Investigating Effects of the November 2004 High-Flow Release from Glen Canyon Dam on Aeolian Sand-Transport Rates in the Colorado River Corridor, Grand Canyon

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Archaeological site erosion/ preservation

- Archaeological sites built on fluvial, aeolian, slope-wash deposits; many preserved by subsequent aeolian deposition
- Erosion of cultural features believed tied to reduced sediment sources (loss of open sand bar area → less sand supply for aeolian deposits → deflation/erosion by wind)

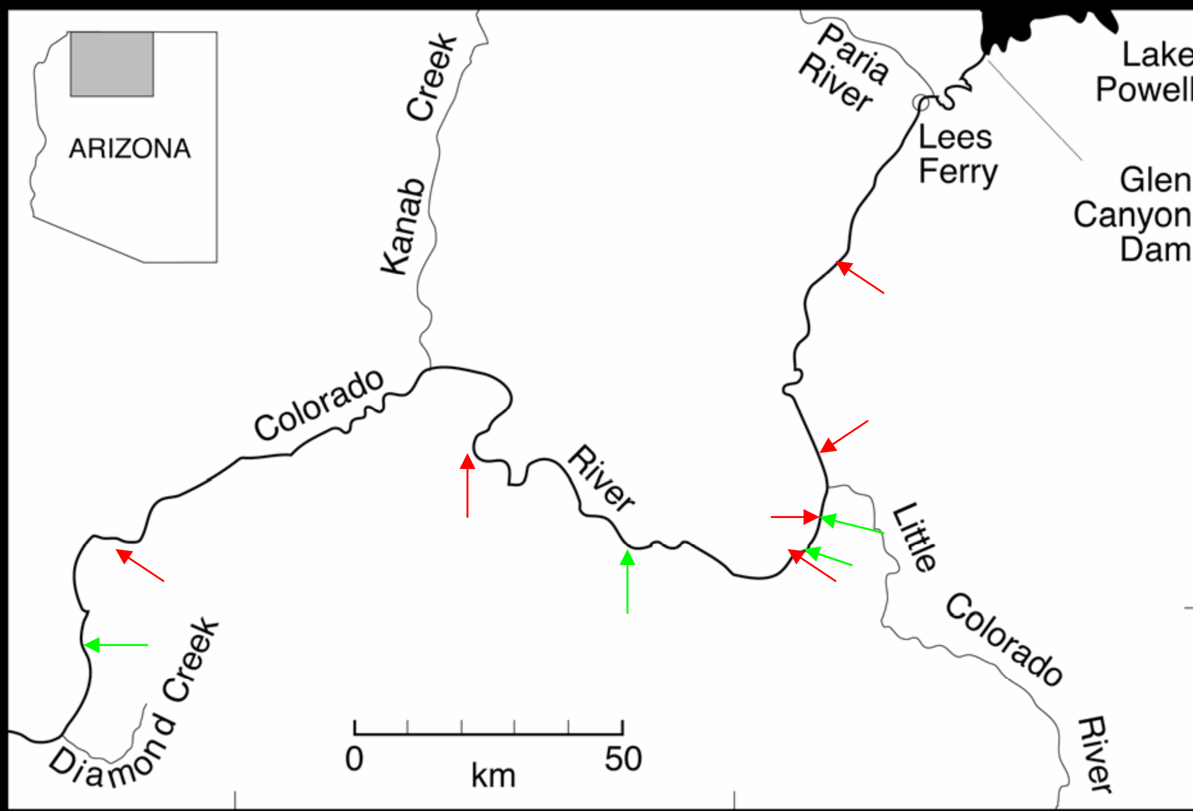
River-level sand bar

Sand dunes above river

Gully undercutting roasting feature

Potsherds exposed by wind deflation

Studying aeolian sediment in the river corridor



Instrument station (anemometers, rain gages, sand traps)

Stratigraphic analysis

Sedimentology & stratigraphy:

- Sedimentary structures help identify depositional environments

- Detailed work at 3 locations; briefer work at ~40 others
- **Many archaeological sites are protected (wholly or partially) by aeolian sediment cover**

