ADOPT-A-BEACH PROGRAM
Long-Term Monitoring of Camping Beaches in Grand Canyon

A Comparative Examination of the Results for Eight High Flow Experiments in Grand Canyon, 1996 - 2018

By
Paul Lauck[1]

March 4, 2022


Example of camp restoration resulting from the early November 2018 High Flow Experiment event.
Hot Na Na Camp, RM 16.6L
Photo on left taken July 19, 2018, on right April 1, 2019

[1]Grand Canyon River Guides, Inc.
PO Box 1934, Flagstaff, AZ 86002

Adopt – A – Beach:
Long-Term Monitoring of Camping Beaches in Grand Canyon
A Comparative Examination of the Results for Eight High Flow Experiments in Grand Canyon, 1996 - 2018

By Paul Lauck[1]

Abstract

For the past twenty-five years, volunteer photographers for the Adopt-A-Beach repeat photography program have been monitoring beaches along the Colorado River through Grand Canyon. Comparative examination of photos gathered through the year, often accompanied by on-the-spot observations contributed by the volunteers, reveal any changes in conditions pertaining to the desirability of the beach as a camp for rafting or hiking parties. Factors that contribute to changes that may have an effect on the camp, both positive and negative, include: fluctuating river flows, aeolian action, vegetation increase/decrease, human introduced change, rain associated erosion or other actions, natural or anthropomorphic. Probably the most important factor effecting the recreational opportunities on beaches, and the reason that initiated this study, are the manmade flood flow releases or High Flow Experiments (HFE). Since 1996, eight flow releases from Glen Canyon Dam of approximately 40,000 cubic feet per second have coursed through Grand Canyon and redistributed the sediment residing on the bottom and along the shoreline of the Colorado River. This report is a comparative look at the results of those floods, 1996, 2004, 2008, 2012, 2013, 2014, 2016 and 2018 as evaluated on their impacts to camping beaches for use by river parties.

Beginning at River Mile 11.3, as measured downstream from the United States Geological Survey gaging station at Lees Ferry, AZ (USGS, 2013), 44 separate beaches distributed along 250 miles of river are in the study. The resulting evaluations of the effects of a High Flow Experiment are divided into three classifications, relative to the status of the beach immediately prior to the event, as Improved, Unchanged or Degraded. In addition to the outcomes system wide, the results are additionally examined per their distribution in each of four separate geomorphic reaches. The conclusions are presented as observational, monitoring data only.

There were 278 useable data points spread across the 8 years in the study. This averages to slightly less than 35 beaches per year being evaluated. Overall, 189 (68%) were classified as having Improved thanks to the HFE, with a low success of just 41% in 2004 and a high of 86% during the first event in 1996. A total of 31 beaches Degraded after the HFE across the 8 years , or 11% of the instances. The lowest year for this classification was 2004 with 6% of the beaches suffering degradation. The highest was during the next event in 2008 at 20% of the reporting beaches. Beaches that remained Unchanged for all years totaled 58, 21% of the study and an average of 7.25 beaches per year.

In upstream to downstream order, the Marble Canyon reach, river miles 11 to 42, had a 63% Improvement rate, a 25% Degradation rate and an 11% overall Unchanged result. The Upper Granite Gorge, river miles 75 to 116, totaled a within reach of 69% Improvement rate, Degraded in 9% of the instances and remained Unchanged 22% through the 8 years. The Muav Gorge, river miles 131 to 168, had the highest by reach Improved rate with 71%, Degraded in 5% of the examples for that reach and was Unchanged for 25%. The Lower Granite Gorge, river miles 230 to 250, had a within reach Improved rate of 64%, Degradation of 0% and 36% of the instances for that reach remained Unchanged.

