Effects of Natural Flow, and Controlled-flow Releases from Glen Canyon Dam on Grand Canyon Beaches, 1999: A Continuation of a Repeat Photography Study by Grand Canyon River Guides, Inc. (Adopt-a-Beach Program)

by

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Abstract

During the past four commercial river seasons 1996-1999, river guides, scientists and NPS personnel have participated in a volunteer program of beach monitoring called Adopt a Beach (AAB). This program of repeat photography documents the condition of Grand Canyon camping beaches from April through October of each year. The program assesses visible change to beaches resulting from changing flow regimes. River guides are a unique group of volunteers in that they run the Colorado river many times in one season and are able to provide a fine resolution set of repeat photographs for each study beach included in the program. To date, guides have produced over 1000 repeat photographs and associated field sheets recording sequential condition of beaches across seasons and years. Annual research results include total change to beaches within the entire system, longevity of the 1996 beach/habitat building flow deposits, change to individual beaches between monitoring seasons, and the determination of processes that cause a decrease in camping beach size.

Observations from the 1999 summer season show an overall decrease in beach size from the previous years 1996-1998. However, for the first time in the five-year span of the monitoring program, the percentage of beaches showing decrease was less than the percentage of total beaches that showed comparatively little change. This trend was also evident for the 1998-1999 winter season. Beaches in the upper Marble Canyon reach showed relative stability compared to the Upper Gorge reach which showed a much larger overall decrease in beach size due to intense rainfall during the summer months. Processes that caused change to beaches, including fluctuating flows, visitation effects, rain damage, and wind effects, also displayed a shift in relative influence from previous years, with a higher percentage of beaches affected by rainfall and flash flooding, and a lower percentage showing change due to effects of fluctuating and changing flow releases from Glen Canyon Dam. Beaches still showing evidence of high-elevation sand deposited by the 1996 BHBF were fewer in number than previous years, and the impact to campsites due to increased vegetation was essentially negligible. The AAB program reports annual results to funders, participants, and interested agencies, and is incorporated in the Adaptive Management Program through representation by recreational interests.

Introduction

Adopt-a-Beach (AAB) is a program of repeat photography conducted through volunteer effort and implemented by Grand Canyon River Guides, Inc. (GCRG), a nonprofit grassroots organization representing the interests of the Grand Canyon river running community. River guides, who work throughout the summer months on the Colorado River, are interested in the effect that controlled flow releases from Glen Canyon Dam have on beaches they depend on for campsites and lunch stops. Throughout the years 1996-1999, guides have observed changes to beaches and have recorded this information through repeat photography and written comments associated with each photograph.

Controlled flow releases from Glen Canyon Dam have a direct influence in the Colorado River's ability to build, shape and maintain sand bars in the Grand Canyon (Kaplinski and others, 1999; Thompson and others, 1996). Sand bars form when sediment supply carried by the river, either from bedload or suspended load, is deposited by the action of eddy currents in recirculating zones. This occurs Primarily on the downstream end of debris fans, but also in areas along the channel margin.

In 1981, the Glen Canyon Environmental Studies (GCES) began under the administration of the Bureau of Reclamation to study the effects of controlled flow releases from the dam on the downstream river ecosystem (Dam and river management, 1987), including effects on sediment supply and recreational resources. Studies of sediment dynamics showed that fluctuating flow releases from the dam have had a degrading effect on sand bar deposits (Hazel and others, 1993; Parnell and others, 1997) since the closure of the dam, but that beaches can also be replenished by high flows adequate to entrain bedload sand and cause deposition to the high elevation areas of beaches. Studies of campsite resources demonstrated that impact to sand bars due to erosion decreases the carrying capacity and campable area available for river parties and backpackers (Kearsley and others, 1993, 1997). In 1992, the Grand Canyon Protection Act was passed by Congress and ensured that ecological and cultural resources downstream of the dam would be monitored for changing conditions imposed by operations of the dam. The October, 1996 record of decision (ROD) for operation of the dam states that the dam:

"….must be managed in such a way as to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park….were established, including, but not limited to, natural and cultural resources and visitor use"(NRC, 1999, pp171).