Fairley, SCORE Report Chapter 11

Draut et al., 2005: USGS Scientific Investigations Report No. 2005-5072

Draut et al., Geomorphology, in review

Measuring modern aeolian sediment transport

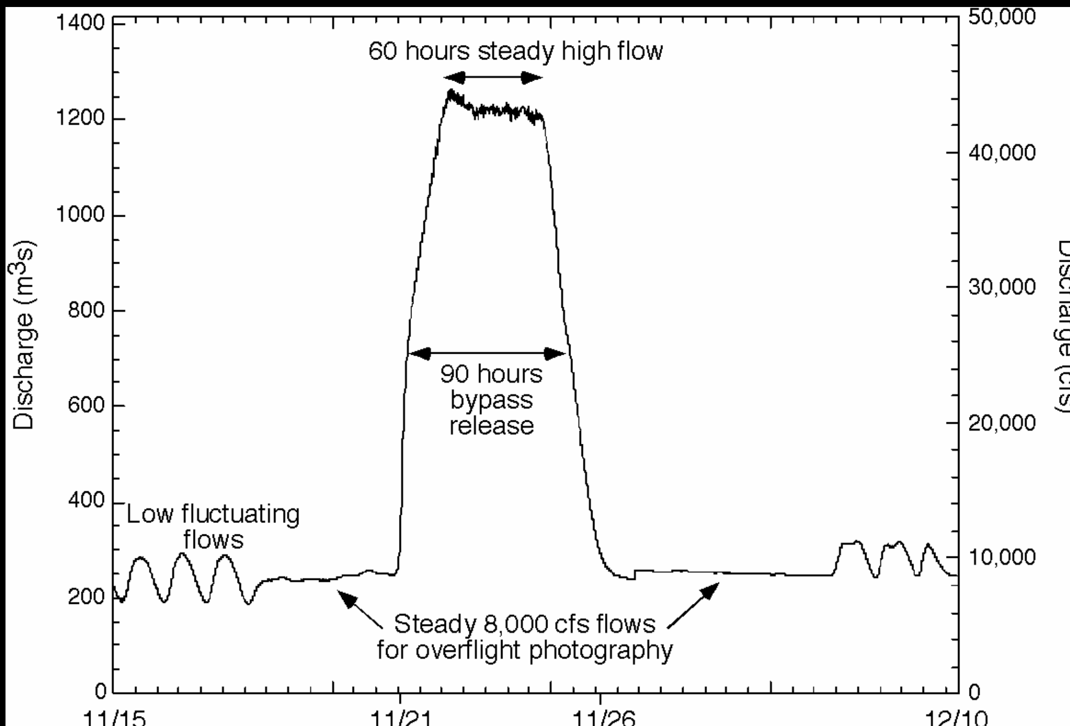
- Anemometers → wind speed and direction
- Sand traps → integrate total transport 0-1 m from the bed
- Rain gages → identify events causing gully incision / determine when sand too wet to transport

22 months of wind, precipitation, and sand-transport data show that:

- Wind velocities highest in April-May (with sand-transport rates 3-10x the non-windy season)
- Aeolian sediment transport 10x greater on dune fields without cryptogamic soil crust
- Wind velocity higher above riparian zone (less vegetation)
- Rainfall is highly variable spatially

Draut and Rubin, 2005: USGS Open-File Report No. 2005-1309

2004 flood experiment

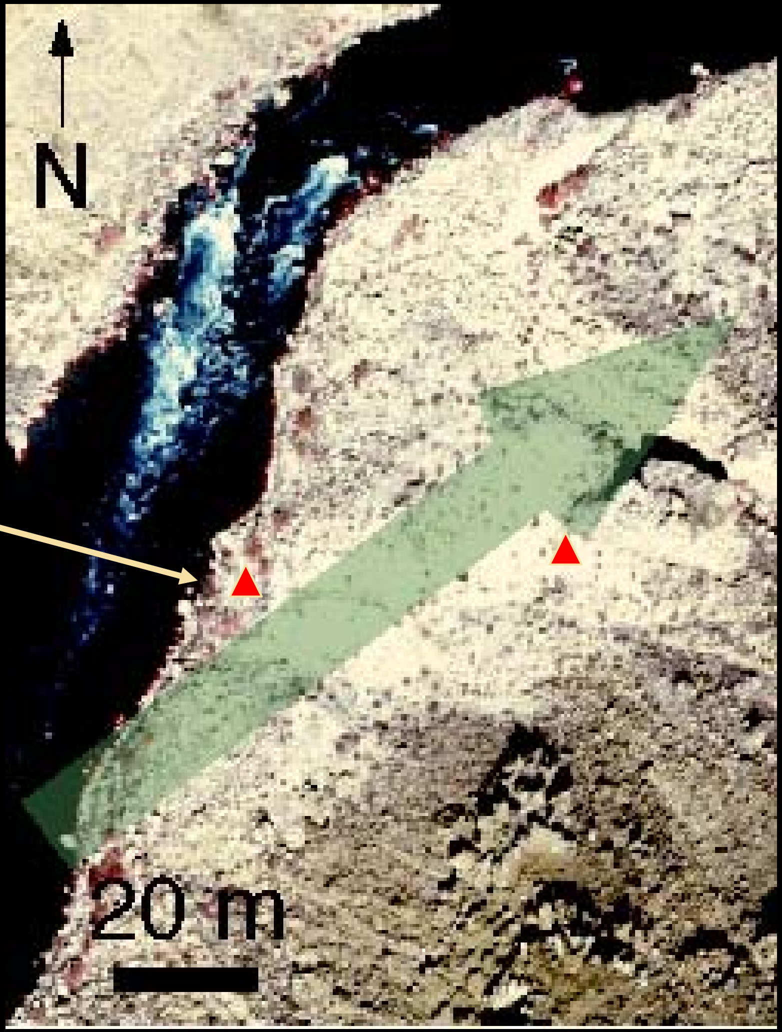


- Deposition of new sand on sandbars that source aeolian dunes?
- Measurable increase in aeolian sand transport?

In some areas, redistribution of flood sediment by wind could benefit archaeological site preservation

24.5 mile: net sand transport

Sand deposit photographed



Net vector sum: Aeolian sand transport from 229°, from river-level sand bar across dune field

Instrument sites: 24.5 mile

Pre-flood (November 17, 2004)

Post-flood (December 4, 2004)

Instrument sites: 24.5 mile

Pre-flood (November 17, 2004)

Post-flood (December 4, 2004)

Post-5-20k (March 8, 2005)

Instrument sites: 24.5 mile

Pre-flood (November 17, 2004)

Post-flood (December 4, 2004)

