Untangling Geomorphic Processes in the Grand Canyon with Topographic Time Series

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PROBLEM STATEMENT

Geomorphologists struggle with the challenge of comprehensively estimating change in sediment storage in long river segments. To make management decisions that help protect sandbars in the Colorado River in Grand Canyon, it is important to understand the sediment budget, specifically the fluxes and changes in storage. Current monitoring efforts do not and cannot produce a complete (spatial) sample of all the change in storage throughout the Canyon. This project was established to develop strategies by which the precise measurements, currently made at site and reach-scales, can be extrapolated to a larger segment scale. Here we attempt to develop metrics of eddy dynamism and persistence to help answer the broader question: Can eddy dynamism and persistence be explained by comparing changes in sediment storage to geomorphic, hydrologic, and vegetative metrics obtained through repeat topographic surveys?

STUDY SITE LOCATION

FIST Reach 5 consists of 9 debris fan-eddy complexes in Marble Canyon, located on the Colorado River approximately 95-98 km downstream from Glen Canyon Dam and 76-79 km downstream from Lees Ferry (Figure 1). Seven of the 9 eddies were used for this project.

Figure 1: FIST Reach 5 on the Colorado River in Grand Canyon area, Arizona.

Debris fan – eddy complexes are the fundamental reach-scale organizational framework of Marble Canyon (Figure 2). Operations of Glen Canyon Dam result in flows generally from 8-30,000 cfs, resulting in exposed sandbars at corresponding elevations.

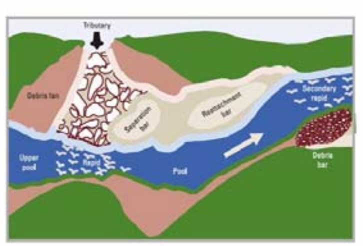


Figure 2: Diagram of a debris fan – eddy complex (taken from Wright and Kaplinski 2011).

DATA COLLECTION METHODS

Since the mid 1990s, data have been collected by Northern Arizona University and USGS. Topographic data were collected by ground-based surveys, aerial LiDAR, and single-beam and multi-beam bathymetric surveys. Data points were processed to eliminate points associated with vegetated areas and points above 97,000 cfs. Multi-beam bathymetric data were processed to remove bad soundings and meet IHO special order specifications. Data were referenced to a geodetic control network developed by Grand Canyon Monitoring and Research Center (Hazel et al. 2008). Reference benchmarks have positional accuracy <0.03 m and ellipsoid height accuracies 0.01-0.10 m, at 95% confidence. Processed data were used to construct TINs and derive digital elevation models (DEMs).

WHAT IS DYNAMISM?

DEFINITION: frequency over which a significant proportion of the total eddy area gains or loses sediment

METRIC:

A metric representing dynamism was calculated using the detailed topographic survey data. By differencing two DEMs over a survey interval of interest, the change in elevation due to erosion and deposition was estimated by calculating a DEM of difference (DoD) using the Geomorphic Change Detection extension in ArcGIS 10 (Figure 3). Uncertainties in individual DEMs propagate into DoD calculations and were accounted for here through assuming a uniform uncertainty of 0.1 m. Transient storage was calculated by differencing the minimum and maximum elevations for the entire interval over which surveys were conducted – August 2000 to May 2009.

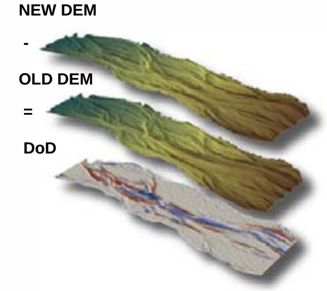


Figure 3: Method for calculating a DEM of difference (DoD).

A Relative Change Ratio (RCR) of elevation change to transient storage was calculated for each cell of the raster within the eddy boundary. A significant amount of change was considered to occur when the absolute value of the RCR was >0.7.

WHICH EDDIES ARE DYNAMIC?

Depending on survey interval, percent of total eddy area with RCR>0.7 ranged from 1% to nearly 80% (Figure 4). Specific findings of interest includes:
1) Flood events (August 2000, November 2004, March 2008) resulted in relatively large areas of high RCR.
2) For all but the 44.05 eddy, the interval following a flood event had a larger area of high RCR.
3) Trends of erosion and deposition are not the same for all eddies.