[1] Grand Canyon River Guides, Inc., Flagstaff, Arizona (928) 773-1075

Keywords: repeat photography; river sandbar erosion; river sandbar restoration

Introduction and Background

In 1981, the Glen Canyon Environmental Studies (GCES), under the administration of the Bureau of Reclamation, began to study the effects of controlled flow releases from the dam on the downstream river ecosystem (U.S. Department of Interior 1987). Included in this study were 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, Schmidt and Graf 1990) since the closure of the dam. However, beaches can also be replenished by high flows adequate to entrain bedload sand and cause deposition to high elevation areas of beaches (Parnell and others 1997, Wiele and others 1999, Grams and others 2018). Studies of campsite resources demonstrated that the impact to sand bars due to erosion decreases the carrying capacity and camping area available for river parties and backpackers (Kearsley and Warren 1993, Kearsley and Quartaroli 1997).

The Grand Canyon Protection Act was passed by Congress in 1992 to ensure that ecological and cultural resources downstream of the dam would be monitored for changing conditions imposed by operation of the dam. The Act states that Glen Canyon 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" (U.S. Department of Interior 1996).

In 1996, following completion of the "Operation of Glen Canyon Dam: Final Environmental Impact Statement" (EIS), a Record of Decision was signed and implemented that included provision for the use of "beach/habitat-building flows." Now referred to as High Flow Experiments (HFE), the EIS defined these events as "…scheduled high releases of a short duration designed to rebuild high elevation sandbars, deposit nutrients, restore backwater channels and provide some of the dynamics of a natural system" (U.S. Department of the Interior, 1995), with the added intent of restoring some of the dynamics that resulted from flooding in the ecosystem. Further, an HFE is defined as a flow release between 31,500 ft^3/s and 45,000ft^3/s (Glen Canyon Dam Adaptive Management Program WIKI, HFE, n.d.).

Sandbars form when sediment carried by the river, either from bed load or suspended load, is deposited by the action of eddy currents in recirculation zones. This occurs primarily on the downstream end of debris fans, but also in areas along the river's channel margin (Schmidt 1990). The first HFE was conducted in late March 1996, and consisted of a 7-day steady release of 45,000 ft^3/s that was preceded and followed by steady flows of 8000 ft^3/s for 4 days each (Melis, 2011).

Grand Canyon beaches form the substrate for communities of plants, invertebrates and vertebrates, including species such as riparian birds (Carothers and Brown, 1991). These beaches are also an important resource for river parties conducting trips through Grand Canyon. Both commercial and private river trips, as well as backpackers who travel along the river side, rely on wide sandy areas for camping and recreation. Consequently, those who run the river are interested in observing the changes to camping beaches throughout the river corridor in the Grand Canyon. As a non-profit organization dedicated to protecting Grand Canyon and the Colorado River experience, guide members of Grand Canyon River Guides, aided by guidance from GCES staff, developed and implemented the Adopt-a-Beach Repeat Photography (AAB) program prior to the initial flood event in 1996 in order to assess the evolving state of the recreational resource. The use of photographic duplication over time, and analysis of the differences between photo duplicates as a means of detecting change in the Grand Canyon landscape, has been demonstrated previously (Turner and Karpiscak 1980, Webb 1996).

The Adopt-a-Beach project is a long term monitoring program that relies on systematic photograph replication to document and analyze changes in sand deposition and other physical attributes using a dataset of 44 camping beaches along the Colorado River corridor in Grand Canyon. A cooperative agreement with Grand Canyon Monitoring and Research Center (GCMRC), ensures that the extensive AAB photo archive and legacy data are incorporated into the GIS Campsite Atlas project to build a more complete and robust understanding of the status, trends and conditions of camping beaches in the river corridor affected by the operations of Glen Canyon Dam.

Since its inception in 1996, the Adopt-A-Beach program has utilized volunteer photographers to conduct repeat photography of these camps. With the exception of the annual baseline photos acquired during the annual GCRG Guides Training river trip, professional river guides, private party river runners and occasional backpackers make the program possible. These unpaid volunteers contribute 100% of the manpower, nearly the entire dataset of repeat photographs, and valuable input about the condition of beaches throughout each field season and between years. Volunteer photographers for this program are unique in that many run the Colorado River more than once in a season, and are able to provide multiple date sets of repeat photographs and on-the-spot comments for their adopted study beach(es). With the end of the 2020 season, river runners have produced more than 17050 replicate photographs on more than 4150 dates with associated field sheets recording the sequential condition of beaches. More than 250 additional images, mostly used as location references, are also in the archive.

