in a state of sediment supply limitation, so any additional sand supply will be transported downwind to the dunes. Addition of sand as a result of the proposed flood control structures will also increase the length of time taken to deplete the sand deposited by flood events by as much as 9 to 18 months.

The conclusions of this study reinforce those of prior studies of interactions between fluvial and aeolian sand transport processes in the Coachella Valley – that wind energy is more than sufficient to transport all sand that is supplied by fluvial processes.

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