As part of the impetus to ensure overall health of the downstream ecosystem, including critical habitat for vertebrates, invertebrates and plant communities, the 45,000 cfs Beach/Habitat Building Flow was scheduled for the spring of 1996. In response, the AAB program was launched by guides and GCRG to document the effects of the high flow on camping beaches they would see firsthand. Prior to the onset of the high flow, just after, and throughout the 1996 commercial river season, guides photographed beaches and recorded information about their changing conditions. The overall conclusion of that study demonstrated that the BHBF was effective in depositing new high-elevation sand, but that the post-BHBF return to lower fluctuating flow schedules caused renewed erosion of sand bars (Thompson and others, 1996).

Camping beaches are an important resource for river guides conducting trips through Grand Canyon and for the public these trips serve, as well as for private river parties and backpackers. In conjunction with other river corridor monitoring programs overseen by the Grand Canyon Monitoring and Research Center (GCMRC), AAB reports annual results to the Adaptive Management Program through representation by recreational interests on the Technical Work Group (TWG). In 1998, Adopt-a-Beach was reorganized as an annual monitoring program, to observe the continued effects of combined natural and controlled flow releases on campsite conditions. River guides make the program possible, contributing 100% of the manpower, the entire data set of repeat photographs, and valuable input about the condition of beaches throughout each season and between years. Monitoring includes information on natural and human-induced impacts to beaches such as cutbank retreat, wind erosion and dune formation, rain gully formation and the effects of visitation. The purpose of this report is to present the findings of the 1999 data collection effort, and to document the qualitative evidence of continued, first-hand observations by professional river guides. This study also furthers the effort to report cumulative observations of beach conditions pertinent to the monitoring years from 1996 through 1999.

Methods

Data collection

The primary method of assessing camping beaches in this study is by rephotography. During the summer months (April 1-October 31) volunteers (river guides, scientists, GCNP personnel) photograph a specific “adopted” beach every time they pass it while conducting commercial or science river trips (disposable waterproof cameras and data sheets are provided by GCRG). This allows each participant to take stewardship of a site, and enables him or her to detect subtle changes over the course of a season. During each visit, guides photograph their adopted beach from a pre-established photo location that provides a view of the beachfront and as much of the camp as possible. A data sheet accompanies each photograph with questions pertaining to the condition of the beach and the possible causes of changes that are visible. Also included is information on site location, date, time, and approximate water level (Appendix A). At the end of the season guides mail cameras and data sheets back to GCRG for analysis. Typical photo sets include 2-15 photographs per beach per season. The entire data set of photographs for all beaches is assembled and assessed for any visible change that occurred during the season. Comments from datasheets corresponding to each photograph are entered into a database (Appendix B) along with information contained in the photographs (Appendix C). The current database contains over 1000 photographs and comments, for the monitoring years

1995-1999. The assessment of guide observations (comments) along with the corresponding photograph provides a crosscheck between these types of information. If the guide comments do not provide enough information about the site at the time a photograph was taken, the photo is used to assess the site for that visit. If the photo shows very little or no change in the appearance of the beachfront but the guide comment includes information that is descriptive of conditions throughout the site, the comments receive priority.

Critical Reaches

Since 1996 the AAB program has studied 43 beaches from within three *critical reaches* of the river corridor (Fig 1). The practice of assessing camping beach resources within (or partitioned into) critical reaches was first developed by Kearsley and Warren (1993), and modified for the 1996 Adopt-a-Beach study by Thompson and others (1996). A critical reach is defined as a section of the river where camps are in high demand, few in number, or small in size. The same reach system has been in use for all years 1996-99: 1) Marble Canyon, RM 9-41; 2) Upper Gorge, RM 71-114; and 3) Muav Gorge, RM 131-165.