Standardized comment forms completed by the volunteers at the time the photographs are acquired, assist in the effort to document the beach conditions (see Appendix B). The program assesses the visible photographs and first-hand, objective comments pertaining to changes to beaches, and reports on the conditions as influenced by regulated flow regimes, rainfall, wind, vegetation, human impacts or any other factors that may be present. Monitoring includes information on natural and human-induced impacts to beaches such as cutbanks formed from retreating beach fronts, wind erosion and dune formation, rain gully formation and the effects of visitation and camping (Lauck, 2009).

Research results include reporting positive “Improved” conditions, negative “Degraded” conditions or “Unchanged” conditions, when no appreciable changes were found in beaches. Examples of “Improvement” could be expansion of relatively level camp/sleeping area through sand addition (defined as smooth, sandy area at less than 8 degrees of slope and of sufficient size to erect a small tent, Kearsley, 1995) or vegetation reduction, or ‘friendlier’ (less rocky) boat parking and ease of access when loading/unloading boats.

Beach degradation is the loss of ‘campable area’ on a beach for a variety of possible reasons. Reduction in overall beach size as a result of beach front loss, the action of sediment sluffing off and being washed away due to fluctuating flows, a product of daily dam release regimes, is considered the primary reason. This also contributes to exposure of rocks or other obstacles to safe boat parking at camps. Camp area reduced by erosion from rain events can be as prevalent, especially during rainy summers. Gully formation is commonly associated with camp area reduction and can occasionally be catastrophic to a camp. Vegetation increase within a camp area is not unusual, though human traffic will help keep most growth to a minimum. Aeolian sand removal affects all beaches to a degree, both by exposing rocks and through uneven ‘sculpturing’ of camp surfaces. Wind scour often takes longer than one season to noticeably effect a camp. Human impacts range from vegetation disfiguring or removal to heavy erosion from people simply traveling to and from the river. However, while moving rocks or logs constitutes an impact, it rarely contributes to degradation of a camp. Attributes of the primary and secondary processes that cause change in camping beach area and quality are also included.

At the end of each ‘river season’, early to mid-October, the cameras are collected and the photos for the beaches are coded to identify the beach location and date and time of acquisition. Each beach is then evaluated for change during two time periods, from early April through late September/early October (“summer”), and then again through the winter to early April (“winter”). These time periods are dictated by the seasonal variations in flow regime, frequency of natural events impacting the beaches and the period of concentrated recreational use. An Annual Report with the results of these evaluations is then produced. The November HFE impacts were included in the Winter evaluation and the March HFE results were presented in the Summer evaluations. Tabular results are created for each season and presented in the report (Table 1).