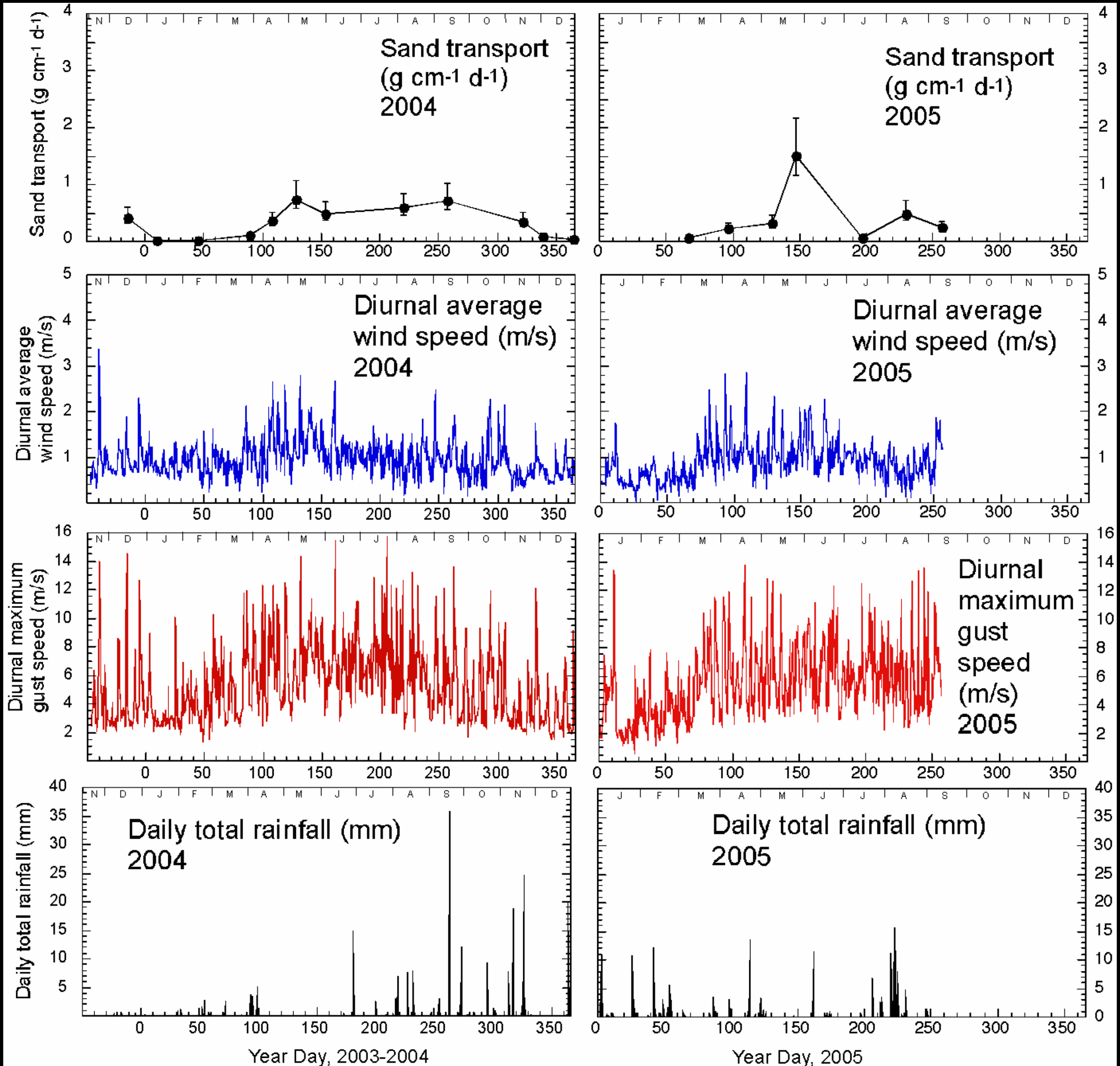
Instrument sites: 24.5 mile

Pre-flood (November 17, 2004)

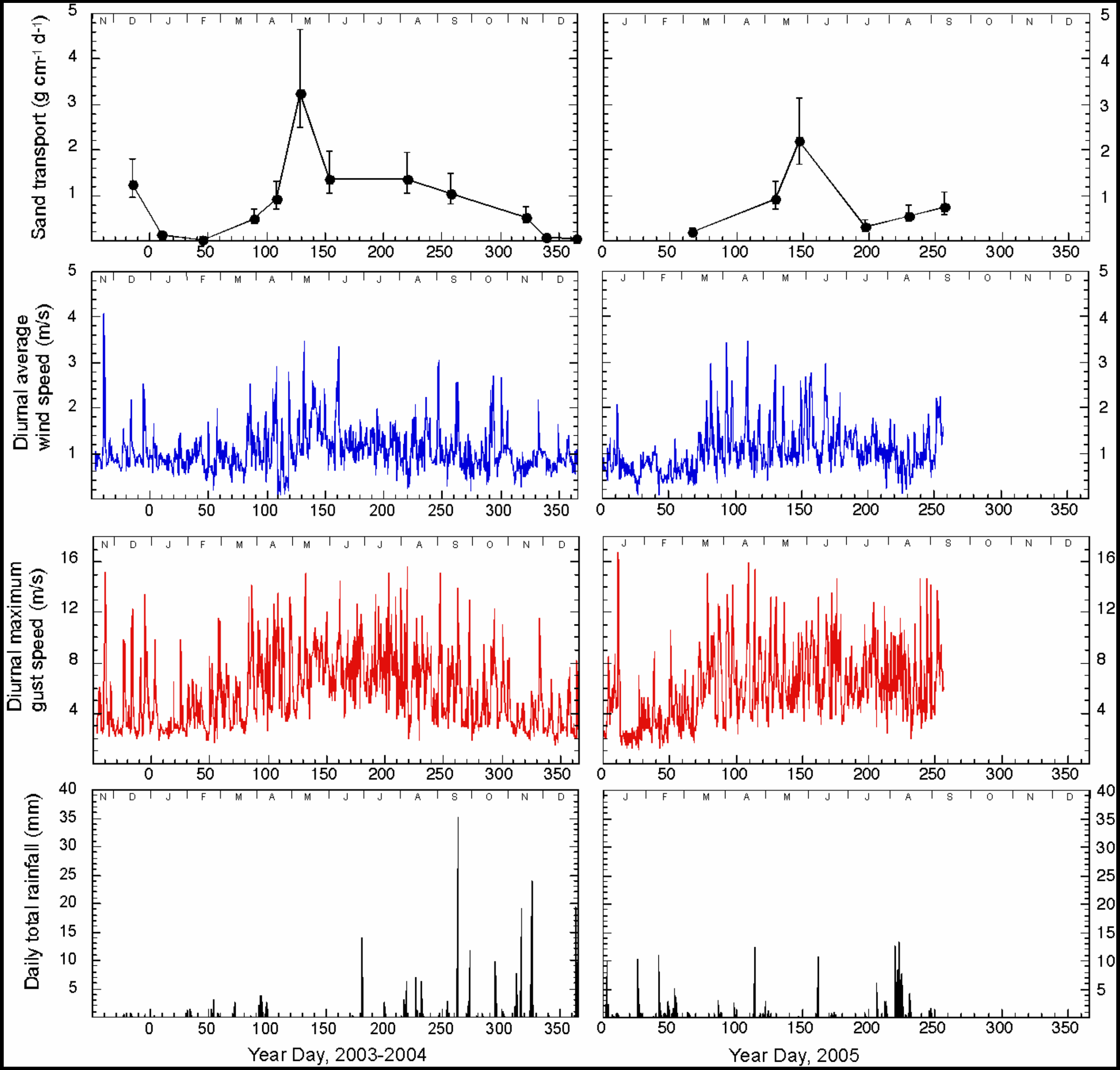
Post-flood (December 4, 2004)

