Effects of Continuous High Flows and Daily Fluctuating Flows from Glen Canyon Dam on Grand Canyon Beaches, 1997 and 1998: A Continuation of a Repeat Photography Study by Grand Canyon River Guides, Inc. (Adopt-a-Beach Program)

by

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Abstract

The announcement of the 45,000 cfs test flood release from Glen Canyon Dam in March and April 1996 sparked the interest of river guides in hands-on documentation of the changes in Colorado River sand bars ('beaches'). During a program of repeat photography called Adopt-a-Beach, river guides took photos of and answered research questions about 44 selected beaches, immediately after the test flood and throughout the commercial boating season (March to October, 1996) (Appendix A). The results of the study showed that 82% (36 of 44 sites) of the beaches photographed gained sand visibly, 11% stayed about the same, and 7% (3 beaches) lost sand because of the test flood. After observing the initial effects of the 45,000 cfs release, the guides documented four processes that eroded the beaches. The most significant of these were the daily fluctuating flows, followed by visitation, wind, and finally side canyon flash floods.

In 1997 and 1998 the Adopt-a-Beach (AAB) program has continued it's work as a utility for long-term monitoring. While no controlled releases of equal magnitude to the 1996 restorative flow were implemented during these years, careful attention was paid to the effects of several continuous high flow and spike flow events. Results of the 1997 study show 25% of beaches photographed stayed about the same, while 63% lost sand. In 1998, 38% remained stable and 48% showed further decrease in sand. For both years, fluctuating flow was the most influential process that eroded beaches, followed by tributary flash floods, visitation, and scouring by wind. The series of photographs of campsites showed that erosion due to cutbank retreat was more pronounced during three intervals of high, continuous flows of the 1997 season than it was during regular fluctuating flows of the1998 season. Little if any increase in beach size was observed during either year, except for increases in sand within recirculation zones

below the level of the constant high flows at some sites. Constant high flows occurred during the 1997 spring and summer seasons and following the 31,000 cfs spike flow of November, 1997. Guides generally agreed that most adopted beaches appear to have been eroded heavily by high constant flow releases. At the end of 1997, about 50% of photographed beaches were still larger in size than before the 1996 flood flow, but 30% had returned to it, or had gotten smaller. Pre- and post-flood conditions of 20% of beaches could not be determined due to lack of sufficient repeat photography or because pre-flood photographs were not available. At the end of 1998, 52% of beaches were still larger in size than before the 1996 test flow, and 38% had returned to pre-test flood conditions. Changing conditions in 10% of beaches could not be determined due to lack of sufficient repeat photography or because pre-flood photographs were not available.

Introduction

The operation of Glen Canyon Dam directly influences the Colorado River's ability to deposit, shape, and maintain sand bars in Grand Canyon. River guides have watched these sand bars decrease in area, height, and number as releases from the dam have diverged dramatically from predam flows. In this study, "sand bars" are defined as sand deposits that mostly form in the recirculation zones downstream of debris fans located at the mouths of side canyons. These deposits include both campable and non-campable sandy areas. River guides generally refer to sand bars or sand deposits as "beaches". The guides' interest in beaches stems not only from intimate daily use, but from recognizing these sand deposits as indicators of overall health for the river ecosystem.

Guides depend on sand deposits for camping and lunch stops. Even with user limits, the large number of river trips has made that resource vital, especially in critical areas where beaches are scarce and in high demand (Kearsley and Warren, 1993). The beaches also form the substrate for communities of plants, invertebrates, and vertebrates, including obligate species such as riparian birds (Carothers and Brown, 1991). Grand Canyon beaches nurture unique biologic diversity, preserve ancient cultural features, and foster our enjoyment of these resources.

Prompted by guides, their passengers, and many others, the Bureau of Reclamation administered the Glen Canyon Environmental Studies (GCES) in 1982-1996. Studies show that sand bars can be replenished at higher elevations above the river by releasing flows larger than the maximum daily discharges (Hazel and others, 1993; Kaplinski and others, 1994, 1995; Kearsley, 1995; Schmidt and Graf, 1990; Hereford and others, 1993). Because sand bars are accumulations of sand settling out of water, the water level determines the elevation of the deposit. In the Glen Canyon Dam EIS that resulted from the studies, scientists and managers agreed to release an experimental "beach/habitat building flow" of 45,000 cfs for 7 days, March 26 - April 1, 1996 (the "1996 test flood"). This discharge level was designed to remobilize sand stored in the eddies and the main channel and deposit some of it as higher elevation sand bars.

The size and shape of sand bars reflects the dynamics in recirculation zones (eddies) formed by debris fans constricting the river channel (Schmidt and Graf, 1990). During a flood release, sand may be eroded from an individual bar if the debris fan is overtopped and the sand bar is subjected to erosive downstream current. Otherwise, sand may be deposited in the enlarged eddy created just below the fan (Webb and others, 1989; Schmidt, 1990). In 1983, a flood release of 97,000 cfs built many beaches (Brian and Thomas, 1984). However, most eroded back to their pre-1983 size during the erosive, high flows of 1984-86, and the high fluctuating flows that followed (Hereford and others, 1993; Kearsley and Warren, 1993). Hence, researchers are concerned with the longevity of sand bars formed by the 1996 test flood.

Many river guides observed changes during the mid-1980's and offered these observations to researchers as anecdotal evidence on GCES research trips. When the test flood release was scheduled for March-April 1996, river guides working with Grand Canyon River Guides, Inc. (GCRG), a volunteer, non-profit organization, started a program of repeat photography called Adopt-a-Beach to document changes they would see. The guides would be on site much more often than any of the scheduled research science trips. Also, they could see first-hand, processes such as wind deflation, trampling, flash flooding, and calving of beach faces, that erode and reshape beaches. Thus, the goal of this project is to provide through repeat photography, qualitative, anecdotal evidence of the continued effects of controlled release flows on camping beaches and their condition over time. Also, the study adds to the collection of photographs for campsite documentation by Kearsley and Quartaroli (1997) and complements ongoing sand bar and eddy studies by Kaplinski and others. This report continues from the 1997 Adopt-a-Beach report by Thompson and others, 1996.

Methods

Data collection

For the three years of the Adopt-a-Beach Program (1996-98), GCRG has examined a study set of 44 representative beaches (sand bars commonly used as campsites) in three critical reaches of the Colorado River (Marble Canyon: RM 8-42; Upper Gorge: RM 75-116; Muav Gorge: RM 131-167) (Table 1). The three reaches are narrow sections of river corridor where beaches are either few in number, small in size and/or in high demand (figure 1).

