GULLY ANNEALING BY FLUVIALLY-SOURCED AEOLIAN SAND: REMOTE SENSING INVESTIGATIONS OF CONNECTIVITY ALONG THE FLUVIAL-AEOLIAN-HILLSLOPE CONTINUUM ON THE COLORADO RIVER

EXTENDED ABSTRACT

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INTRODUCTION

Processes contributing to development of ephemeral gully channels are of great importance to landscapes worldwide, and particularly in dryland regions where soil loss and land degradation from gully erosion pose long-term, land-management problems. Whereas gully formation has been relatively well studied, much less is known of the processes that anneal gullies and impede their growth. This work investigates gully annealing by aeolian sediment, along the Colorado River downstream of Glen Canyon Dam in Glen, Marble, and Grand Canyons, Arizona, USA (Figure 1).

In this segment of the Colorado River, gully erosion potentially affects the stability and preservation of archaeological sites that are located within valley margins. Gully erosion occurs as a function of ephemeral, rainfall-induced overland flow associated with intense episodes of seasonal precipitation. Measurements of sediment transport and topographic change have demonstrated that fluvial sand in some locations is transported inland and upslope by aeolian processes to areas affected by gully erosion, and aeolian sediment activity can be locally effective at counteracting gully erosion (Draut, 2012; Collins and others, 2009, 2012; Sankey and Draut, 2014). The degree to which specific locations are affected by upslope wind redistribution of sand from active channel sandbars to higher elevation valley margins is termed "connectivity". Connectivity is controlled spatially throughout the river by (1) the presence of upwind sources of fluvial sand within the contemporary active river channel (e.g., sandbars), and (2) bio-physical barriers that include vegetation and topography that might impede aeolian sediment transport. The primary hypothesis of this work is that high degrees of connectivity lead to less gullying potential.