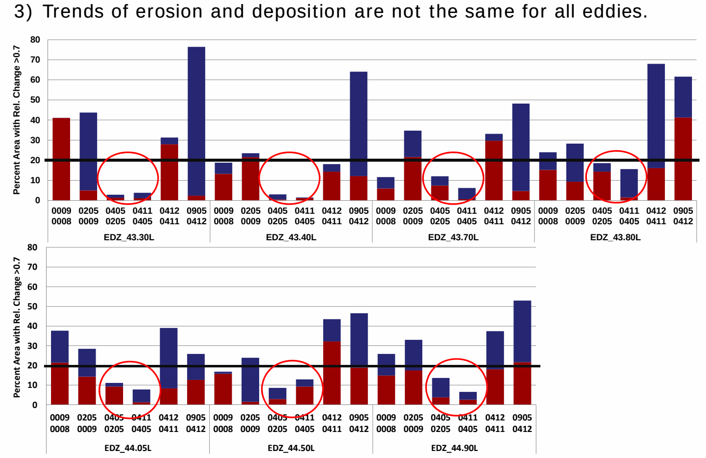


Figure 4: Total area where the relative change ratio (RCR) for erosion and deposition are >0.7 for each of the survey intervals. Blue bars represent deposition. Red bars represent erosion. Survey intervals are in the format of 'new survey - old survey' in YYMM format. For example, 0009 0008 represents the interval of August 2000 to September 2000. Red circles highlight time periods that are not either: 1) surveyed as bookends of a flood, or 2) surveys that include the time period immediately following a flood event.

Eddy dynamism is based on three criteria:1) surveys around floods (0009-0008, 0412-0411) >20% area; 2) post-flood survey period >20% area; and 3) all other survey intervals >10% area. An eddy is considered highly dynamic if it meets 1-3, 1 & 3, or 2 & 3. Eddies meeting only 1 & 2 were moderately dynamic and all else have low dynamism. Using this set of rules:
• High dynamism – 43.8 & 44.5
• Moderate dynamism – 43.3, 44.05 & 44.9
• Low dynamism – 43.4 & 43.7

To explore differences in high vs. low elevation sandbar deposits, RCR was separated by elevation zones. Eddy 44.5 is given as an example (Figure 5):
• *<8k cfs elevation zone*: Erosion and deposition greater than 0.7 RCR accounts for 5-60% of total RCR. Almost all the activity in the high elevation zone is erosion. Using criteria from above, this portion of the eddy has low to moderate dynamism.
• *8-25k cfs elevation zone*: There is more erosion during floods and more deposition in the periods post-flooding. Time in between flood events is dominated by deposition. Using criteria from above, this portion of the eddy is highly dynamic.

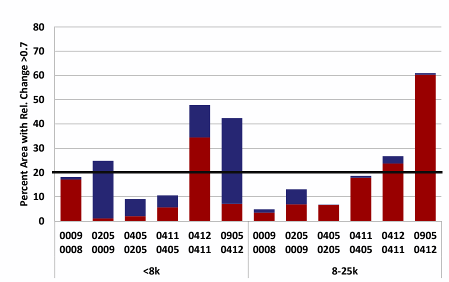


Figure 5: Area of eddy 44.5 where the relative change ratio (RCR) for erosion and deposition are >0.7 for each of the survey intervals. For an explanation of the plots see Figure 3. Note that the percent area shown for the zones is calculated based on the size of the zone.

WHAT IS PERSISTENCE?

DEFINITION: longevity over which exposed sand remains present

METRIC:

A metric for persistence was calculated using fill ratios developed by Schmidt et al. (2004). A fill ratio is the area of an eddy occupied by sand in the particular photo per the total extent of area ever occupied by sand in all photos (Figures 6 & 7). Photos used in this analysis are from eight distinct periods, spanning from 1935 to 1996. Data are summarized for two periods – pre-dam and post-dam. In the Schmidt et al. (2004) analysis, eddies 43.3 and 43.4 are merged into one eddy. Persistence was evaluated by comparing standard deviation and mean pre- and post-dam fill ratios.

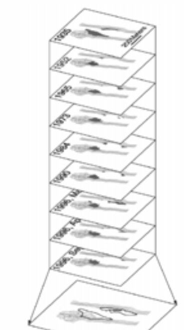


Figure 6: Method for calculating total extent of area occupied by sand in all photos (figure from Schmidt et al. 2004).

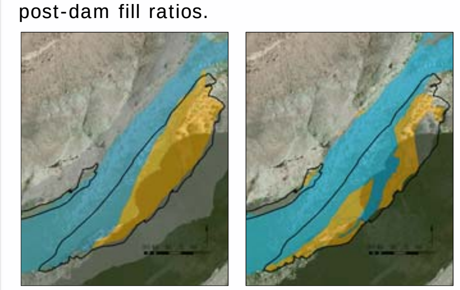


Figure 7: Examples of how eddy 44.5 was delineated in 1935 and 1996. Yellow are exposed sandbars.