Camp name	Rvr mile	Late 2013	to	Early 2014	reason
		Same	Improved	Degraded	POST HFE
Soap Creek	11.3 R			X	Poor comparison due to differing H2O levels
12.4 Mile	12.4 L		X		Gully filled, bigger camp
Hot Na Na	16.6 L				No late season 2013 photo for comparison
19.4 Mile	19.4 L			X	Huge loss of sand (high flow?)
Upper North Canyon	20.7 R		X		Rocks covered in camp
23 Mile	22.7 L		X		Better parking
Shinumo Wash	29.5 L		X		Longer & wider, but severe cutbank
Nautaloid	35 L				No late season 2013 photo for comparison
Tatahatso	37.9 L				No late season 2013 photo for comparison
Martha's	38.6 L			X	Sand lost across front parking area
Buck Farm	41.2 R		X		More camp area on upper end
Total MC	11	0	5	3	
Nevills	76 L		X		Better parking, more camp area
Hance	77.1 L				No late season 2013 photo for comparison
Grapevine	81.7 L		X		Rocks covered in camp, still steep
Clear Creek	84.6 R			X	Steeper with cutbank, still heavy veg
Zoroaster	85 L		X		Much improved, much larger
Trinity Creek	92.1 R		X		Lots of rocks covered, gully filled
Schist	96.6 R		X		Rain erosion covered
Boucher	97.3 L	X			Lots of driftwood in camp, more sand area
Crystal	98.7 R	X			Steeper, but rain erosion covered
Lower Tuna	100.2 L				No late season 2013 photo for comparison
Ross Wheeler	108.3 L	X			No change
Bass	109 R				No late season 2013 photo for comparison
110 mile	110 R				No late season 2013 photo for comparison
Upper Garnet	114.9 R		X		Much larger camp area
Lower Garnet	115.1 R		X		Gully filled, bigger camp
Total UGG	15	3	7	1	
Below Bedrock	131.7 R	X			Modified but not improved
Stone Creek	132.5 R		X		Beach wider, higher, rocks covered
Talking Heads	133.7 L		X		More useable area, flatter
Racetrack	134.2 R	X			Slight sand deposit increase across front
Lower Tapeats	134.5 R		X		Much larger camp area
Owl Eyes	135.2 L		X		Larger, flattened
Backeddy	137.8 L				No late season 2013 photo for comparison
Kanab	144 R		X		Huge increase in camp area
Olo	146.1 L		X		Huge increase in camp area
Matkat Hotel	148.9 L				No late season 2013 photo for comparison
Upset Hotel	150.9 L		X		Better parking, rocks covered
Last Chance	156.3 R		X		Lots of sand added to camp area
Tuckup	165.2 R		X		Lots of rocks covered, gully filled
Upper National	167 L		X		Some camp area added, still bad parking
Lower National	167.2 L				No late season 2013 photo for comparison
Total MG	15	2	10	0	
Travertine Falls	230.6 L				No early season 2014 photo for comparison
Gneiss	236.1 R	X			Little or no change
250 Mile	250.0 R		X		Some useable beach added
Total LGG	3	1	1	0	
Totals	44	6	23	4	

Table 1. Table containing results of Fall 2013 HFE evaluations.
An X is placed in the appropriate Classification column indicating finding. A gray cell indicates "No data".

The purpose of this report is to present a comparison of the results of the initial High Flow Experiment (known as the Beach Building/Habitat Flow) in1996 and the subsequent HFE events through 2018 and examine possible variations in outcome.

Specific research questions that are addressed by this report are:

- How do the results of the 8 HFE's compare per AAB criteria of camp classifications?
- What are the contributing factors dictating the results of an HFE on beaches?
- How are the resulting observations distributed throughout the river corridor?

Methods of Data Acquisition

Study locations and beaches

Since 1996 the AAB program has studied an average of 34 of the 44 targeted beaches per year from within three of the five *critical reaches* of the river corridor (Figure 1). The practice of assessing camping beach resources within critical reaches was first developed by Kearsley and Warren (1993), and modified for the 1996 Adopt-a-Beach study by Thompson and others (1997). A critical reach is defined as a section of the river where camps are in high demand and few in number. The same reach system has been in use for all years of study, 1996-2021. All river miles used conform to the GCMRC mileage system (USGS, 2013). The reaches are as follows: 1) Marble Canyon (MC), river miles 11-42; 2) Upper Granite Gorge (UGG), river miles 75-116; 3) and Muav Gorge (MG), river miles 131-168.

Two additional critical reaches were added during the 2003 monitoring season. The purpose was to increase the sample set of beaches in order to more widely represent the effects of beach erosion and building throughout the whole river corridor below Glen Canyon Dam. These new reaches included Glen Canyon (GC), from the dam to Lees Ferry (river mile 0), and Lower Granite Gorge (LGG), from Diamond Creek (river mile 226) to Gneiss Canyon (river mile 236). Unfortunately, no data has been collected for the Glen Canyon reach for a few years, but the Lower Gorge reach, which was been extended to include the 250 Mile Camp in 2009, is still being actively monitored.