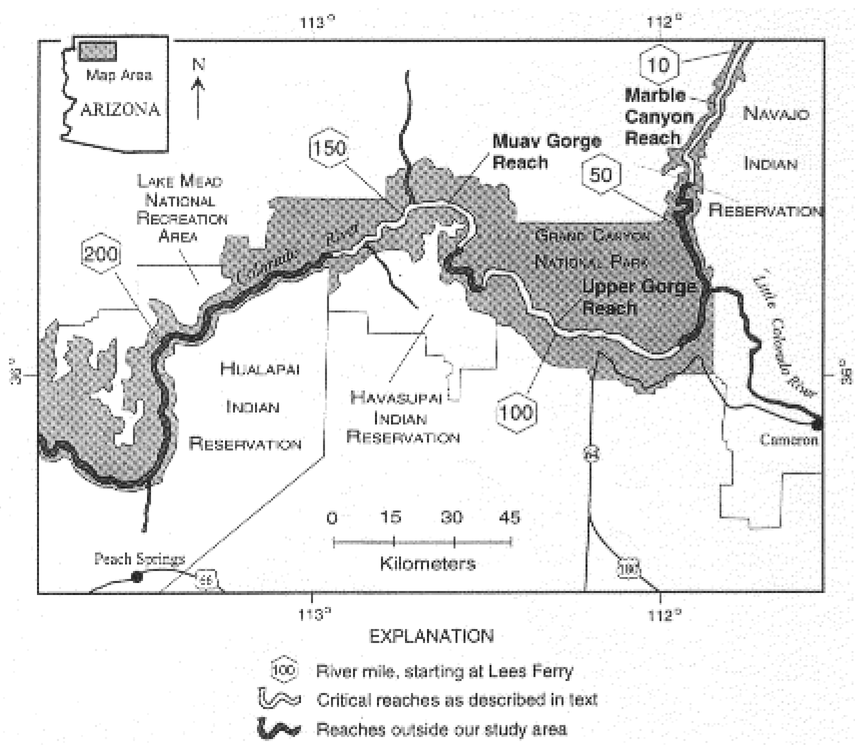

***Figure 1.** Locations of the three critical reaches in Grand Canyon National Park (After Thompson et al, 1996).*

Annual assessment of change in the condition of beaches

Table 1 shows the current inventory of 43 study beaches. Every beach in the inventory has an established photograph location that shows an optimum view of the beachfront and as much of the actual camping area as possible. Time-series photos taken from these locations allow assessment of relative change over the course of each season and between monitoring years.

Reach/Mile		Camp	Reach/Mile		Camp	Reach/Mile		Camp
1	8.0	*Badger*	2	75.6	*Nevils*	3	131.1L.	*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	*M. Nautiloid*	2	96.7	Boucher	3	137.0	*Backeddy*
1	34.7	*L.* 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*			

Table 1. *Beaches within the three critical reaches used in this study. Beaches adopted in 1999 are in italics.*

In following discussions we refer to various periods of study. To illustrate, a full year such as 1998-99 includes the 1998 commercial river season (summer season) that begins on April 1st and ends October 31st, and the intervening winter season that begins November 1st, 1998 and ends March 31st, 1999. Also discussed are the years 1996-1999, or the total monitoring years of the study.

Data analysis is based on the assumption that time-series photographs of individual beaches will show annual decrease in size, increase in size, or negligible change. All beaches are first ranked into one of these categories, based on end-of-season results (Fig 2). Statistical methods are based on the simple percentages of beaches falling into each category at the end of the time period of interest, either the current summer season, the intervening winter season, or throughout the span of the monitoring years. After determining results of seasonal change, a number of pertinent research questions is addressed, including change by critical reach, processes that cause decrease in beach size, longevity of beach sand since the 1996 Beach/Habitat Building Flow, distribution of beach change between beaches for all monitoring years, and the effect of increased vegetation at study sites over time. Given that no actual measurements are taken at each site, change to beach size, shape, elevation, and volume can only be estimated using anecdotal evidence provided by guides at the site, and by use of specific reference markers (such as rocks, bushes or trees, the skyline, or adjacent cliff faces or other features) visible in each photograph to estimate the relative distribution of sand from one photograph to the next, regardless of changing water levels. The methods of this study do not differentiate *intensity* of change in developing the annual statistics, only that change was evident. However, intensity of change to beaches is visible in photographs, allowing observations to be made about the focus and distribution of natural processes, such as rainfall induced gully formation and precipitation intensity throughout the system.

Results

As in previous monitoring years, data collection for the 1999 season began in April and continued through the end of the commercial river season in October. Twenty-nine beaches were adopted (italicized names in Table 1) of the original study set of forty-three, and 235 photograph records and comment sheets were submitted by guides. This was a significant increase in participation over 1998, when only twenty-one beaches were adopted.

Results of the winter season (November 1, 1998 to March 31, 1999).