WHICH EDDIES ARE PERSISTENT?

In line with findings from Schmidt et al. (2004), the mean and standard deviation (STD) of the fill ratio for pre-dam eddies are generally larger than for post-dam eddies. (Table 1). Specific conclusions include:
1) Only eddy 43.8 has a higher post-dam mean fill ratio.
2) Pre-dam eddies with low STD have higher mean fill ratios.
3) For the cases where the STD of the fill ratio is relatively low, the pre-dam and post-dam STDs are fairly similar and sometimes higher post-dam.

Table 1. Fill ratios by photo year and summary statistics for pre- and post-dam. Fill ratios calculated for 'all sand above water level' (Schmidt et al. 2004).

	Pre-dam		Post-dam					Pre-dam		Post-dam	
Eddy	**1935**	**1952**	**1973**	**1984**	**1990**	**1996**	**1996**	**MEAN**	**STD**	**MEAN**	**STD**
43.3 & 43.4	0.71	0.72	0.49	0.48	0.50	0.45	0.42	0.71	**0.01**	0.47	**0.03**
43.7	0.58	0.58	0.37	0.32	0.33	0.25	0.27	0.58	**0.00**	0.31	**0.05**
43.8	0.43	0.62	0.36	0.65	0.64	0.60	0.62	0.53	**0.13**	0.57	**0.12**
44.05	0.75	0.19	0.33	0.17	0.11	0.12	0.15	0.47	**0.39**	0.18	**0.09**
44.5	0.72	0.63	0.46	0.53	0.60	0.52	0.55	0.67	**0.07**	0.53	**0.05**
44.9	0.69	0.35	0.50	0.59	0.41	0.38	0.47	0.52	**0.24**	0.47	**0.08**

Eddy persistence is based on the STD. If STD>0.1 pre-dam and near or >0.1 post-dam, it is considered to have low persistence. If STD<0.05 pre and post-dam, it is considered highly persistent. All other cases are considered moderate persistence. Using this set of rules:
• High persistence – 43.3, 43.4 & 43.7
• Moderate persistence – 44.5
• Low persistence – 43.8, 44.05 & 44.9

CONCLUSIONS

To gain perspective on the relationship of dynamism and persistence, results were plotted relative to each other (Figure 8). Most of the eddies fall into two categories: a) highly persistent and not very dynamic or b) not very persistent and more dynamic.

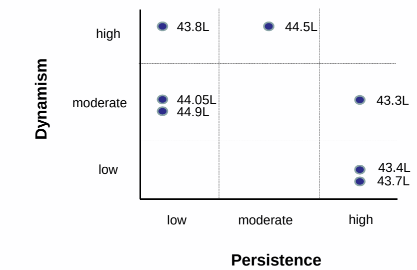


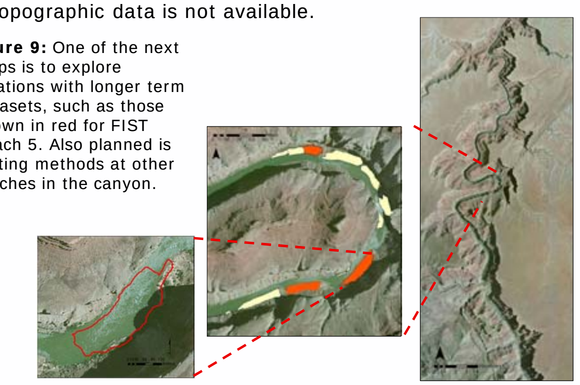
Figure 8: Eddies plotted in dynamic-persistent space.

Comparing total and elevation-based descriptions of dynamism, results suggest that the current metric for dynamism does a good job describing the <8k cfs elevations. There is an apparent correlation It between the metric for dynamism and the metric for persistence – where the dynamism was high, persistence was low and vice versa. When comparing the metric for persistence to the elevation-based evaluation of dynamism, the metric for persistence appears to do a good job describing the 8-25k cfs elevation zone.

NEXT STEPS

1) Apply these methods at other FIST reach locations to test strength of metrics (Figure 9).
2) Apply these methods at eddies where there are longer time series of topographic survey data (Figure 9).
3) Correlate more easily obtainable metrics (e.g.: debris fan slope, upstream rapid elevation change, proximity of downstream debris fan, vegetation coverage) to eddies with dynamic and persistent delineation. Use relationships to describe eddy dynamism and persistence when detailed topographic data is not available.

Figure 9: One of the next steps is to explore locations with longer term datasets, such as those shown in red for FIST Reach 5. Also planned is testing methods at other reaches in the canyon.



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