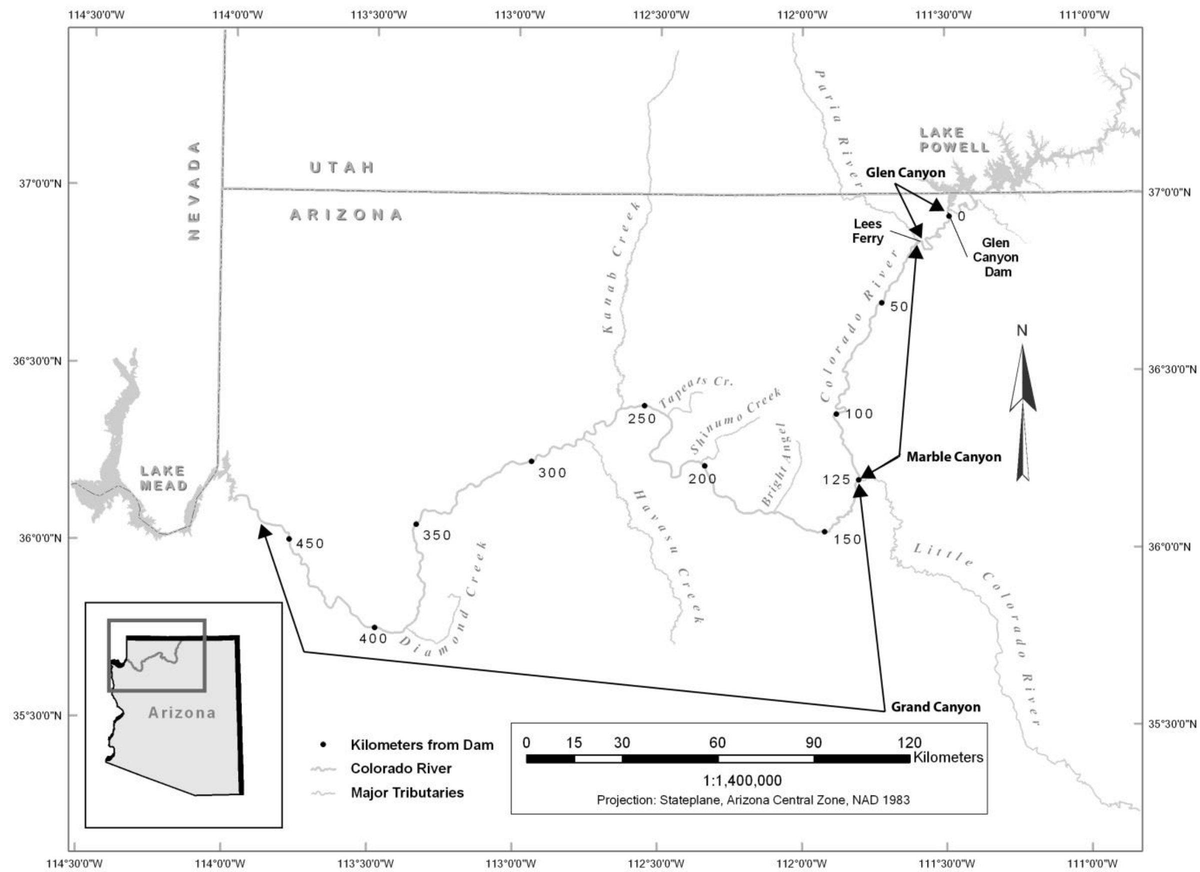

Figure 1 Map of the Colorado River downstream of Glen Canyon Dam, Arizona, USA.

METHODS

We have used a variety of remote sensing and field methods to map the distribution of fluvially-sourced aeolian sand within gullied valley margins above the active river channel (Draut, 2012; Collins and others, 2009, 2012; Sankey and Draut, 2014). We define the active channel as the area below the 1,270 m^3/s flood shoreline; 1,270 m^3/s is the approximate magnitude of recent controlled floods of the Colorado River from Glen Canyon Dam that have been conducted episodically since 1996. We have used remote sensing observations, including topographic modelling with high resolution automated digital photogrammetry and topographic change detection with lidar (light detection and ranging), to map and measure changes in gullies and fluvially-sourced aeolian surfaces (Collins and others, 2009, 2012; Sankey and Draut, 2014). Topographic change detection with repeat ground-based lidar surveys was conducted periodically from 2006 to 2010 at a total of 13 study sites (Collins and others, 2009, 2012).

In addition to high resolution change detection at sample locations, the spatial distribution of fluvially-sourced aeolian sand located above the active river channel has been mapped for six reaches of the river (Draut, 2012; Sankey and Draut, 2014). Mapping was completed in the field on high resolution imagery (22 cm-resolution). Fluvially-sourced sand units were identified as either active or inactive with respect to contemporary aeolian transport (Draut, 2012). Draut (2012) and Sankey and Draut (2014) showed that there is substantially less active sand area than inactive sand area throughout the river valley.

To investigate the effect of fluvially-sourced aeolian sand on gully development within these reaches, identification of potential gullies was conducted with high resolution digital elevation data (1-m grid cell resolution). Potential gullies were defined topographically as hillslope flowpaths with concave across-slope shape with potential to channel overland flow. Potential gullies were detected using a novel combination of overland-flow accumulation and topographic modelling procedures commonly available in GIS and remote sensing software. Methods for the identification of potential gullies are described in detail in Sankey and Draut (2014).

RESULTS

Sediment volume changes that were previously mapped with ground-based lidar and attributed to aeolian deposition (Collins and others, 2009, 2012) were summarized for three types of sites as a function of connectivity. The types were: 1) sites with recent Colorado River controlled flood sediment deposited upwind, and with a connected aeolian pathway from the active channel flood deposit to the site (where change detection was conducted); 2) sites with recent controlled flood sediment deposited upwind, but with reduced connectivity due to vegetation or topography that interrupted the aeolian pathway between the active channel flood deposit and the site; or 3) sites without a recent, upwind active channel controlled flood sediment deposit. Results are based on a small sample size, yet suggest that influx of fluvially-sourced aeolian sand is larger in valley margin landscape positions that have greater connectivity (Figure 2). Sediment volume changes were similar for type 1 and 2 sites, which was somewhat unexpected. A larger sample of sites could be studied in the future to either confirm this finding, or test whether changes in sediment volume vary as a function of transport barrier types (i.e, vegetation or topography) and characteristics (e.g. size, roughness, porosity).