In order to provide a link between monitoring years and increase the resolution by which incremental change can be seen throughout each full year, the visible change to beaches over each winter season is documented by comparing the last photo of the previous summer season with the first photo taken the following summer season. Although no repeat photography is conducted over this period, and processes that cause incremental change to beaches cannot be evaluated, the overall effects to beaches during the winter season is clearly visible in the first new photo of the summer season, thus documenting the condition of each beach at the beginning of each new summer season.

Results of the 1998-99 winter season showed little or no change in size for 52% of beaches, while 32% showed some kind of decrease. 14% showed a slight increase in deposition on the beachfront (this increase was seen to be minor, and in most cases disappeared by the beginning of the commercial river season in May 1999). For 3% of beaches, change could not be determined because the same beach was not adopted in both 1998 and 1999 summer seasons (Fig. 2).

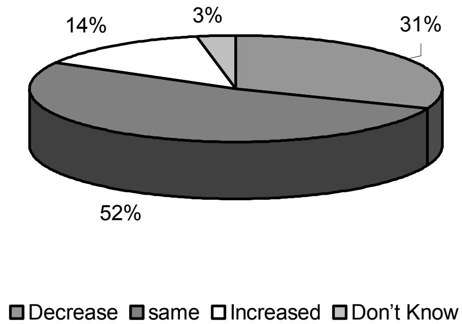

Figure 2. *Change to beaches over the 1998-1999 winter season.*

Figure 3 compares the percentages of beaches that decreased, increased, or stayed the same for each of the study years. The most notable feature of these results is that the 1999 value for beaches staying the same is greater than the three previous years. Although the percentage of beaches for which change could not be determined was higher in the earlier years, the trend demonstrates that the percentage of beaches decreasing in size are apparently in decline over the four year period.

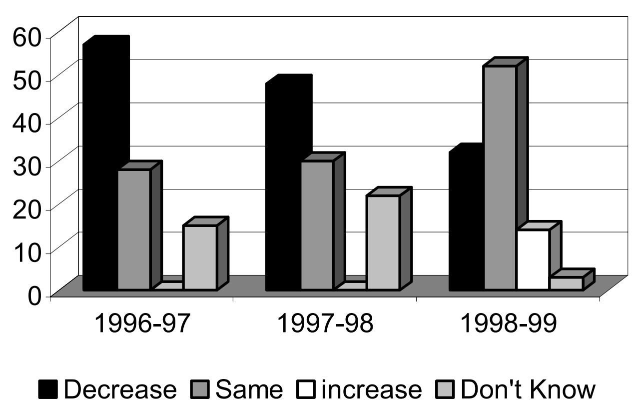

Figure 3. *Comparison of change observed during winter seasons 1996-1997 through 1998-1999.*

Results of the 1999 summer season (April 1-October 31st)

Of the total twenty-nine beaches adopted in 1999 (Table 1), 52% showed little or no change, while 40% showed some type of decrease in size. However, results varied within each critical reach. In the Marble Canyon reach, the proportion was evenly split, while in Upper Gorge, two-thirds of beaches showed a significant damage due to rain induced gully formation (Fig. 4). In Muav Gorge, the trend was reversed, with only one-third of beaches showing a decrease in size. It is notable that the percentage of beaches observed to decrease varied between the three reaches. In Marble Canyon and Muav Gorge, the amount of visible decrease in beach size was minor compared to Upper Gorge where intense monsoon rains caused significant erosion. It is notable that throughout the river corridor, the only change in beach size observed was a decrease.

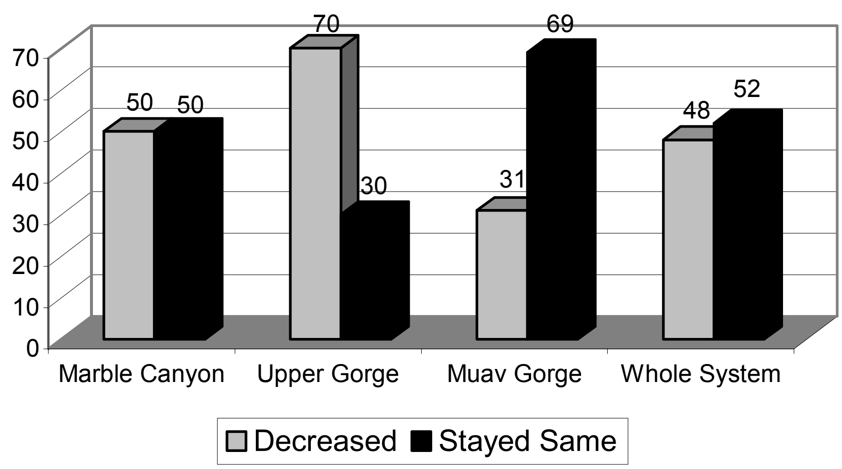

Figure 4*. Change to beaches over the 1999 summer season.*

Processes causing decrease in beach size.