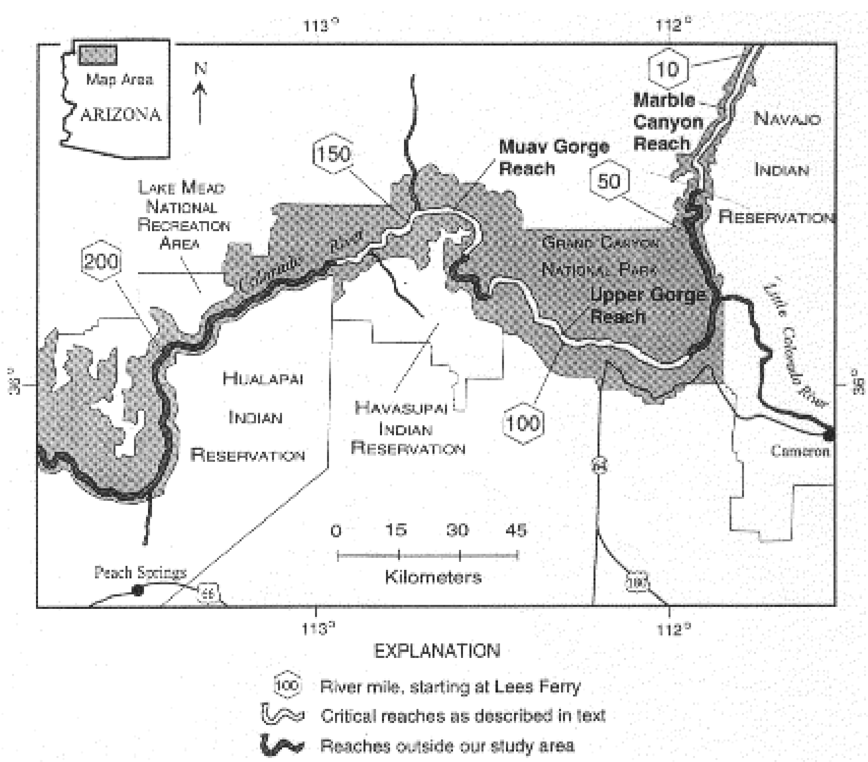


Figure 1. *Locations of the three critical reaches in Grand Canyon National Park.*

These are the same critical reaches defined for the campsite study of Kearsley and Quartaroli (1997). Twenty-two beaches were observed in common by both studies in 1996, which employed slightly different methods. Kearsley and Quartaroli photographed and measured campable space of these beaches on three research trips: in March before the 1996 test flood, in April just after the 1996 test flood, and in September at the end of the 1996 river season.

In the Adopt-a-Beach study, river guides participating in the program volunteered to take photos of individual beaches using disposable 35mm cameras and record specific observations of individual beaches each time they passed them. For consistency between the two studies, Kearsley and Quartaroli provided photo stations and preflood photos for the 22 beaches they had previously photographed. Where possible, guides used those stations. For the remaining 22 beaches, we set up photo stations on trips in March 1996, prior to the test flood. In 1996, logistical difficulties resulted in three sites with no preflood photo. In these cases, several guides were interviewed in order to glean their knowledge of beach changes from pre- to post-flood conditions. In 1997 and 1998, photo stations at several locations were adjusted to provide a clearer view of the beach front.

For each photo rematch, guides first took a photo of a data sheet displaying river mile, date, time, and estimated flow level. On the reverse side of the data sheet, guides answered a series of descriptive questions about observed changes and processes (Appendix A).

Table 1. Beaches within the three critical reaches used in this study.

Reach/Mile		Camp	Reach/Mile		Camp	Reach/Mile		Camp
1	8.0	Badger	2	75.6	Nevils	3	131.1	L. Bedrock
1	12.2	Salt Wash	2	76.6	Hance	3	132.0	Stone Cr.
1	19.1	19 Mile	2	84.0	Clear Cr.	3	133.0	Talking Heads
1	19.9	20 Mile	2	84.5	Zoroaster	3	133.5	Race track
1	20.4	North Cyn	2	91.6	Trinity	3	133.6	Tapeats
1	23.0	23 Mile	2	92.2	Salt Cr.	3	133.7	Lower Tapeats
1	29.3	Silver Grotto	2	96.1	Schist Camp	3	134.6	Owl eyes
1	34.7	Middle Nautiloid	2	96.7	Boucher	3	137.0	Backeddy
1	34.7	Lower Nautiloid	2	98.0	Crystal	3	143.2	Kanab
1	37.7	Tatahatso	2	99.7	Lower Tuna	3	145.6	Olo
1	38.3	Bishop	2	102.7	Shady Grove	3	148.5	Matkat
1	41.0	Buck Farm	2	107.8	Ross Wheeler	3	155.7	Last Chance
			2	108.3	Bass	3	164.5	Tuckup
			2	109.4	110 Mile	3	166.4	U. National
			2	114.3	Upper Garnet	3	166.6	L.National
			2	114.5	Lower Garnet			

Data Analysis

At the end of October 1996, 1997, and 1998, the photos and data sheets were assembled in chronological order per site. We compared photos for each site, looking for changes in beach size and shape above the approximate 20,000-cfs level. Specifically, we identified rocks and vegetation as reference points in each photo to recognize apparent sand loss or gain. In this way we could evaluate relative amounts of cutbank retreat, slope retreat, surface scouring, and gullying.

We compared the guide comments and compiled them into a spreadsheet along with our assessed changes that we observed from the photos. In 1996, we used Kearsley and Quartaroli (1997) area measurements of campsites for comparison to what the guides reported. No obvious discrepancies were found between the two studies for the 22 overlapping sites. For each of three years (1996-98), we grouped the data into three categories of change: beaches that increased in size, beaches that decreased in size, and beaches that remained the same size. We then analyzed and calculated the number of beaches that showed size change for specific time periods. In 1996, they were: 1) from pre- to post-flood (March to April); 2) during the commercial boating season (April to October); and 3) from pre-flood to the end of the boating season (March to October). Our study paid particular attention to the effects of the March/April 1996 test flood for its potential in adding significant volumes of sand to beaches. Subsequent high, constant flows of 27,000 cfs (February/March and June/July, 1997) and 31,000 cfs (November, 1997) were also significant flow events that were assessed.