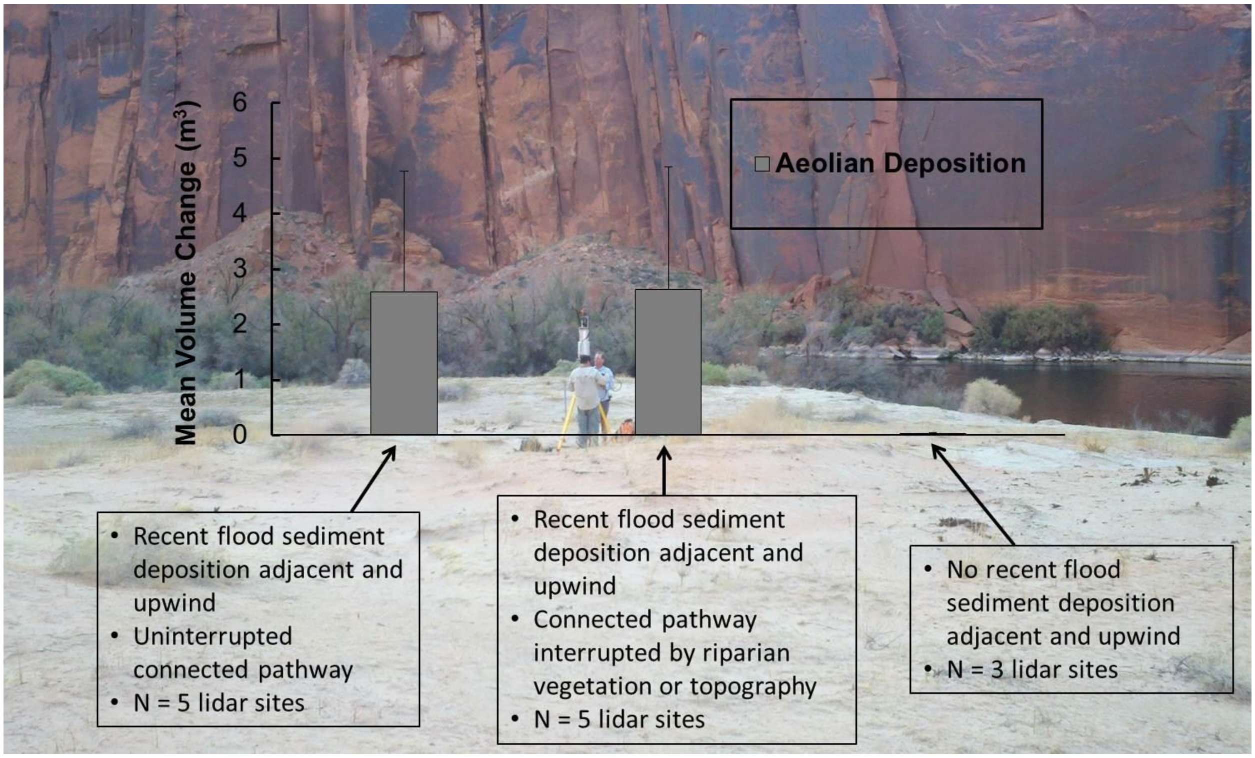

Figure 2 Volumetric surface change measured with ground-based lidar. Only volumetric changes attributed to aeolian deposition of fluvially-sourced sand are shown. Lidar study sites were located in valley margins above the contemporary active Colorado River channel and are prone to gully erosion. Individual site change data are from Collins and others (2009, 2012). Site change data are summarized by presence/absence of: 1) an upwind flood sediment source (sandbar); and 2) a topographic or vegetation barrier that might interrupt the connected pathway for aeolian transport of fluvially-sourced sediment to the higher elevation study site. Changes were determined at 1-3 year intervals for 13 sites between 2006 and 2010. Error bars show the standard error of the mean for n sites.

Figure 3 shows an example of the relative distribution of river-derived sediment above the active river channel for one reach of the river (70.8–98.2 km downstream of Glen Canyon Dam and within Grand Canyon National Park). In this reach, river-derived sediment that is active with respect to aeolian transport (showing evidence of contemporary aeolian sand transport) is located closer to the active river channel. This suggests that the degree to which valley margins are comprised of river-derived, active aeolian sand is influenced by connectivity, and specifically the length of the connected pathway to the active river channel and controlled flood sandbar deposits.