Annual monitoring of camping beach condition includes an assessment of the processes that cause a decrease in beach size. Although it is not possible to account for all mechanisms that affect beach morphology, change resulting from the following processes are used as criteria to recognize decrease in beach size: 1) Cutbank formation and bank retreat due to fluctuating flows; 2) Erosion of camp areas and beach fronts due to rain gully formation and side canyon flash floods; 3) Deflation of beach surfaces and dune formation due to wind; and 4) Degradation of camp areas and beach fronts due to visitation. In this assessment, more than one of these effects may impact each site. The results are calculated by the number of processes that affect each site within each critical reach, and within the entire system.

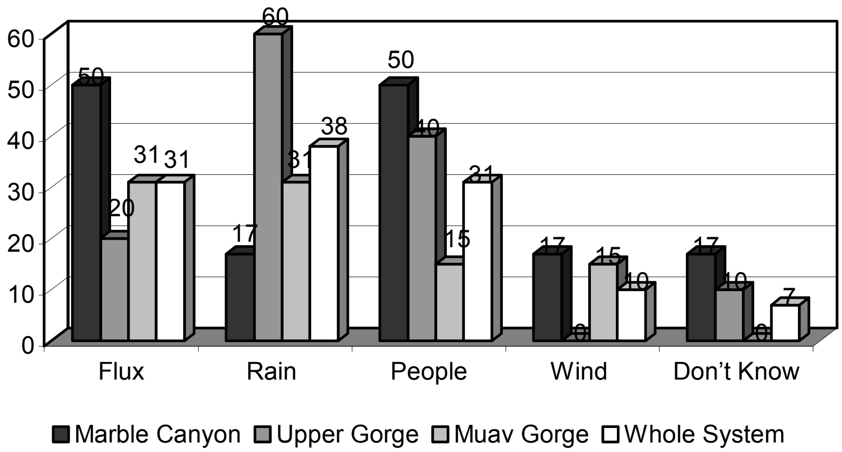

Figure 5. *Processes that contribute to decrease in beach size per critical reach, and throughout the corridor. Note: more than one process can affect each beach.*

Figure 4 shows that overall the effects of precipitation had a greater influence in degrading beaches than did fluctuating flows, effects of wind, or visitation. In Marble Canyon, fluctuating flows and visitation had equal influence (50% of beaches), followed by the lesser effects of rain and wind (17%). At 17% of these beaches the process causing a decrease in beach size could not be determined either due to lack of guide comments or because evidence of the process could not be assessed from the photo series alone. The dominating effect of precipitation is evident in the Upper Gorge reach, where 60% of beaches showed evidence of rain gully formation or side canyon flash floods. Effects of visitation impacted 40% of beaches, while fluctuating flows affected 20%. The effects of wind were negligible in this reach. For 10% of beaches, the cause of decreasing beach size could not be determined. Within the Muav Gorge, The strongest erosive effects to beaches were equally weighted between fluctuating flows and damage due to rain and flash flooding (31%). Visitation and wind deflation were lesser effects, also equally weighted at 15%.

This distribution suggests that 1) the overall ability of fluctuating flows to degrade beaches is still a primary mechanism, but is decreasing with respect to previous years and with time since the 1996 BHBF (O'Brien and others, 1998; Thompson and others, 1996). 2) The effects of precipitation vary annually, but are seen to have a powerful ability to degrade camping beaches. The erosive effects of precipitation are evident in all reaches, but were concentrated in the Upper Gorge reach in 1999; 3) The effects of visitation (primarily due to foot traffic up and down the beach front) exert significant but lesser effects to the decrease in beach size annually (the weight of this observation is roughly consistent with previous years); and 4) Wind erosion is seen to be a significant but lesser effect overall. Several guides commented that dune formation caused a slight increase or redistribution of sand in some camps, primarily in Muav Gorge.