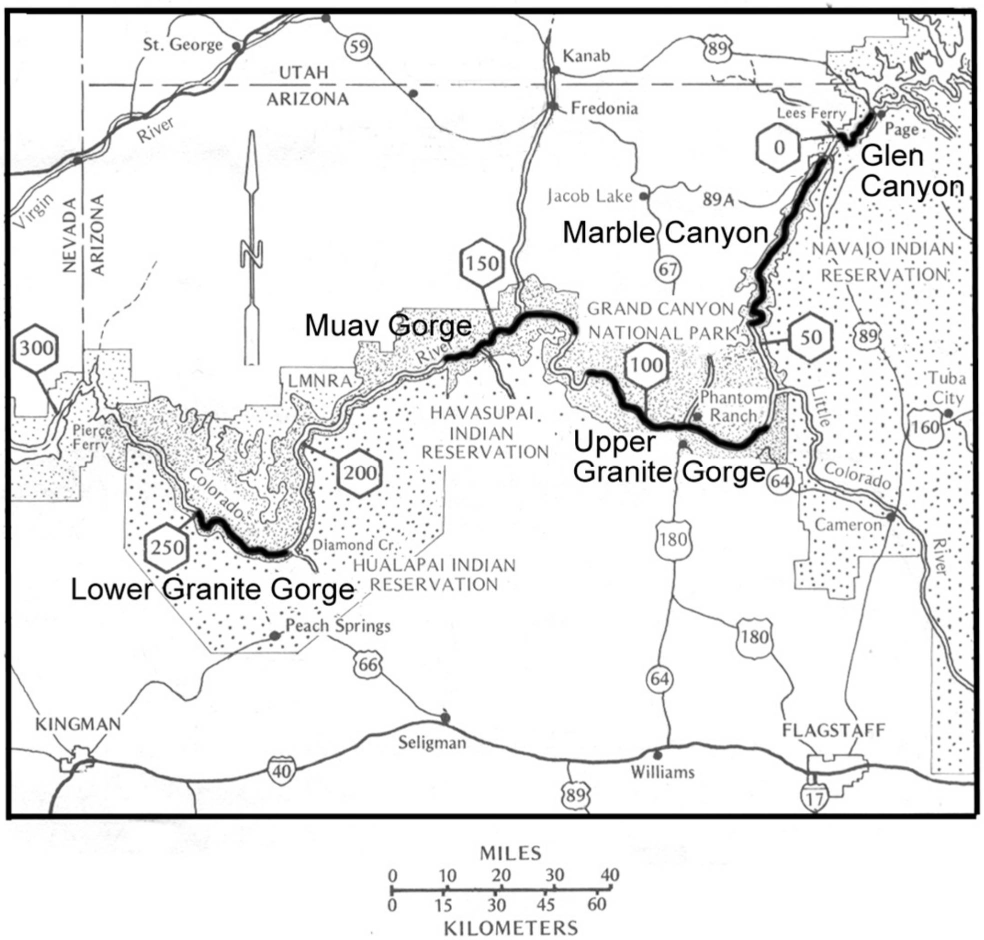


Figure 1. Locations of five critical reaches along the Colorado River in Grand Canyon National Park

Table 1 shows the study campsites (n = 46), 34 of which were originally inventoried in 1996, and includes beaches added in 2000, 2001 and 2009. Note that all analysis statistics are now based on 44 study beaches, beginning with Soap Creek at 11.3 miles downstream from Lees Ferry.