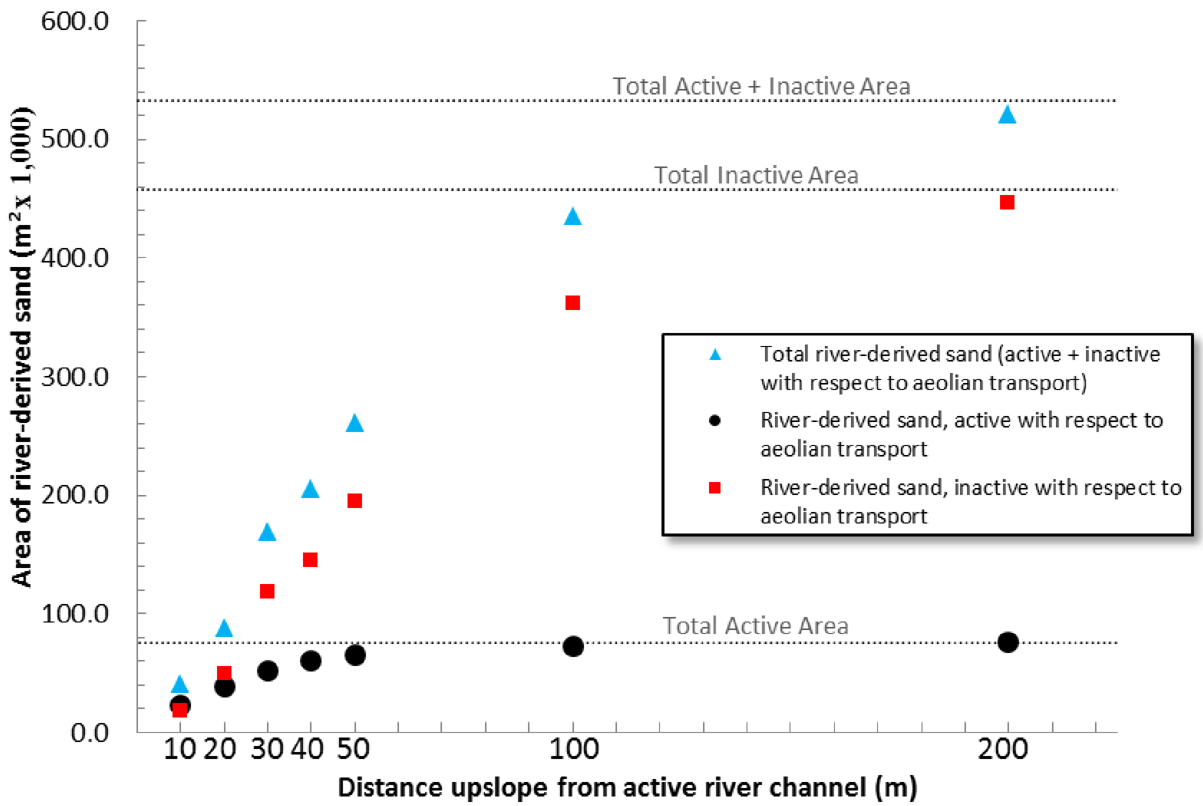

Figure 3 Distribution of river-derived sand that is active and/or inactive with respect to aeolian transport as a function of proximity to the contemporary active Colorado River channel. The active channel is defined as the area below the 1,270 m^3/s maximum controlled flood shoreline. Results are shown for a reach of the river (70.8–98.2 km downstream of Glen Canyon Dam) within Grand Canyon National Park.

The spatial intersection of mapped fluvially-sourced aeolian sand and potential gullies identified with digital topographic modelling indicate that gullies are less prevalent in areas where surficial sediment undergoes active aeolian transport (Figure 4). Potential gullies also have a greater tendency to terminate in fluvially-sourced sand that is active as opposed to inactive with respect to aeolian transport (Sankey and Draut, 2014). Although not common, examples exist in the records of historical imagery of gullies that underwent infilling by aeolian sediment in past decades and evidently were effectively annealed (Sankey and Draut, 2014).