Longevity of beaches since the 1996 Beach/Habitat Building Flow

Beginning with 1997, photo series of beaches taken during the summer seasons 1997-99 have been compared with photographs taken in April, or in some cases May of 1996, just after the 45,000 cfs (45K) releases subsided. In this simple comparison it is possible to evaluate the relative persistence of high elevation (above the 20,000 cfs. stage level) and beach front sand that was deposited by the BHBF, for each site where both a pre-flood and post-flood photograph is available (Fig. 6). The pre-1996 BHBF photograph is used to determine visually the point at which each site has returned to its original pre-flood condition. In some cases sites appear to have lost more sand than the pre-flood condition. This assessment is based on comments from guides, and coverage visible in photographs. In most cases, the photograph location is situated to emphasize coverage of sand at the beach front. High elevation sand deposited with distance from the shoreline (the main camp area) is not visible in many photo locations.

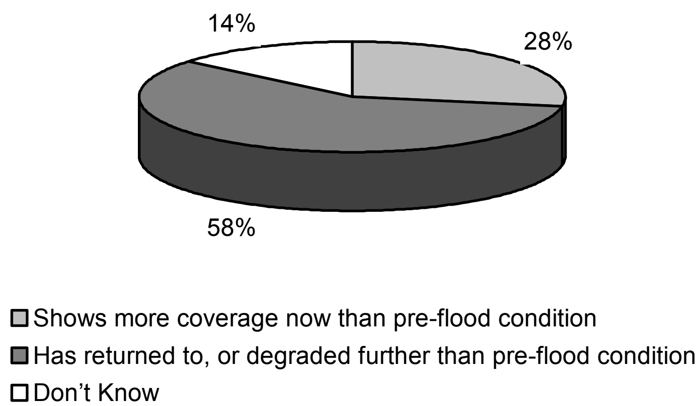

Figure 6*. Longevity of beach size for each site in 1999 compared to pre-1996 BHBF photographs*.

In 1999, 58% of beaches showed a return to pre-BHBF conditions, while 28% still showed evidence of greater coverage of sand than their pre-BHBF photograph. It must be emphasized that in no case has any beach reached its pre-BHBF condition and rebounded due to increased deposition by recent higher stage releases (i.e., there has been no later flow releases of 45k). When compared to 1997-1998, the trend is shows *increase* with respect to the number of beaches that have returned to or degraded further than their pre-flood conditions (Fig. 7).

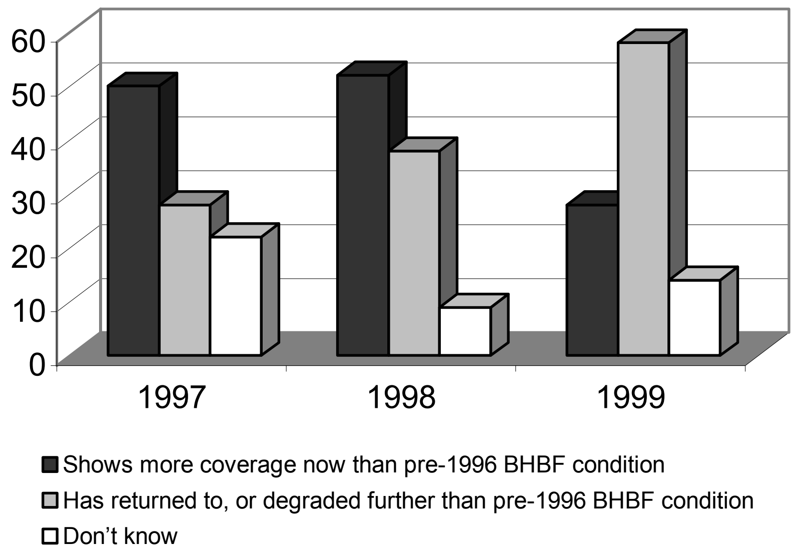

Figure *7. Change to beaches annually as compared to pre-1996 BHBF conditions, for years 1997-1999.*

