USING OBLIQUE DIGITAL PHOTOGRAPHY FOR ALLUVIAL SANDBAR MONITORING AND LOW-COST CHANGE DETECTION

EXTENDED ABSTRACT

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Abstract The maintenance of alluvial sandbars is a longstanding management interest along the Colorado River in Grand Canyon. Resource managers are interested in both the long-term trend in sandbar condition and the short-term response to management actions, such as intentional controlled floods released from Glen Canyon Dam. Long-term monitoring is accomplished at a range of scales, by a combination of annual topographic survey at selected sites, daily collection of images from those sites using novel, autonomously operating, digital camera systems (hereafter referred to as 'remote cameras'), and quadrennial remote sensing of sandbars canyon-wide. In this paper, we present results from the remote camera images for daily changes in sandbar topography.

Figure 1 Typical setup of a remote camera system, at river mile (RM) 145.9, Grand Canyon. Visible is the waterproof box containing camera and electronics, and the 20W solar panel.

Beginning in the early 1990s, 35 mm film cameras were deployed at selected sites in the canyon to take photos daily at many of the long-term sandbar monitoring sites (Dexter et al., 1995). In 2008, higher-resolution digital cameras capable of taking multiple photos daily were installed at many of these sites, enabling rapid and low-cost analyses of sandbar response to geomorphic events. By 2014, all of the analog cameras had been replaced as well as additional cameras added

to the monitoring network for a total of 45 cameras. These camera systems are completely autonomous and can be left for months to years without maintenance. Each system (Figure 1) consists of a digital SLR camera controlled by a datalogger programmed with an intervalometer script that triggers the shutter release on the camera to take images at prescribed times. Solar panels are used for power, and the datalogger regulates and minimizes power usage by the camera such that batteries do not drain significantly, even in shaded locations. More details can be found in Bogle et al. (2012).

Controlled flood experiments have been periodically conducted to rebuild subaerial sandbars along the river, and the camera imagery is playing an increasing role in the evaluation of the floods' effects. Post-flood images are compared to pre-flood images taken at the same discharge, and qualitatively analyzed for change in sandbar size by visual inspection. Because of the unique geometry at each site, a particular sandbar may be more likely to change in either area or height (though not necessarily both), thus necessitating use of the general term "size." Each sandbar is manually classified as having undergone major negative size change (lost more than 15%, assigned a rating of "-2"), minor negative size change (-15% to -3%, "-1"), negligible size change (-2% to +2%, "0"), minor positive size change (+3% to +15%, 1"), or major positive size change (gained more than 15%, "2"). Examples are shown in figure 2. For a 2008 flood, 22 sites had three sets of topographic surveys corresponding with the photos. The surveys provided area and volume measurements for each site. To address the "size" conundrum described above, a composite change value was derived from these measurements. The visual analysis agreed with the composite topographic survey change values at 78% of the sites, and disagreed at 2%. Surveyed change was not visually recognized at 15% of the sites, and at 6%, surveys indicated that no change occurred where visual analysis indicated it had.

A 2012 flood was evaluated primarily by photo analysis, and a smaller subset of five surveyed sites was in 100% agreement with the outcomes. Of the 33 sites photographed, this flood produced positive change at 51%, negligible change at 39%, and negative change at 9%. Six months later, 28% of the sites were still larger, while 47% showed negligible change, and 24% were smaller. A 2013 flood, with 42 sites photographed, resulted in enlarged sandbars at 50% of the sites, negligible change at 38%, and negative change at 12%. Six months later, 27% were still enlarged, 50% had negligible change, and 17% were smaller. The two floods resulted in the same type of response at 61% of the sites, while 33% had a recognized change from one flood and negligible change from the other. Six percent showed responses of differing sign. These data show that, overall, the 2012 and 2013 floods were successful in building sandbars in the short term, but that long term results are only marginally improved. Resource managers can use these data (along with sediment budget data) to help design aspects of future controlled flood events, such as duration, peak flow, time of year, and up-ramp/down-ramp rates.

Figure 2 Photos of before and after the November 2012 controlled flood, at two monitoring sites on the Colorado River. The score on the lower right is the qualitative assessment of how much the sandbar changed in size - major negative size change (-2), minor negative size change (-1), negligible size change (0), minor positive size change (1), or major positive size change (2). Both sites in this example saw an increase in size, though to differing degrees.

While this method of photo analysis is based on qualitative assessment, it has been demonstrated to provide a rapid and fairly accurate metric for assessing the immediate downstream effects of controlled floods on bars. Results of controlled floods on sandbar maintenance were available to resource managers within two weeks of the flood events in 2012 and 2013. As well as their primary use in examining sandbar dynamics, these photo datasets can also been used for monitoring other aspects of the river corridor, including vegetation encroachment, spring discharge, endangered species habitat, archeological site protection, and recreational use patterns.

In order to provide a more accurate and quantitative assessment of how sandbar areas are changing with time, photos from the large (and ever-growing) archive of imagery are now being orthorectified using a network of surveyed ground control points at each site. An automated computer process extracts georeferenced shorelines from the orthorectified photos, and calculates an area value for the bar (Figure 3).