To analyze seasonal change in beach size for 1997 and 1998, two time periods were used: 1) from the end of the commercial boating season of each year to the beginning of the next boating season (November 1-March 31); and 2) during the commercial boating season of each year (April 1-October 31). These time divisions allow us to identify the processes that affect beach size over time and to assess beach condition at the beginning and end of the commercial boating season.

Results

Of the 44 study beaches adopted by guides in 1996, 40 were studied again in 1997, and 21 in 1998. All beaches adopted in 1998 were also adopted in 1997. We analyzed 254 photographs received from guides, scientists and NPS river rangers in 1997, and 106 photographs in 1998. Repeat photo sets ranged from one to fifteen per beach, spanning from February in the winter season of each year to late October at the end of the summer season. Photographs and accompanying data and comments averaged one per month per beach. The collection provides the basis for the following results which are summarized for four separate periods: 1) results of the 1996-1997 winter season, 2) results of the 1997 summer season, 3) results of the 1997-1998 winter season, and 4) results of the 1998 summer season.

1996-1997 Winter Season Results (November 1, 1996 to March 31, 1997)

In order to link the 1997 data to that of 1996, we first analyzed change in beach size by comparing the last photographs taken in 1996 for each beach, with the first photographs taken at the beginning of the 1997 commercial boating season (November 1, 1996 to March 31, 1997). Isolating the "off season" change in beach size enabled us to evaluate overall beach condition at the end of the winter months, and to set a basis for determining total change during the 1997 commercial boating season (April 1 to October 31, 1997). Although no beaches were visited between October, 1996 and February, 1997, photographs showed a clear decrease in 57% of the beaches which were adopted in both 1996 and 1997. Very little or no change was evident for 28% of the beaches (figure 2).

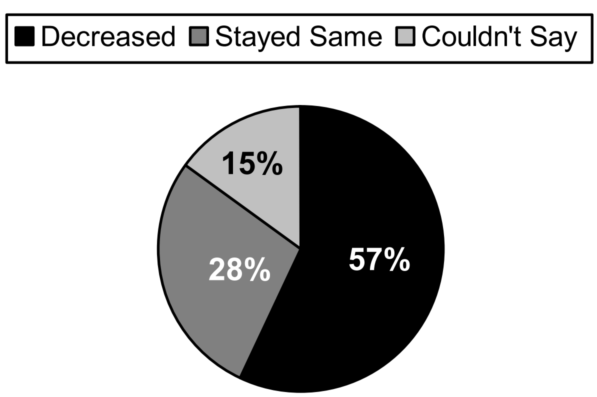


Figure 2. Percent change in beach size from November1, 1996 to March 31, 1997.

For the remaining beaches (15%), photograph stations were changed in the winter season to improve the visibility of the beach front in future records. In these instances, a positive determination of change in beach size could not be made due to different photographic perspectives. Beaches that decreased in size were evenly distributed in the Upper Gorge (nine beaches), and Muav Gorge (ten beaches). Marble Canyon showed less impact with only four beaches showing decrease and six more showing no change (figure 2).

Summer Season (April 1 to October 31, 1997)

During the summer months, guides took photographs and made written comments about beaches, noting first hand observations of any evident changes, as well as the processes causing the change. By the end of the season (October 31), 25% of the beaches showed minimal change, while 65% showed a decrease. At four sites (10% of beaches), change could not be determined because only one photograph had been taken at that site during the season, and in one case because the photo site had been changed mid-season (figure 3).

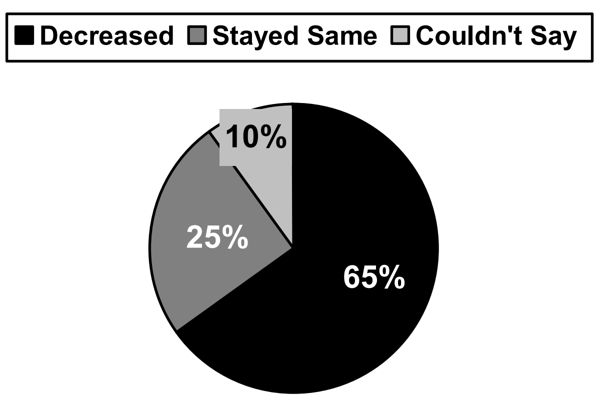


Figure 3. Percent change in beach size from April 1 to October 31, 1997

Guides reported that camping became more difficult in 67% of the beaches, citing cutbank formation, increased slope steepness, and rockiness at parking areas as the leading causes. As in the 1996 Adopt-a-Beach study (Thompson et al, 1997), guides again documented processes which shaped or changed beaches as a way to measure sustainability throughout the season. For continuity with the 1996 study, the same processes were analyzed as the most significant forces impacting beach size: daily or constant fluctuating flow releases, visitation, wind, and flash flooding or gully development from rainfall. In many cases, sites were affected by more than one process. We ranked and summarized these processes by the percentage of beaches within each of the critical reaches that were altered by each process (figure 4).

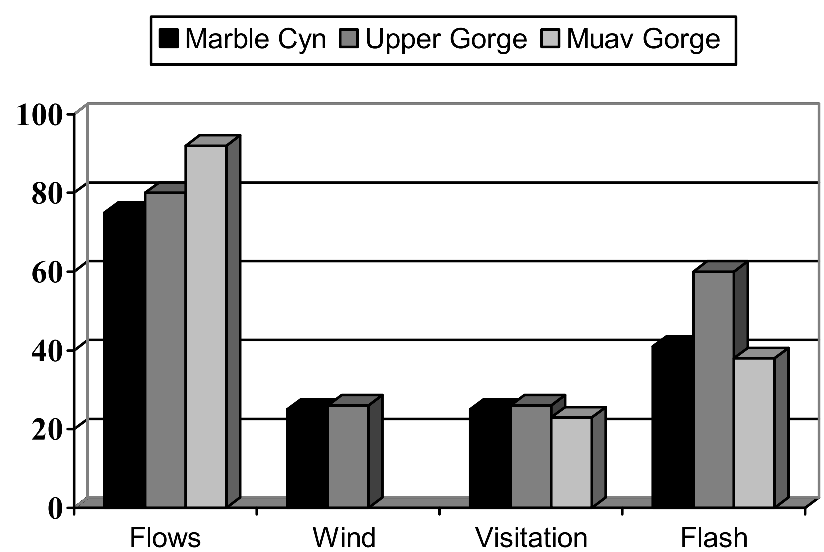


Figure 4. *Processes that contribute to decreased beach size for each of the three critical reaches, 1997. Note: more than one process can affect a beach.*