Change in trends 1996-1999

The primary assessment of change documents whether each site decreased in size, increased in size, or remained relatively unchanged. A further step is to see how this annual result for all critical reaches compared for all four years 1996-99. Analysis of photographs showed that throughout the 1996 season (between April, after the declining limb of the BHBF, and October, at the end of the commercial boating season), sand was removed from beaches primarily due to cutbank formation and retreat as flow regimes returned to lower stage fluctuating flows (Thompson and others, 1996). In many cases, such as in 1996, the degradation of beaches was clearly evident and dramatic. In 1997, beaches continued to eroded primarily by cutbank formation due to the effects of the mid-season continuous high flows of up to 27,000 cfs (O'Brien and others, 1998; Kaplinski and others, 1999). In 1998 the trend of decrease in beach size continued, but the effect was less pronounced as beaches evidently adjusted to mid-range (8-20,000 cfs) steady fluctuating flows (Fig. 8). In 1999, flow releases were in the mid-range (Appendix D), and visible decrease in beaches was least evident of all years, unless affected by rain induced gully formation.

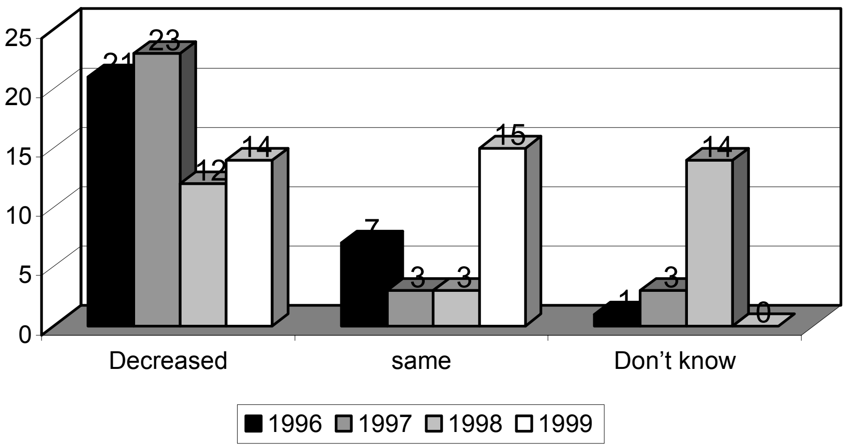

Figure 8*. Comparison of conditions documented for beaches in all years of the study, 1996-1999. This shows how decrease or lack of decrease in beach size varied over the four-year period.*

In general, information compiled by this study has lead to the following observation of longer-term beach shaping: After new high elevation flood sand is deposited by a high controlled flow release such as the 1996 BHBF, these new sand bars are incised by cutbank formation and retreat rather quickly (generally within one season) when the river stage is returned to more usual fluctuating flows (between 10-20,000 cfs.). As river parties use these beaches frequently in the summer months, cutbanks and steep beachfronts are reduced to more gentle slopes by foot traffic. Both of these dynamics may result in the deposition of beach sand in the recirculation zones of adjacent eddies. This becomes apparent at times of lower flows (such as the constant 8000 cfs flow release of June-September, 2000) when low elevation sand benches emerge. High elevation sand continues to winnow from camp areas due to wind deflation and incision by rain and flashflood induced gullying. But although the decrease in beach size is detectable in photographs annually, the apparent decrease in beachfront size is smaller with each subsequent year as the beaches adjust to the flow regime. In some cases, such as Owl Eyes (RM 132), nearly all of the change was seen to occur in one or two seasons following the BHBF, and has decreased very little since that time. In the case of North Canyon (RM 20), the sand bar gained a modest amount of sand during the 1996 BHBF and has decreased in size only in small increments until the present. In most cases, once the beach has adjusted to a new flow release, it shows little change until a new flow regime is adopted that is significantly different from regular operating releases.

Vegetative encroachment since 1996 BHBF

An additional process that may impact the quality and size of camping beaches is the degree of vegetative growth with time after a restorative high flow. To determine this, repeat photographs for years 1996-1999 at all sites were compared with their post-1996 BHBF photos taken shortly after the 45K flow ended. The effectiveness of the rephotography for this purpose was somewhat limited as most photo locations show only the broad beach front and do not show the larger camping area. However, photographs showing the area including and immediately above the fluctuating zone (above and below the 20,000 cfs stage level) at most beaches did reveal some change in vegetative cover. Only 7% showed a large increase, while 48% showed a slight, or noticeable increase. 45% of beaches appeared largely unchanged. Overall, guides have not included comments indicating that increases in vegetation are becoming a problem in widely used camps.