Glen Canyon		Marble Canyon		Upper Granite Gorge		Muav Gorge		Lower Granite Gorge	
Mile	Camp	Mile	Camp	Mile	Camp	Mile	Camp	Mile	Camp
-13.0	Dam Beach	11.3	Soap Creek	76.0	Nevill's	131.7	Below Bedrock	230.6	Travertine
-8.0	Lunch Beach	12.4	12.4 Mile	77.1	Hance	132.5	Stone Creek	236.1	Gneiss Canyon
		16.6	Hot Na Na	81.7	Grapevine	133.7	Talking Heads	250.0	250 Mile
		19.4	19.4 Mile	84.6	Clear Creek	134.2	Race Track		
		20.7	North Cyn	85.0	Zoroaster	134.5	Lower Tapeats		
		22.7	23 Mile	92.1	Trinity Creek	135.2	Owl Eyes		
		29.5	Shinumo Wash	96.6	Schist	137.8	Back Eddy		
		35.0	Nautiloid (Middle&Lower)	97.3	Boucher	144.0	Kanab Creek		
				98.7	Crystal	146.1	Olo		
		37.9	Tatahatso	100.2	Lwr Tuna	148.9	Matkat Hotel		
		38.6	Martha's	108.3	Ross Wheeler	150.9	Upset Hotel		
		41.2	Buck Farm	109.0	Lwr Bass	156.3	Last Chance		
				110.0	110 Mile	165.2	Tuckup		
				114.9	Upper Garnet	167.0	Upper National		
				115.1	Lower Garnet	167.2	Lower National		

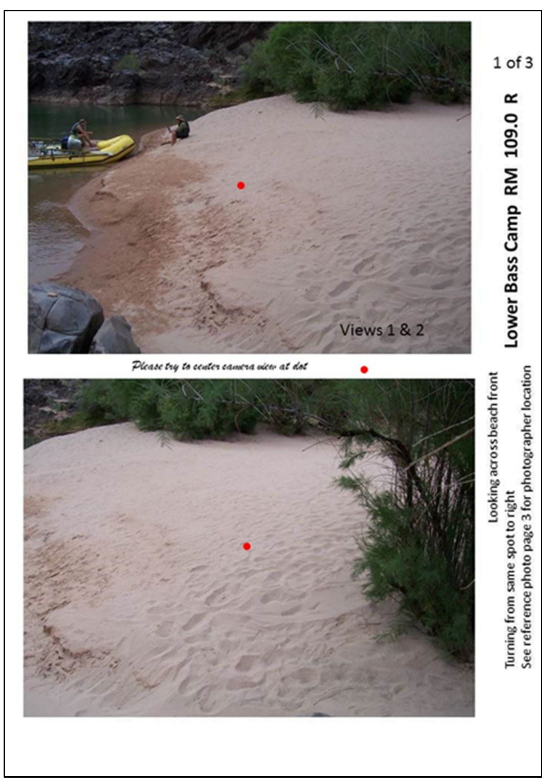
Table 1. Sample set of camping beaches inventoried that lie within the five critical reaches.

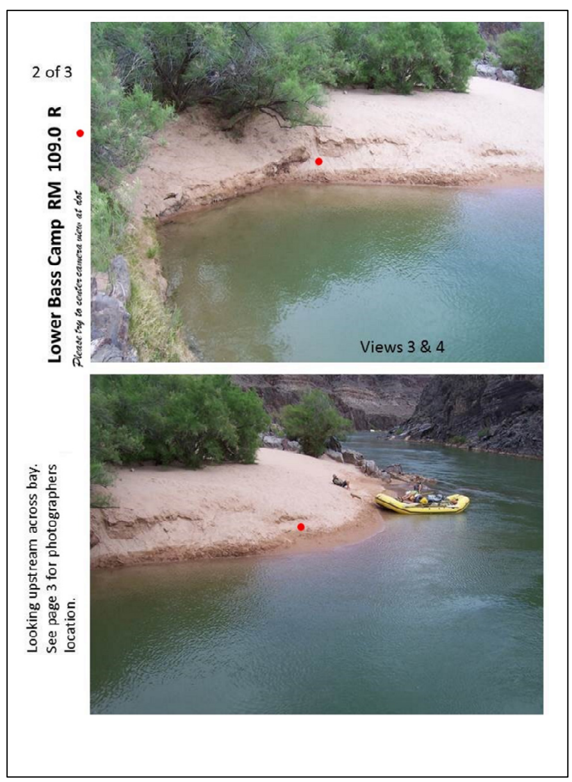
Unlike other established re-photography studies, both within and outside of the Grand Canyon, the AAB program does not adhere to a regime that includes matching photos per a specific time of day or date (Webb 1996, Webb, Boyer and Turner, 2010). The photographs obtained here are much more opportunistic and acquired whenever a volunteer happens to pass their chosen camp. Unfortunately, as will be discussed later, the acquisition of photos within days or a few weeks after a Fall HFE is very limited and plays a role in the evaluation of a beach.