Figure 4 shows that fluctuating flow was the most common process causing erosion of beaches. The flow regime varied throughout the summer months, with early and late season daily fluctuations of 15,000 to 24,000 cfs. (January/February, and September/October), and constant flows of 27,000 cfs for three weeks in each of March and June, and constant flows of 24,000 cfs for one month in March/April (Appendix D). The percentage of beaches noticeably cut back by either the fluctuating flows or the constant flows ranged from 73% to 84%, depending on the reach (figure 4). In many beaches, guide comments and photographs suggested that the constant flows of 27,000 cfs had the greatest effect in cutbank formation, but evaluating their effects proved difficult due to the time spacing of photographs taken for much of the data set. These cutbanks generally retreated upbeach for the duration of the constant flow period, becoming steeper and taller, and gradually evolved to a gentler slope toward the end of the season.

Flash flooding and gully formation due to rainfall was the next most commonly reported impact to beach shape. Guides reported that flash flooding during mid-summer formed deep gullies at Bishops, Lower Tuna, Bass, Olo, Matcat Hotel, and Last Chance camps, making camping more difficult. Significant side canyon flooding affected beach size adjacent to main camping areas at Nautiloid and Trinity camps. Upper Garnet camp suffered the most devastation and was reportedly "uncampable" by the end of the season. Beaches at Salt Water Wash, 19 Mile, Crystal, Ross Wheeler, Tuckup, and Upper National showed minor gullying (table 1).

Impact due to visitation by river runners was visible at 18% of the sites (figure 4). Guides commented that foot traffic reduced the angle of steep slopes and pushed sand downhill, as well as smoothing over cutbanks. Overall, guides did not mention visitation as having a positive or negative effect on campability, only that evidence of visitation was apparent.

Scouring by wind played a minor role in the shaping of beaches. Only four camps, 10% of beaches, were found to have been reduced in size by wind (figure 4). Three more showed improvement from wind by gully infilling and dune formation, but this did not significantly alter the beach shape or size at these camps.

The end-of-season change was divided out by reach to see any concentrated net results. All reaches showed an overall decrease in beach size, with the greatest impact occurring in the Upper Gorge. Ratios of beaches that decreased to beaches showing little change were roughly even in the Marble Canyon and Muav Gorges (figure 5).

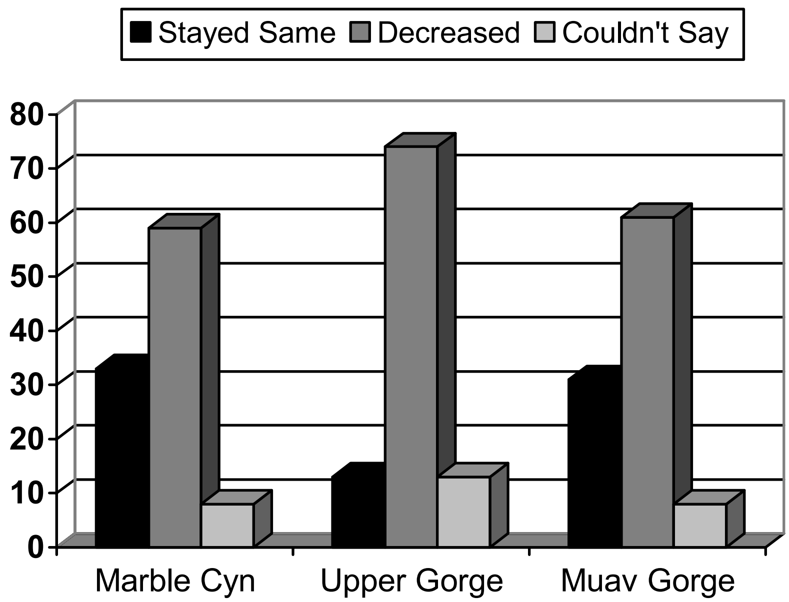


Figure 5. Net end-of-season change in beach size per reach (April 1 to October 31, 1997)

As an additional measure in determining the longevity of beaches to change, we analyzed pre-1996 test flood photographs from March 1996, and compared them to those taken at the end of the 1997 season. Of the forty beaches adopted, 50% still retained more sand than before the 1996 test flood, while 28% had returned to or become smaller than the original pre-flood condition. For the remaining beaches (22%), change could not be determined in the photographs or the pre-flood photo station had been changed. Results of Kaplinski and others (1999) show that high elevation sand bar volumes measured as of April, 1998 are significantly greater than before the 1996 flood flow, by 96% in Marble Canyon, and 45% in Grand Canyon below the Little Colorado River.

1998 Winter Season Results (November 1, 1997 to March 31, 1998)

Winter season changes in beach size from November 1, 1997 through March 31, 1998 were analyzed from photographs taken at the end of the 1997 summer river season and the beginning of the 1998 summer river season. This period was characterized by fluctuating flows from 16,000 to 22,000 cfs, and a notable 31,000 cfs powerplant capacity release for seven days in early November, 1997 (Appendix D). Although sand bars aggraded below the 31,000 cfs level as a result of the November 1997 test flow, the work of Kaplinski and others (1999) showed that most, if not all of this deposition was eroded by subsequent winter flows of 1997-1998. Of the 21 beaches adopted in 1998, 48% showed a decrease in size from the previous season, while 30% remained about the same. For the remaining beaches size change could not be determined for the winter months because photograph stations had been changed between the end of 1997 to the beginning of 1998 (figure 6).