Post-5-20k
(March 8, 2005)

24.5 mile: lower station

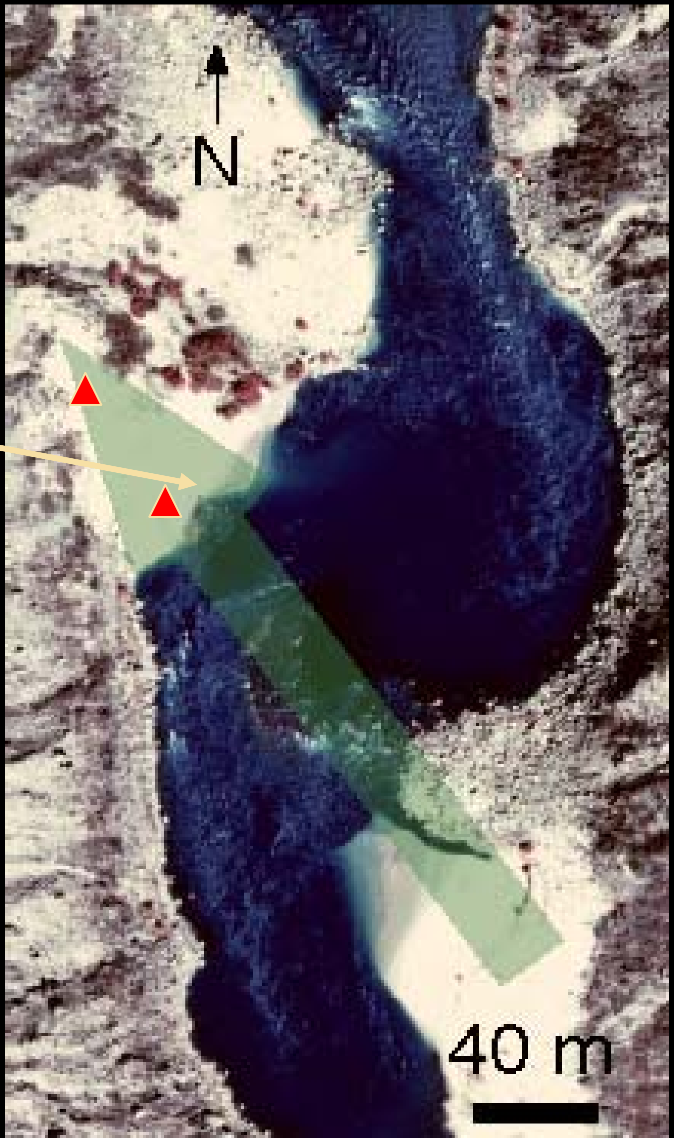


24.5 mile: upper station



Malgosa: net sand transport

Sand deposit photographed



Net vector sum: Aeolian sand transport from 132°, from river-level sand bar(s) across dune field

Instrument sites: Malgosa

Pre-flood (November 17, 2004)

Post-flood (December 9, 2004)