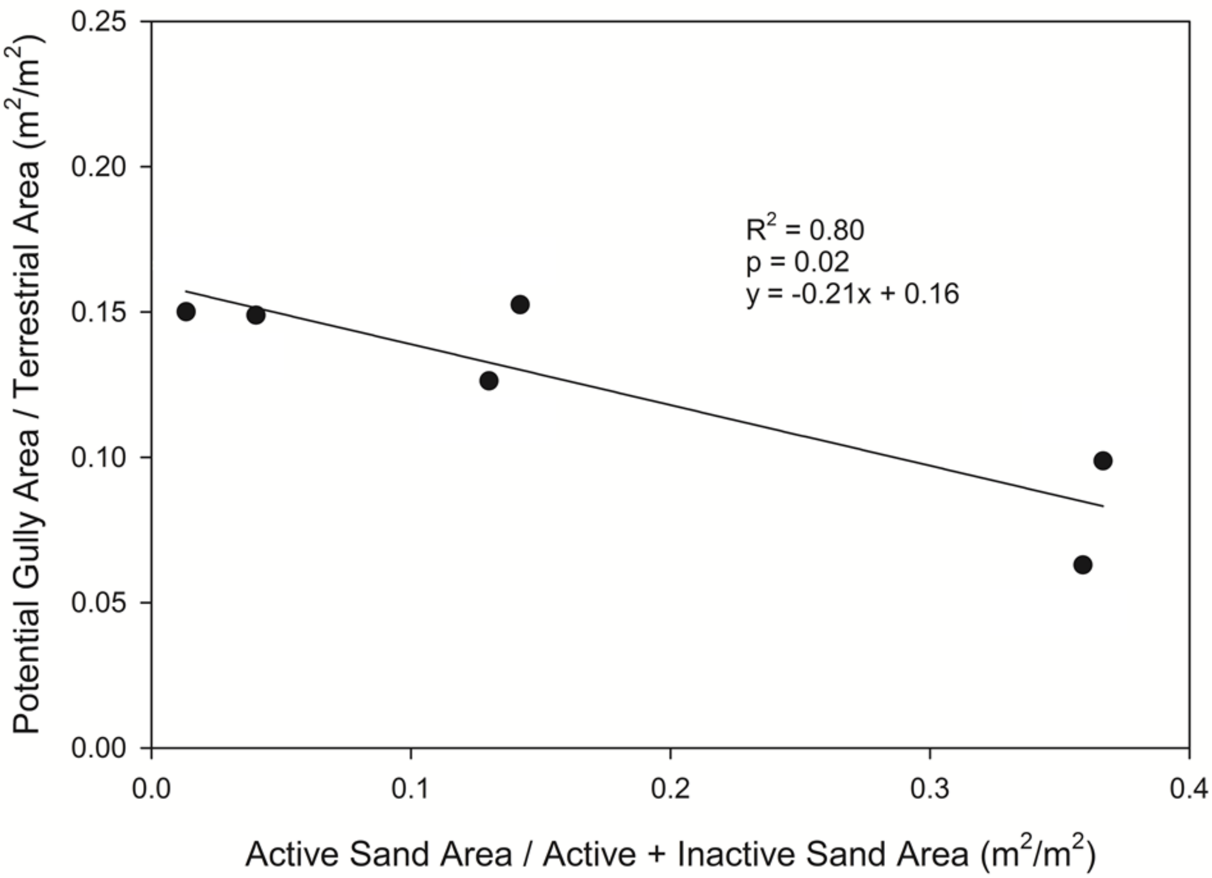

Figure 4 Relationship of area of potential gullies and active sand among six study reaches of the Colorado River in Glen, Marble, and Grand Canyons. Gullies are less prevalent in valley margins above the active river channel where river-derived sediment undergoes active aeolian transport. Figure is modified from Sankey and Draut (2014).

DISCUSSION and CONCLUSION

Connectivity is an important control on the distribution of fluvially-sourced sand in valley margins above the active channel of the Colorado River in Glen, Marble, and Grand Canyons. The distribution of fluvially-sourced sand can in turn influence the prevalence and extent of gullying in valley margins through annealing (e.g., infilling) mechanisms. The degree of connectivity between the active river channel and valley margins can therefore have an important influence on the potential for hillslope erosion in upland landscapes of the canyon-bound river. These investigations provide new evidence for an interaction of aeolian–hillslope–fluvial processes that can affect dryland regions substantially in ways not widely recognized. Continuation of this and related research will provide a basis for studies of natural and anthropogenic landscape change in the Colorado River and along similar river margins.

ACKNOWLEDGEMENTS

This study was supported by the U.S. Bureau of Reclamation through the Glen Canyon Dam Adaptive Management Program, with logistical and managerial support from the U.S. Geological Survey Grand Canyon Monitoring and Research Center. The authors thank the National Park Service and the Hualapai Tribe's Department of Cultural Resources for permission to conduct the field research.

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