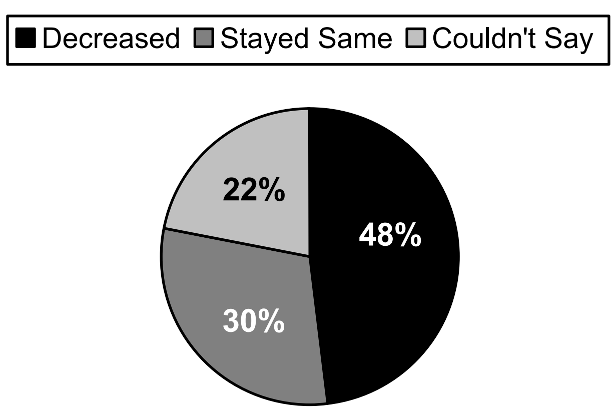
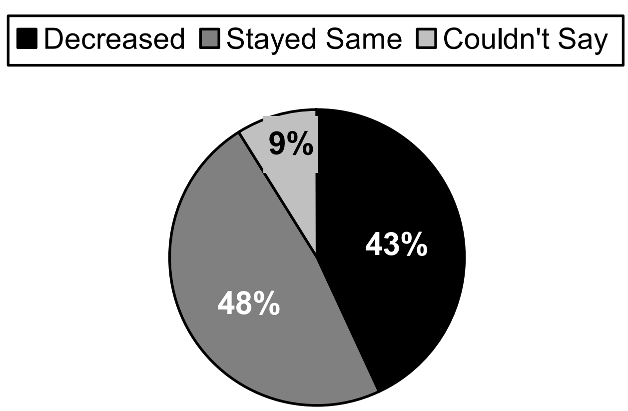


Figure 6. *Percent change in beach size from November1, 1997 to March 31, 1998*

Guides noticed an increase in size from the previous season at several camps, in recirculation zones below the level of the daily high releases. This is supported by the findings of Kaplinski and others (1999), who measured volume increases within recirculation zones and the main channel of 13.7 % between September 1997 and April 1998. While this does not constitute a clear increase in beach size by the criteria of this study (above the 20,000-cfs level), several guides commented that camping was made easier on sand benches of "low water" camps such as Zoroaster and Stone Creek (table 1).

Summer Season Results (April 1 to October 31, 1998)

The 1998 summer season was characterized by a return to season-long fluctuating flows from 10,000 cfs to 17,000 cfs (8000 cfs on the weekends) in April and May, and gradually increased to flows of 16,000 cfs to 24,000 cfs by the end of the season (Appendix D). Of the 21 beaches adopted 48% showed little or no visible change, while 43% showed some kind of decrease. Change could not be determined for 9% of beaches, as these were visited only once (figure 7).



.***Figure** 7. Percent change in beach size from April 1 to October 31, 1998*

As in the 1996 and 1997 summer seasons, beaches were assessed for the types of processes causing change, including: fluctuating flows, visitation, wind, and flash flooding for the 1998 summer season. We ranked and summarized these processes by the percentage of beaches within each of the critical reaches that were altered by each process (figure 8).

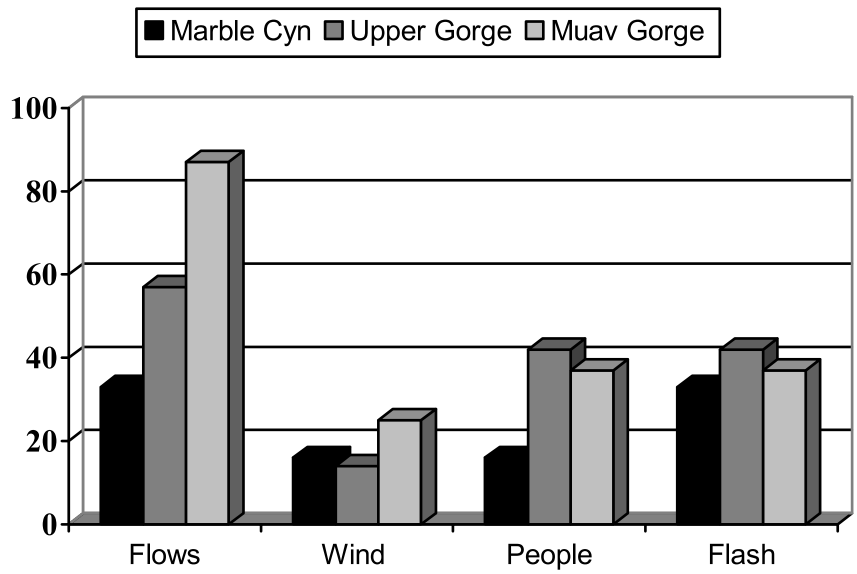


Figure 8. *Processes that contribute to decreased beach size for each of the three critical reaches, 1998. Note: more than one process can affect a beach.*

Fluctuating flows reportedly had the most erosive effect on beach size in 1998 (figure 8). The percentage of beaches noticeably reduced in size by cutbank retreat ranged from 33% to 87%, depending on the reach. Cutbank formation due to fluctuating flows was less pronounced than the previous year. Beaches such as Lower Tuna, Upper Garnet, and Backeddy (table 1) developed tall cutbanks during mid-summer of 1997. In 1998, these same beach fronts became smooth and more gently sloping, with minor cutbank formation.

Tributary flash flooding and gully formation from rain were the next most commonly reported impacts to beach shape (figure 8). The effect of these events were significant, but of a lesser magnitude than those of 1997. Guides reported that tributary flash floods removed sand adjacent to main camping areas at Nautiloid, Trinity, Lower Tuna, and Last Chance camps. Gully formation due to rainfall was observed at Bishop, Upper Garnet, Racetrack, and Upper National camps (table 1) to varying degrees, but was less pronounced than similar events reported in 1997.

Impact to beach shape due to visitation was reported at six sites (Figure 8). Guides noticed that foot traffic aided in smoothing over cutbanks, reduced the angle of steep slopes, moved sand downslope, and aided the infilling of rain gullies. Scouring due to wind again played a lesser role in shaping beaches.

The end-of-season change in beach size was divided out for each of the three reaches to see any concentrated net results. As in 1997, decreased beach size was greatest in the Upper Gorge and the least in Marble Canyon (figure 9).

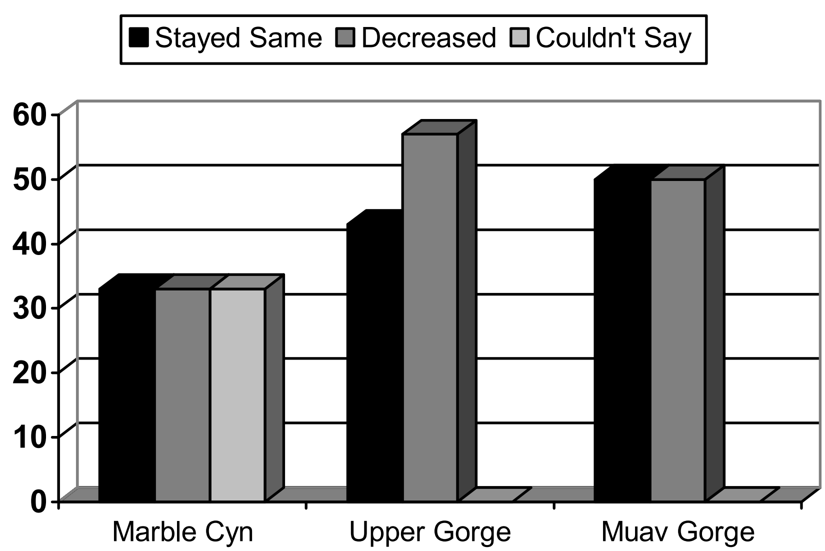


Figure 9. Net end-of-season change in beach size per reach from April 1 to October 31, 1998.