Malgosa (RM 57.5):
flood deposit
~1.5 m thick

December 9, 2004

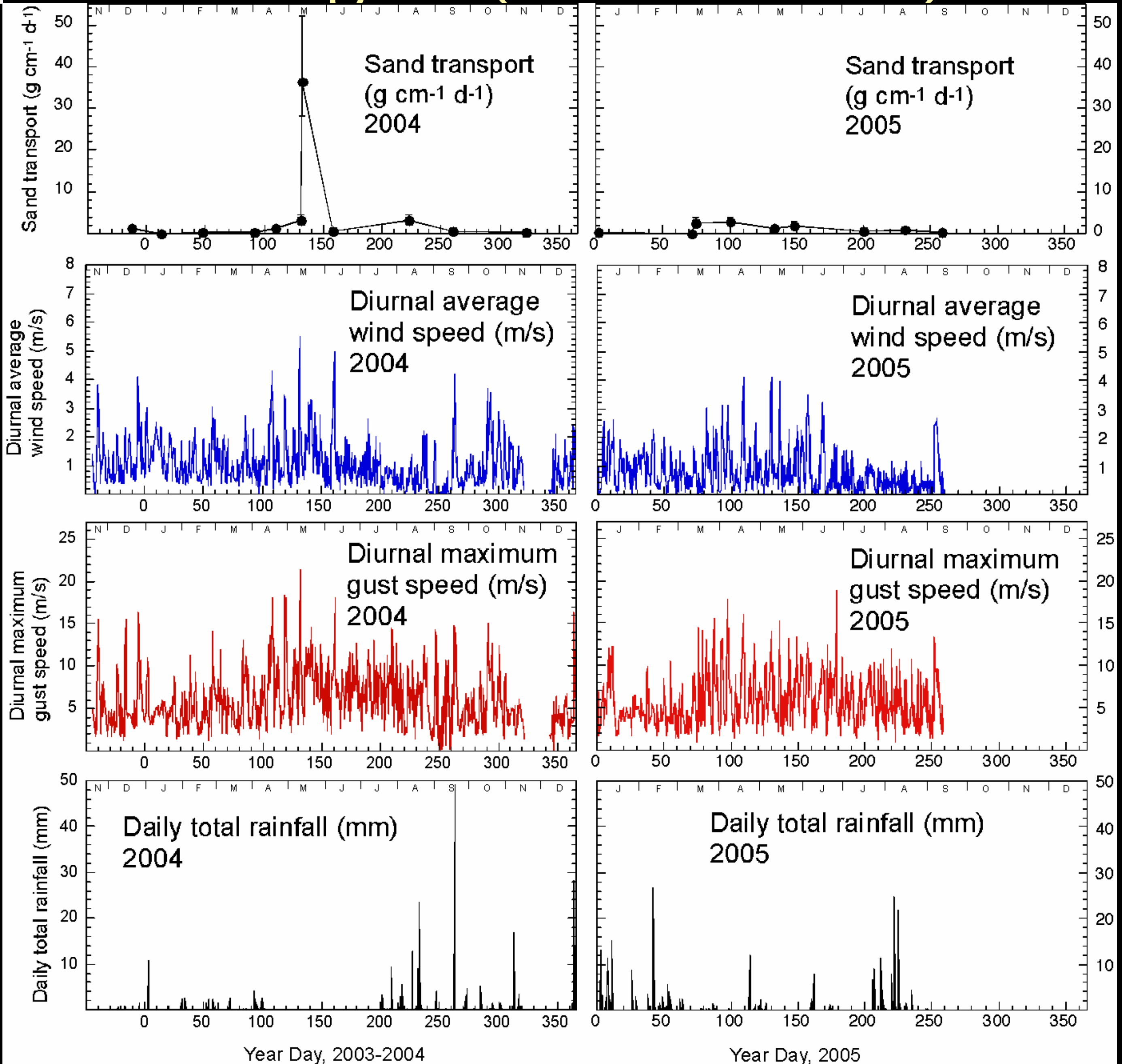
Instrument sites: Malgosa

Pre-flood (November 17, 2004)

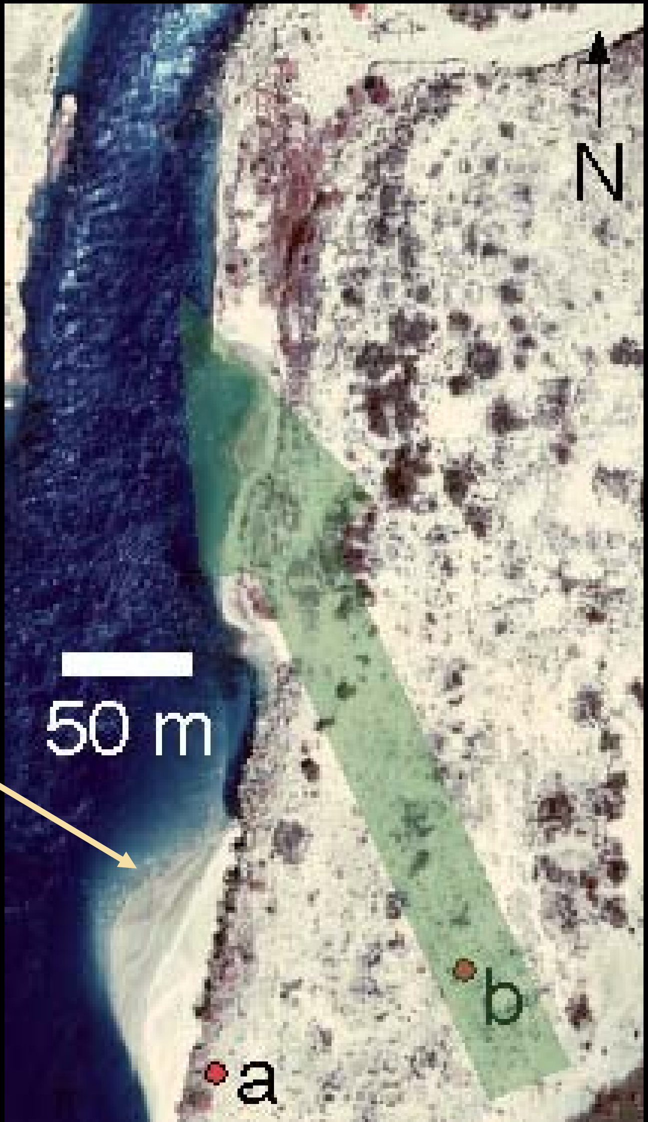
Post-flood (December 9, 2004)