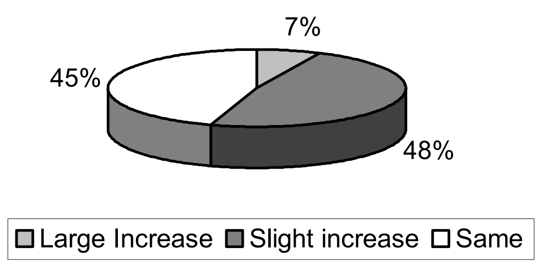

Figure 9*. Degree of visible change in vegetative cover documented over the period of 1996-1999 for all beaches in the study set.*

Summary

The Adopt-a-Beach program has completed its fourth year as an annual Grand Canyon camping beach monitoring study. Implemented by a 100% volunteer force of river guides, scientists and NPS personnel and sponsored by Grand Canyon River Guides, Inc., AAB results are submitted to the Adaptive Management Program through the Cultural Resources Program of the Grand Canyon Monitoring and Research Center (GCMRC). In this way, private and commercial recreational interests are represented as stakeholders in Colorado River management as reported to the Secretary of the Interior.

Overall results of this study showed that beaches continued to decrease in size system-wide, with essentially none showing an increase in size. However, 1999 results differed from 1996-98 trends in that this was the only year during which beaches showing little or no change were greater than those showing a decrease in size. Furthermore, the percentage of beaches degraded due to fluctuating flows was lower than the process of rain and flashflood induced gully formation. It has also been noted that since 1996 the visible intensity of sand loss in individual beaches has declined annually (from the perspective of repeat photographs) since the 1996 BHBF.

The sites included in this study were chosen under conditions within the corridor in 1996. In 1999 it has become apparent that future effort to refine this list may be needed in order to ensure that all sites continue to meet criteria for inclusion in the study. Broadly, this follows the criteria of inclusion within a critical reach, where available camps are scarce or small, or in high demand. Of greatest concern is the number of beaches that have become "uncampable", or undesirable as camps since 1996 due to excessive loss of sand to erosion by rainfall, flash flooding and cutbank formation. Examples of these beaches include Upper Garnet (RM 114.3), Lower Tapeats (RM 132.0) and First Chance (RM 158.0). However, observations during the 2000 summer season and during preparation of this report suggest that low steady flows (8000 cfs) and high flows of 30,000 cfs may have a positive effect on camping conditions throughout the system. If future high, restorative flows are implemented, campable conditions approximating those of 1995 or earlier years may be reattained.

However, the results of this study and those of the previous years 1996-1998 suggest that the net effect of controlled flow releases from Glen Canyon Dam is the continued loss of sand from beach fronts, and combined with the effects of visitation, wind and rain, result in the continued loss of sand from camp areas. While four years is a relatively short period of observation, the change in trends of beach change year to year is an important aspect of this monitoring study. Eventually it will be possible to assess more carefully the long-term effects of controlled flow releases, impact of visitation, and the relative contribution of natural processes such as wind and precipitation in shaping, maintaining, and degrading camping beaches within the corridor. The documentation of the variability of seasonal trends may provide increasing certainty with every monitoring year undertaken.

Acknowledgments

Grand Canyon River Guides, Inc., would like to thank first and foremost the adopters for taking the time to pull over and photograph their beaches trip after trip and year after year, and for their valuable written observations and comments. It takes time and effort to do this, and the dedication shown by guides has literally kept this program alive for five years. The result is the most comprehensive, fine resolution collection of repeat photographs of critical camping beaches in existence for Grand Canyon. An added benefit is the outreach to the public about this effort, and how our resource in Grand Canyon is affected, degraded or maintained by the influence of man and technology. Special thanks are due Lynn Hamilton for exhaustive work in support of this project, and in buttressing GCRG in general, and to Andre Potochnik for his continued hard work as GCRG's (and therefore, this project's) representative of recreational interests in the Adaptive Management process. Many thanks go also to our contributors: Grand Canyon Monitoring and research Center and the Grand Canyon Conservation Fund.

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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)