In 1998, the photograph set was analyzed to determine the condition of beaches as compared to their condition immediately before the 1996 test flood. As in 1997, pre-flood photographs of adopted beaches were compared to those taken at the end of the 1998 summer season. Of these, 52% still showed to be in better condition (greater sand volumes) than before the 1996 test flood, while 38% had evidently returned to, or gotten smaller than before the flood flow. For 9% of beaches, pre-flood photographs were not available for comparison.

Summary

During the period of this study, no releases occurred at a magnitude capable of replenishing sand to the highest elevations of existing sand bars. Sand bars Aggraded as a result of the November 1997 test flood, but this new deposition was mostly eroded by subsequent winter flows of 1997-1998 (Kaplinski and others, 1999). Observation of two additional years of data (1997 and 1998) showed beaches adjusting to the dynamics of several different flow regimes from Glen Canyon Dam. Generally, beaches continued to lose sand over both winter and summer seasons, while many showed little change during the same periods. Significant increases to high elevation areas of beaches were not observed during either year. However, two-, three- and four-week periods of constant flows during 1997 were observed to increase erosion of beach fronts at higher stage levels, while depositing sand in recirculation zones.

Throughout both years of the study, fluctuating flow releases were seen to be the greatest factor contributing to the decrease in beach size. This effect was observed to be greater in the 1997 season due to high constant flows than in 1998, where season-long fluctuating flows dominated (Appendix D). Although it is beyond the scope of this study to determine if constant flows were more responsible for beach erosion than fluctuating flows, the higher stage levels of these constant flows (24,000 cfs to 31,000 cfs) appeared to be a driving force in beach front erosion by cutbank retreat. In 1998, beaches decreased in size in a quantity similar to 1997, but the magnitude of decrease was seen to be less pronounced, as beaches again adjusted to flow levels of 16,000 to 24,000 cfs. Less profound factors causing erosion to beaches include: flashfloods and gullying due to rainfall, visitation, and scouring by wind. Of these, flash floods and local rainfall have the greatest influence on the erosion or redistribution of sand on beaches. Visitation contributes to erosion through trampling of the beach front, but also stabilizes cutbanks by reducing their slope. Similarly, wind may act to erode or deposit sand on beaches, depending on the circumstance.

Guides generally noticed the disappearance of remaining sand at the 45K level at many camps throughout the 1997 and 1998 summer seasons, but a majority of beaches adopted in both years still showed to be in better condition overall than before the 1996 flood flow. While this supports the longevity of sand deposition on beaches due to the 1996 45,000 cfs test flood, more research is needed to confirm intrinsic factors contributing to the equilibrium and stability of beach deposits over time. A significant percentage of beaches showed little change over both years of the study. The cause of relatively unchanged conditions in beaches may include increased vegetation above fluctuating flow levels, increased stability of sand deposits within campable areas due to visitation, and quasi-equilibrium of sand deposits due to wind compaction of sand and infilling of gullies due to wind.

The authors of this report feel that the non-empirical, anecdotal evidence of the long-term condition of Grand Canyon beaches provided by this monitoring program is a valuable addition to resource information required by the Adaptive Management Program in assessing the need for future restorative flood flows.

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References Cited

Brian, N.J., and Thomas, J.R., 1984, The 1983 Colorado River Beach campsite inventory. National Park Service Division of Resource Management, Grand Canyon National Park, Grand Canyon, 56 p.

Carothers, S. W. and Brown, B. T., 1991, The Colorado River Through Grand Canyon: natural history and human change: Tucson, University of Arizona Press. 235 p.

Graf, W.L., 1988. Fluvial processes in dryland Rivers: New York, Springer-Verlag, 346 p.

Hazel, J.E. Jr., Kaplinski, M.A., Beus, S.S., and Tedrow, L.A., 1993, Sand bar stability and response to interim flows after a bar-building event on the Colorado River, Grand Canyon, Arizona, implications for sediment storage and sand bar maintenance: EOS Fall Meeting Abstracts, 74:43.

Hereford, R., Fairley, H.C., Thompson, K.T., and Balsom, J.R., 1993, Surficial geology, geomorphology, and erosion of archaeological sites along the Colorado River, eastern Grand Canyon, Grand Canyon National Park, Arizona: U.S. Geological Survey OFR-93-517, 46 p., 4 plates .

Kaplinski, M.A., Hazel, J.E. Jr., and Beus, S.S., 1994, Monitoring the effects of interim flows from Glen Canyon Dam on sand bars in the Colorado River corridor, Grand Canyon National Park, Arizona: Report for Glen Canyon Environmental Studies, 62 p.

Kaplinski, M.A., Hazel, J.E. Jr., Manone, M.F., Parnell, R.A., and Dale, A., 1999. Final Report for Colorado River sediment storage in Grand Canyon: Report from Northern Arizona University Dept. of Geology, 69 p.

Kearsley, L.H., and Warren, K.W., 1993, River campsites in Grand Canyon National Park: Inventory and effects of discharge on campsite size and availability: National Park Service Division of Resource Management, Grand Canyon National Park, Grand Canyon, 65 p.

Kearsley, L. and Quartaroli, R., 1997, Effects of a beach/habitat building flow on campsites in Grand Canyon: Final Report of Applied Technology Associates for the Glen Canyon Environmental Studies, 18 p.

Parnell, R.A., Dexter, L., Kaplinski, M.A., Hazel, J.E. Jr., Manone, M.F., and Dale, A., 1997, Effects of the 1996 controlled high flow release from Glen Canyon Dam on Colorado River sand bars in Grand Canyon: Final Report for the beach habitat building flow from the Northern Arizona Dept. of Geology for the Glen Canyon Environmental Studies, 22 p.

Schmidt, J.C., 1990, Recirculating flow and sedimentation in the Colorado River in Grand Canyon, Arizona: Journal of Geology, v. 98, p. 709-724.