Post-5-20k
(March 13, 2005)

Malgosa (lower station)



Palisades: net sand transport



Net vector sum: Aeolian sand transport from 149°, upstream and somewhat away from dune field

(Ephemeral) sand deposit photographed

Instrument sites: Palisades

Pre-flood (November 19, 2004)

Post-flood (December 10, 2004)

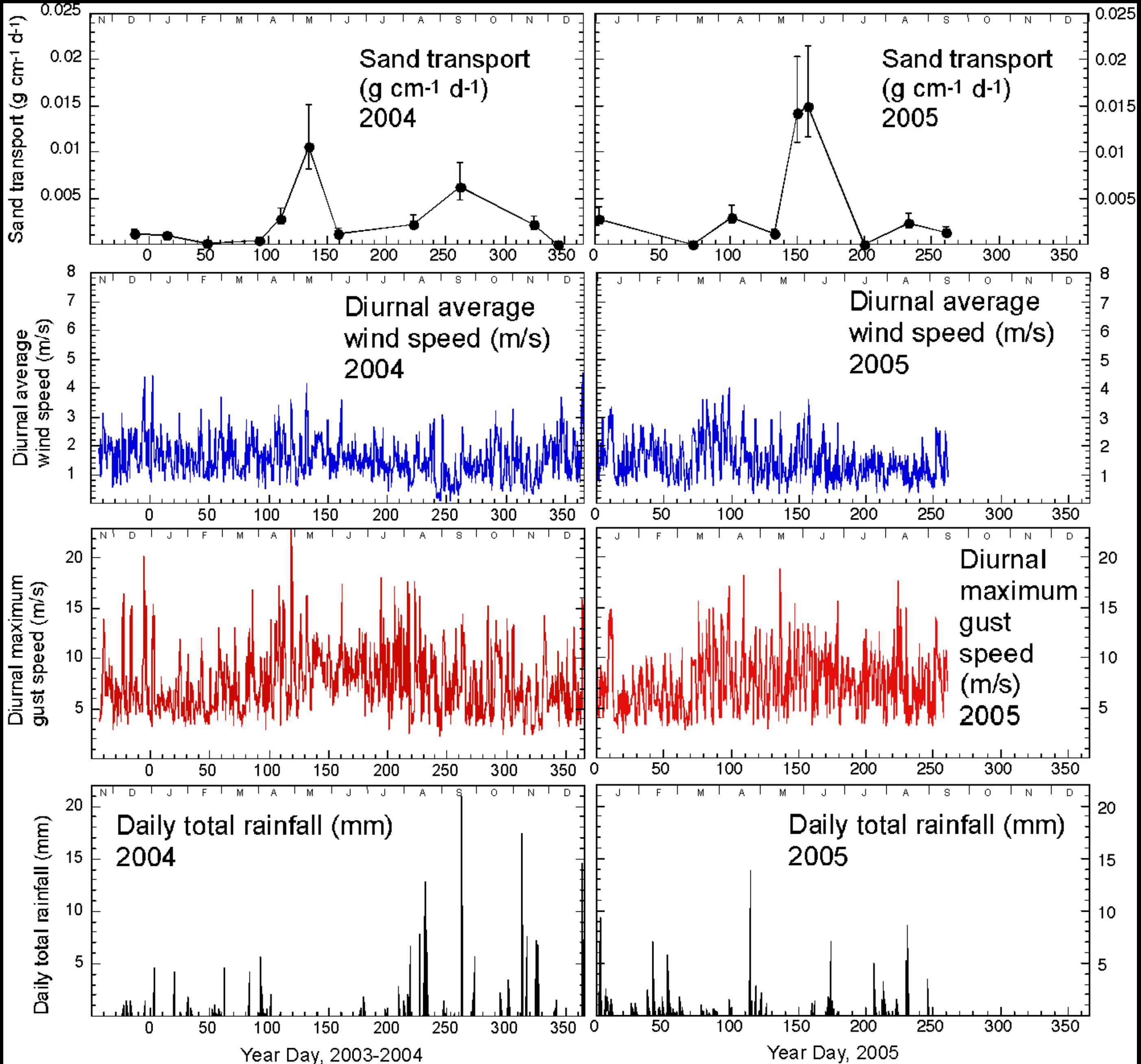
Instrument sites: Palisades

Pre-flood (November 19, 2004)

Post-flood (December 10, 2004)

Post-5-20k
(March 16, 2005)

Palisades: lower station



- Did flood deposit new sand on sandbars that source aeolian dunes?

Yes - all 6 study locations had major deposition of flood sand apparent in December 2004.

However, 5,000-20,000 cfs flows (Jan-Mar 2005) removed most of that new flood-deposited sediment before the start of the 2005 windy season.

- Measurable increase in aeolian sand transport?

At sites where some flood sand remained, small increase in windy-season sand transport (vs. 2004) at stations near river level. Effect not (yet?) propagated to upper-elevation weather stations.

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Rainfall: 2003-04 vs. 2005

Factor increase	24.5 mile	Malgosa	Palisades
Jan-Aug	2.3	2.1	1.4
Winter storms (Dec-Feb)	8.1	4.9	3.3
Summer monsoon (July-Aug)	2.1	1.2	0.6

⇒Effects on vegetation, potential for gully incision?

Summary: What do we know?