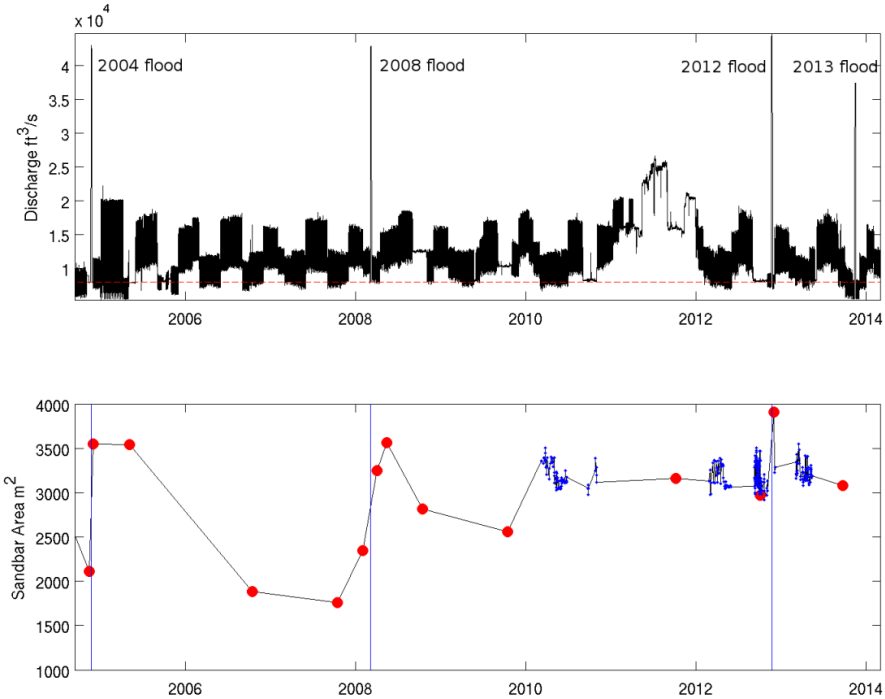

Figure 3 Top panel: the hydrograph at RM 30 in Upper Marble Canyon from summer 2004 to early 2014. The four controlled floods during this period are labelled. Bottom panel: the sandbar area at the RM 30.7 site, at a river discharge of 8000 ft^3/s, prior to the 2013 controlled flood. Red dots are from annual total station surveys. Blue dots are derived from remote camera images and show the short-term variability not captured by infrequent conventional monitoring.

Examining the changes in sandbar area for a given period can yield clues about the effects of different flow patterns on sandbar area and stability. The sandbar at river mile (RM) 30.7, for example, increased in area 33% as a result of the 2012 controlled flood (topographic surveys are in agreement). The next topographic survey, conducted 11 months later, shows the bar back to within 5% of its pre-flood size. Areas derived from the orthorectified photos, however, show that the bar had shrunk to this size within three months of the flood, and then maintained a mostly steady area for the following eight months (Figure 3). In the summer of 2011, for another example, flows were elevated (though not as high as during controlled floods) to equalize the amount of water in upstream and downstream reservoirs (Figure 3). Area calculations for the sandbar at RM 22.0 show the potential bar-building effects of these moderately elevated flows: this sandbar attained its largest area since the 2008 flood, including after the 2012 and 2013 floods.

A weakness of this method is the inability to recognize positive size change in sandbars that aggrade significantly while showing little change in area. To better derive a comprehensive calculation of size change, efforts are underway to extract 3D topographic data from image sets, thus potentially providing a means to estimate sandbar volumes. This process is facilitated by the dam-controlled diurnal stage fluctuations on this section of the Colorado River. Cameras are programmed to take hourly photos, and traces of the water's edge on the sandbar (hereafter

referred to as “shorelines”) are extracted from rectified images using the same methods as above (Figure 4).