Schmidt, J.C., and Graf, J.B., 1990, Aggradation and degradation of alluvial sand deposits, 1965 To 1985, Colorado River, Grand Canyon National Park, Arizona: U.S. Geological Survey Professional Paper 1493, 74 p.

Thompson, K.S., Potochnik, A.R., and Burke., K.J., 1997, Adopt-a-Beach: Boatman's Quarterly Review (Published by Grand Canyon River Guides, Inc.) v. 10, no.1.

Thompson, K.S., Potochnik, A.R., and Burke., K.J., 1997, Effects of the beach-habitat building flow and subsequent interim flows from Glen Canyon Dam on Grand Canyon beaches, 1996: a repeat photography study by Grand Canyon River Guides (Adopt-a-Beach program). Administrative report for Grand Canyon Monitoring And Research Center by the Grand Canyon River Guides Adopt-a-Beach program. 22 p.

Webb, R.H., Pringle, P.T., and Rink, G.R., 1989, Debris flows from tributaries of the Colorado River, Grand Canyon National Park, Arizona: U.S. Geological Survey Professional Paper 1492, 39 p.

Appendix A

(example of the data sheet used by river guides to identify a beach photograph and document observed changes)

Appendix B

(Spreadsheets of results analyzed in this study, compiled from river guides' data sheets and photographs)

Appendix C
(not included)

(beach photograph collection is archived at the office of Grand Canyon River Guides, inc., 515 West Birch St., Flagstaff, AZ., mailing address:
GCRG
PO Box 1934
Flagstaff, AZ 86002)

Appendix D

(hydrographs of the Colorado River used for analysis in this study, for October 1996-October 1997, and October 1997-October 1998)

Appendix E

(results of 1996 Adopt-a-Beach study from Thompson et al, 1997)

Results

We analyzed a total of 284 photographs, out of over 350 photos received from adopters and scientists for the 1996 commercial boating season. The number of photo chronologies ranged from 3 to 14 per beach, spanning from shortly before the test flood to the end of the commercial boating season in mid October. Photographs with accompanying data and comments averaged 1 per month per beach. This collection provides the basis for the following results which are summarized in three separate periods: 1) results from the test flood, 2) results from subsequent processes during the summer months, and 3) net results at the end of the season.

Test-Flood Results

Photo observations and adopters' comments show that 82% of 44 sites visibly gained a large volume of sand immediately following the flood release. Only 11% stayed about the same and 7% (3 sites) lost sand. All adopted sites aggraded vertically, including the 3 that lost some beach frontage which are 110 Mile, Ross Wheeler, and Upper National.

By comparison, the study of Kaplinski and others (in prep.), shows from pre- to post-flood topographic surveys that 93% of their studied sand bars (N = 33) increased in volume above the 15,000 cfs level. Volumes increased an average of 176% for all sand bars, on which new sand was deposited as 1-2 meters of vertical gain. Only 62% of their sand bars actually expanded in area by an average of 7%. This result substantiates our observations that beaches increased vertically much more than areally.

Studies by Kearsley and Quartaroli (1997), which focussed on campable area, infer that campsites generally increased in area following the test flood. Using their data of "established campsites" within the 3 critical reaches, we calculated that 62% of beaches significantly increased just after the test flood. However, only 50% of 22 beaches that coincide with our study increased in campable area; 27% decreased and 23% stayed the same. Although their data is directed at estimating campable area as a valuable resource, it does not directly reflect overall gain in sand. Since the mission of Adopt-A-Beach is to evaluate beach "health" over time, we based much of our results on beach volume change, with a minimal emphasis on campable area.

For the beaches that gained sand, most adopters reported that camping was generally easier because of the improved quality of beaches, in spite of the difficult hike up many steep slopes. Only 11% of adopters complained of harder camping on these beaches because of steepness or height of the cutbank. For the 3 beaches that were eroded by the test flood, adopters reported that camping was harder because of reduced area.

Summer Results

Beach change through the summer months was often witnessed first-hand and noted by most participating guides, as well as documented by photographs. By the end of the season (mid-October), 30% of the beaches remained intact with minimal changes, whereas 70% showed some kind of decrease (figure 1).

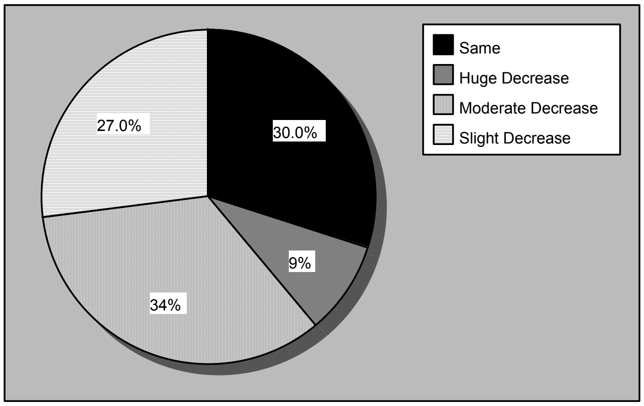

Figure 1. Percent change in beach size from mid-April to mid-October

Results of Kaplinski and others (1997 in prep.) indicated a more pronounced, system-wide effect through the summer. From mid-April to September, the volume of sand decreased by an average of 44% above the 15,000 cfs level (the average daily maximum flow) at 91% (N = 33) of their studied sand bars.

Many guides reported that camping was harder on beaches that lost sand because less space was available than just after the test flood, and more rocks were being exposed. Because river guides were concerned about the sustainability of the beaches through the summer, most adopters systematically documented processes which helped shape or change beach sites. Several forces that reportedly impacted beach size were identified: summer fluctuating flows, wind, people, flash floods or gullying from rainfall, and unknown processes.