- Aeolian sand helps preserve many arch sites
- High-resolution records of local wind, rainfall

  $\Rightarrow$ *Sensitivity of arch sites to dam operations varies*
- Sediment-rich floods successfully form new sand deposits in areas that source aeolian dunes: could benefit many archaeological sites
- Best potential for transporting new flood sand to arch sites by wind in April-May windy season
- 5,000-20,000 daily flow fluctuations removed most new flood sand from these aeolian source areas before 2005 windy season began

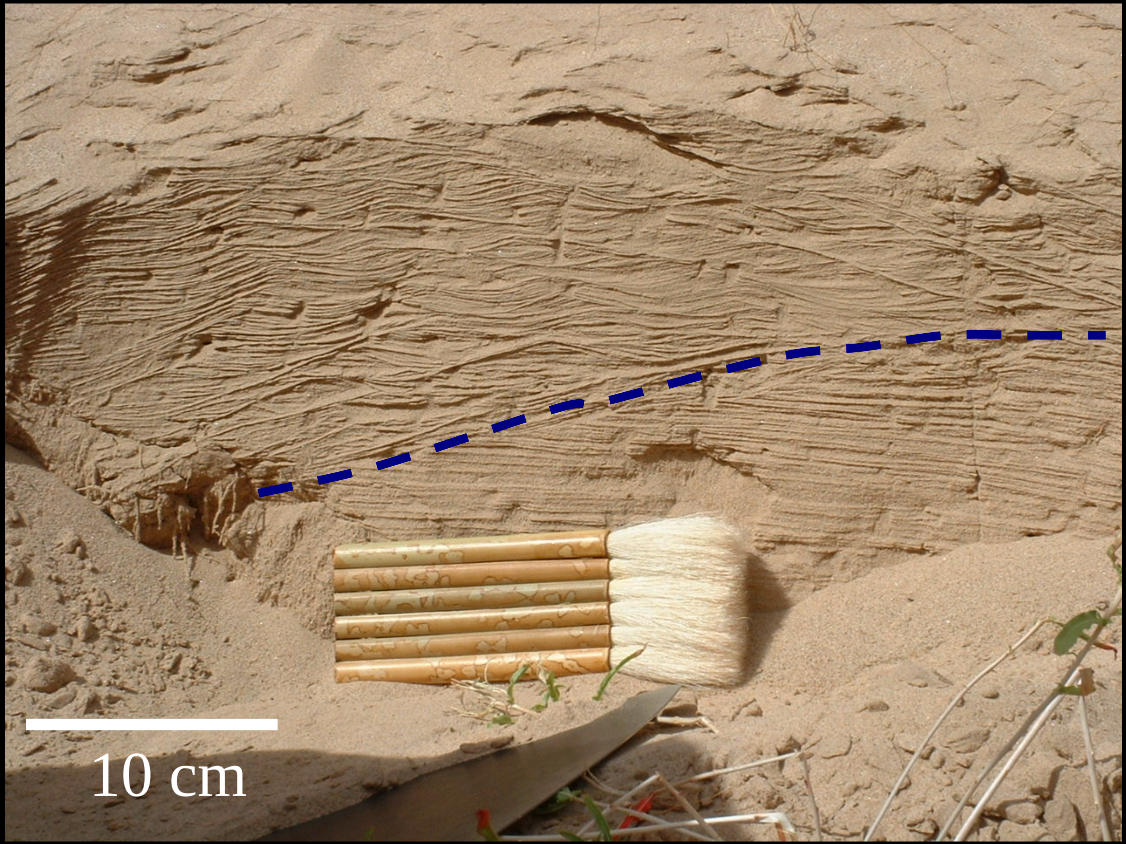
Summary: what don't we know?

- Higher rainfall in 2005 vs. 2003-04: magnitude of effects on vegetation, gullies?
- Range of interannual variability uncertain (data collected for only 2 years)
- For archaeological sites at which local geomorphology and wind conditions not yet evaluated, potential response to dam operations is unknown

Publications to download:

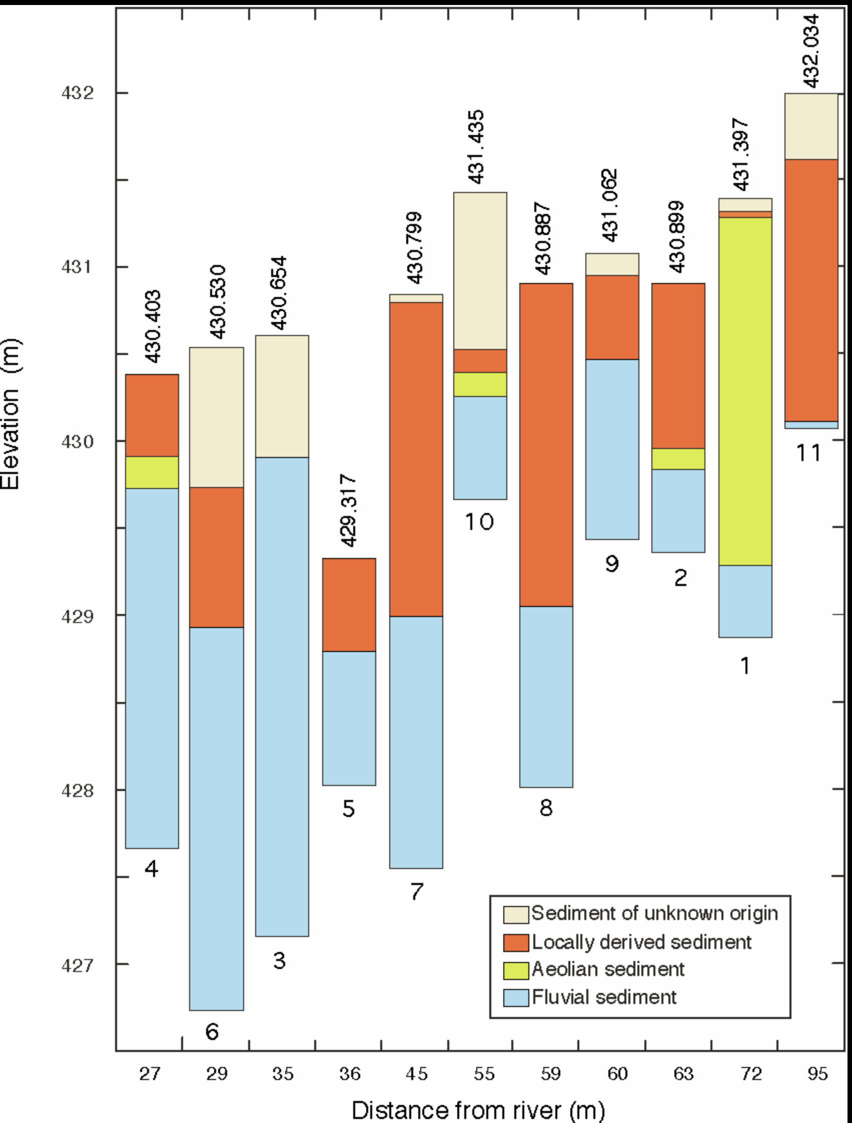
- Draut, A. E. and Rubin, D. M. 2005. Measurements of wind, aeolian sand transport, and precipitation in the Colorado River corridor, Grand Canyon, Arizona—November 2003 to December 2004. U.S. Geological Survey Open-File Report 2005-3019, 70 pages: http://pubs.usgs.gov/of/2005/1309/
- Draut, A. E., Rubin, D. M., Dierker, J. L., Fairley, H. C., Griffiths, R. E., Hazel, J. E. Jr., Hunter, R. E., Kohl, K., Leap, L. M., Nials, F. L., Topping, D. J. and Yeatts, M. 2005. Sedimentology and stratigraphy of the Palisades, Lower Comanche, and Arroyo Grande areas of the Colorado River corridor, Grand Canyon, Arizona. U.S. Geological Survey Scientific Investigations Report 2005-5072, 68 pages: http://pubs.usgs.gov/sir/2005/5072/

Stratigraphic interpretation



Sedimentary structures help identify depositional environments

Pre-dam depositional environments



- Thick Holocene fluvial terraces form substrate for many arch. sites
- Aeolian reworking of sediment on terrace surfaces
- Locally derived (slope-wash, debris-flow) sediment


A few words about modeling…

Aeolian sediment transport presents a modeling challenge…

- Many sources of uncertainty: air flow around obstacles (vegetation, rocks, etc.), interstitial moisture, salt encrustation, cryptogamic soil, bedform irregularities, solar heating & convection, sand-source limitations (esp. in coastal dunes…)
- Bauer et al., 1996: “Accurate predictions of aeolian sediment flux may never be realized…”

- So… **eliminate as much uncertainty as possible.**

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Testing transport models:

Bagnold (1941)	$q \quad 1.8\sqrt{\frac{d}{D}}\frac{}{g}u_*^3$
Kawamura (1951)	$q \quad 2.78\frac{}{g}\, u_* \quad u_{*_t} \quad u_* \quad u_{*_t} \quad {}^2$
Zingg (1953)	$q \quad 0.83 \; \frac{d}{D} \; {}^{0.75} \; \frac{}{g}u_*^3$
Williams (1964)	$q \quad 4.066\frac{}{g}u_*$
Hsu (1971)	$q \quad 10^{\ 4}e^{4.79d \quad 0.47}\frac{u_*^3}{gd^{\ 1.5}}$
Lettau and Lettau (1977)	$q \quad 4.2\sqrt{\frac{d}{D}}\frac{}{g}\; u_* \quad u_{*_t}\; u_*^2$
White (1979)	$q \quad 2.61u_*^3\ 1 \quad \frac{u_{*_t}}{u_*} \quad 1 \quad \frac{u_{*_t}^2}{u_*^2} \quad \frac{}{g}$
Sørensen (1991)	$q \quad 10^{\ 4}\ u_*\ u_* \quad u_{*_t} \quad u_* \quad 7.6u_{*_t} \quad 205$

Results

Dumont Dunes	*Measured*	*105% Trap Efficiency*	*115% Trap Efficiency*
Measured transported sand (g)	61.8	58.9	53.7
Ratio of Predicted: Measured Flux			
Bagnold (1941)	1.47	1.54	1.69
Kawamura (1951)	0.856	0.898	0.985
Zingg (1953)	0.712	0.747	0.819
Williams (1964)	34.9	36.6	40.2
Hsu (1971)	2.29	2.41	2.64
Lettau and Lettau (1977)	0.430	0.452	0.495
White (1979)	0.406	0.426	0.467
Sørensen (1991)	0.241	0.253	0.277

Malgosa	*Measured*	*95% Trap Efficiency*	*115% Trap Efficiency*
Measured transported sand (g)	2770	2910	2400
Ratio of Predicted: Measured Flux			
Bagnold (1941)	1.82	1.73	2.09
Kawamura (1951)	2.58	2.45	2.96
Zingg (1953)	0.880	0.840	1.01
Williams (1964)	17.3	16.4	19.8
Hsu (1971)	2.85	2.70	3.27
Lettau and Lettau (1977)	1.99	1.89	2.29
White (1979)	1.38	1.31	1.59
Sørensen (1991)	0.620	0.590	0.710