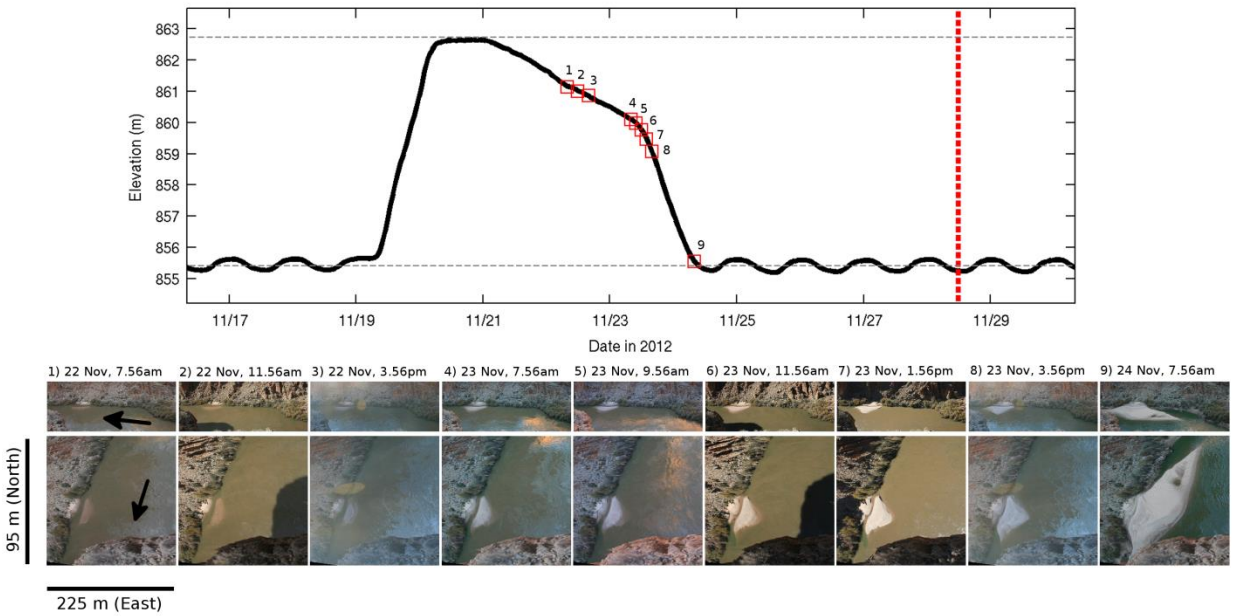

Figure 4 Top panel: the 2012 controlled flood hydrograph at RM 30. The dashed line shows the time when a conventional total station survey was carried out after the flood. The markers indicate the times an image was taken with the remote camera system at RM 30.7. Bottom panel: a time-series of those images, and orthorectified images, from which shoreline locations and elevations are extracted. The arrows in the first panels show the direction of river flow.

These shorelines essentially become contour lines if the stage at the time of the photo is known. A pressure transducer deployed at the site provides the river stage, and thus elevation of the shoreline at the time the photo was taken. Grouping several of these extracted shorelines over a diurnal stage fluctuation will constitute a contour map of the wetted portion of the bar. The process is schematized in Figure 5. The contour model made from the sequences of images in Figure 4 is shown overlain onto the rectified image, in Figure 6.

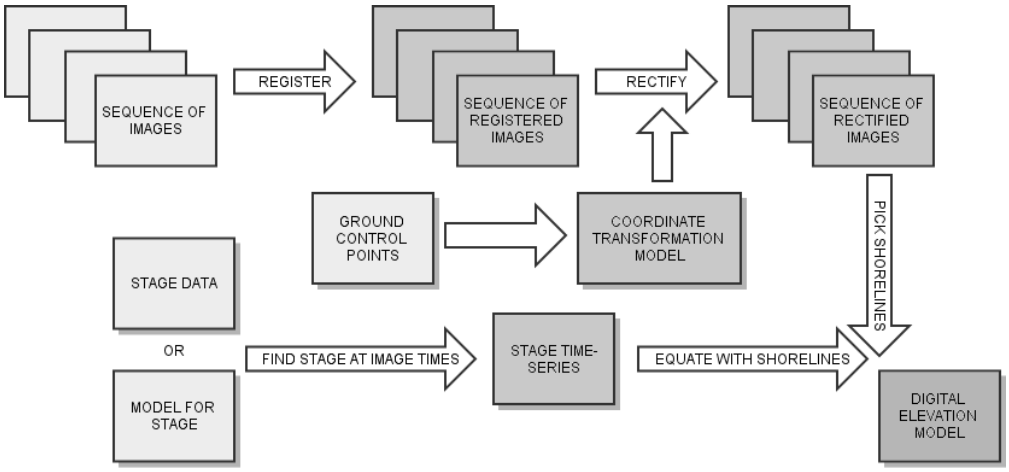

Figure 5 Schematic of the stages required to build a 3D digital elevation model (DEM) of a sandbar using a time-series of sandbar images which have been registered and rectified, and a known stage elevation or stage-discharge relation used to map shoreline elevations.

Figure 6 A colored DEM with contours of the RM 30.7 sandbar, overlain onto an orthorectified image of the bar after the 2012 controlled flood. This DEM was computed from the sequence of images taken during the flood shown in Figure 4, and associated stage elevations, following the methods summarized in Figure 4.

Change in pre- and post-event digital elevation models derived from the contour sets will allow estimates of volumetric changes to be made, and provide quantifiable topographic data that can be processed quickly and without the need to repeatedly send survey crews into the field. Such data provide valuable insight into sandbar changes during times between ongoing annual topographic surveys, especially for sandbars that don't change much in area, but may significantly aggrade - a characteristic that can be difficult to recognize with area calculations

and visual inspection methods. Knowing the sign of sandbar volume change can also be used to corroborate suspended-sediment transport data collected along the river by the USGS (Griffiths et al., 2012). During a flood event, for example, river reaches shown to have a negative sediment mass balance should also show sandbars that decreased in volume. While still in its developmental stages, this technique has the potential to provide high-resolution, low-cost topographic data to help resource managers better understand sandbar dynamics, in the short-term and the long-term, as a result of river management actions.

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