We summarized and attempted to rank these processes within each of the critical reaches (figure 2). Fluctuating flows of 15,000 to 20,000 cfs characterized the flow regime throughout

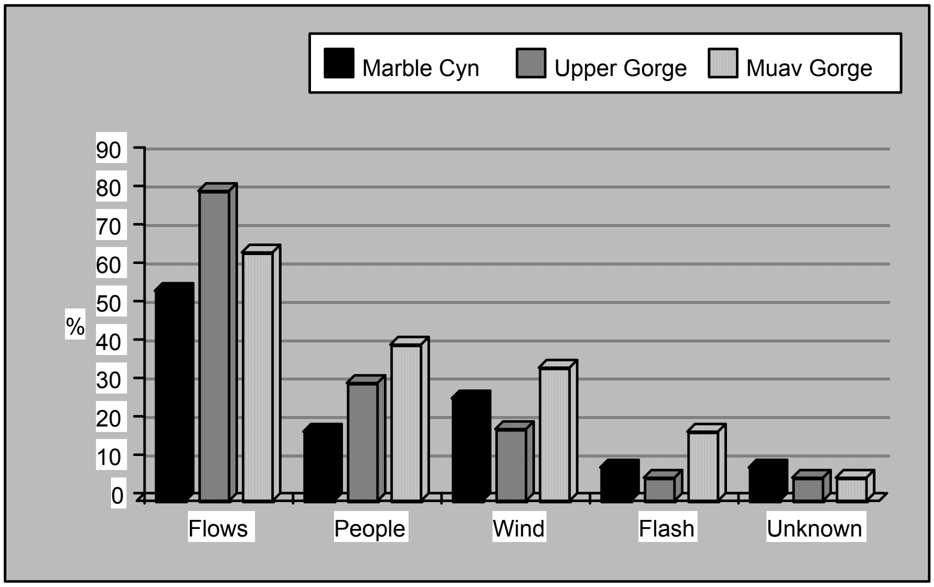

Figure 2. Processes that contribute to decreased beach size for each of the 3 critical reaches (April through October).

most of the summer months, with the exception of lower weekend flows. The fluctuating flows reportedly had the most devastating effect on beach size. Fifty-five to 81% of beaches were noticeably cut back by the summer flows leaving steep cutbanks as they retreated. Adopters also noted when and how cutbank activity changed through the summer. From May to July, cutbanks generally retreated up beaches and became taller because of the summer fluctuating flows. By September, most cutbanks had become subdued, and steep beach fronts had evolved to more gentle slopes.

Trampling by people (figure 2) contributed to 18 to 41% of beaches decreasing in size through the summer. The result was sand pushed down steep slopes, accounting for minor beach front retreat. This helped lessen overall steepness, which many guides found to be beneficial as it afforded easier access to camping.

Adopters reported that wind was active in reshaping most beaches by mounding sand on the surface and deflating cutbanks. It contributed to volume decrease on 19 to 35% of sites (figure 2). The only repeatedly recorded, detrimental effect was surface scour, which visibly exposed rocks on the surface.

Flash floods and gullying from rainfall, which are tangible events easily recognized on beaches, accounted for sand loss in 5 sites (figure 2), 3 of which lie within a 5-mile section of Muav Gorge. Flash floods scoured large quantities of sand from Nautiloid and Olo Camps, whereas Schist, Kanab, and Matkatimiba Camps showed minor gullying. For 3 sites, North Canyon, Hance, and Kanab Creek, some of the sand loss was unexplained and could not be determined from photo observations.

We used either September or October and photographs and corresponding data collected by guides to evaluate end-of-summer beach stability. An estimated 84% of beach fronts achieved quasi-stability, indicated by a gentle slope and low-water bench extending into the eddy. A few adopters suggested that calving of beach faces in early summer may have initiated beach stability. By late summer, many adopters had reported on the processes that formed gentle beach slopes, alluding that people were pushing sand downhill simply through visitation and camping. This is well-documented in photo series where people are actively trampling beach fronts when loading and unloading boats. Each of the beach slopes in the photos appear to become successively more gentle until the fall, when they finally appear to stabilize.

End-of-Season Results

The results at the end of the 1996 commercial boating season show a net positive gain in sand from March to October for over 80% of adopted beaches. Eleven percent suffered a net loss, mainly from the combination of the test flood and summer flows.   Nine percent remained or returned to the same beach as in pre-flood time.

Our observations generally support the following results of Kaplinski and others (in prep.) regarding volume change. Despite the system-wide decreases recorded in September as compared to April volumes, their sand bars still showed a net gain from preflood time (February) to September.   During this time period 93% of sand bars increased, with an average volume gain of 97%.

However, our observations as compared to the results of Kearsley and Quartaroli (1997)are notably different.   Based upon their measurements in March and September, only 45% of the 22 camps that coincide with our study increased in area in the end. Comparatively, 82% of the same 22 camps were reported by adopters to have increased in size in the end. These sites all averaged a net gain of 22% in area (Kearsley and Quartaroli, 1997).

We divided out end-of-season change for each of the 3 reaches (figure 3) in order to see

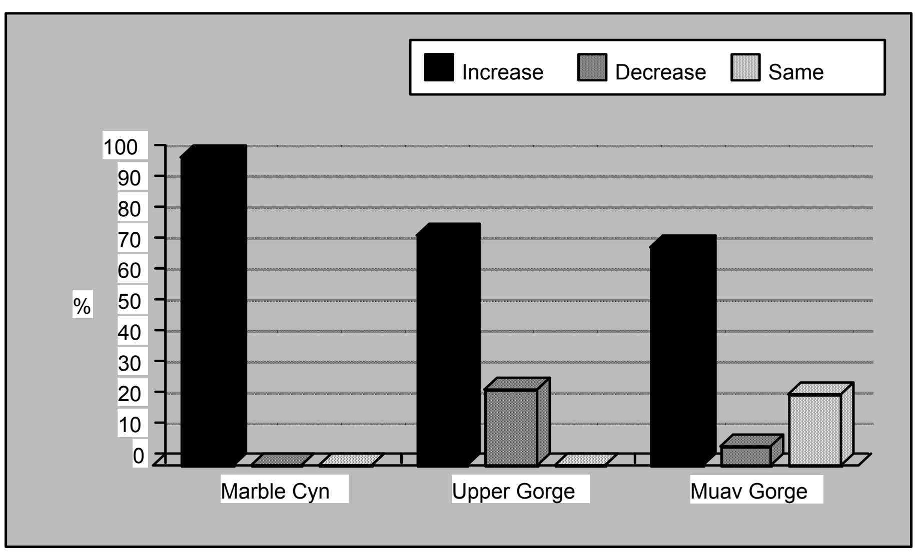

Figure 3. Net end-of-season change in beach size per reach (March

any concentrated net results. Marble Canyon was originally expected to be impacted the most by regulated flows following the test flood, yet 100% of the beaches show a net end-of-season increase. Conversely, most of the net decreases occurred in the Upper Gorge reach where 4 beaches (25%) were cut back, 2 of which were eroded by the test flood.