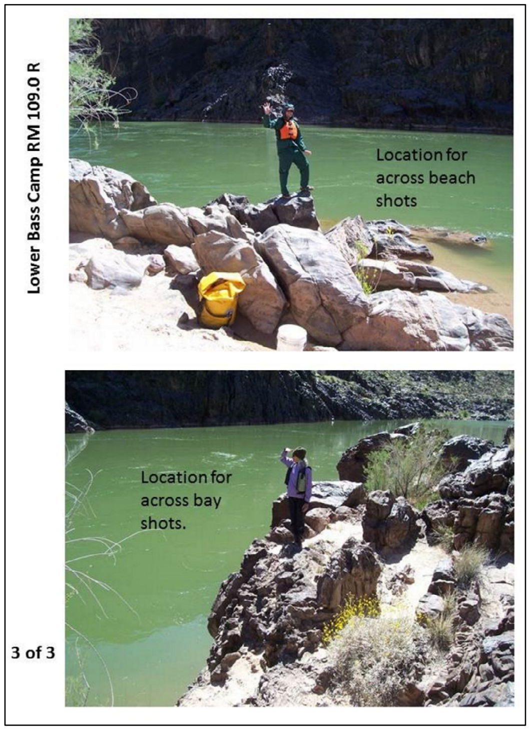
Guidelines for the volunteer are provided to help regulate the consistency required to make adequate comparisons between the images. Every beach in the inventory has established photographic locations that show an optimum view of the beachfront and as much of the actual camping area as possible. However, the portion of the camp photographed at each beach, the relative photographic locations between beaches and the number of images acquired per beach are not all the same. This means that one beach may be evaluated through slightly differing information than another one, in that not every beach photo set contains the same ‘clues.’ Most commonly, photo sets are taken from the boat on the river, taken as a single image or overlapping series, to provide a full, upstream to downstream look at the beach. Photos taken from specifically designated locations on shore, looking across the front of the beach, usually from an elevated, oblique angle, are usually acquired as well (See Figures 2 & 3). Combined, these views provide a considerable amount of information for analysis.

A few beaches are photographed from the river only. Unfortunately, this often limits the visibility of the upper or rear part of the camp. Efforts are being made to expand these visits to include a shore-based view, but this is completely up to the volunteer and their time available. Approximately half of the beaches have photo locations toward the back of the camp, looking across the upper part of the beach or toward the river. While not always practical, these views are invaluable additions to the beach dataset.

Each year, GCRG motivates guides to adopt as many beaches as possible. To encourage a relatively complete data set from year to year, GCRG encourages adoption of high-priority beaches (n = 27) first. These beaches have been adopted consistently for most of the study years. Usually, they are camps that can be used year after year by the river community, and thus are continually in high demand. Due to Park regulations or changes in the river channel, seldom used beaches, like Hance, Kanab Creek, Lower Tapeats or Gneiss are considered as lower priority but are still photographed regularly. The remaining beaches are adopted once high-priority beaches have been claimed.







Figures 2, 3 & 4. Examples of reference sheets supplied to volunteers directing photographer on where to stand and which views should be acquired.

The time-series photos taken within study locations allow assessment of relative change over the course of each season and between monitoring years. Each record in the data base represents an individual visit to a beach where each beach usually has 2-5 photos associated with it. Adopters often take extra snapshots of various impacts such as flash flooding in Hot Na Na (July 2018) and North Canyon (October 2010) and debris flows at National Canyon (July 2012). These documented events and data are available to any interested researchers through Grand Canyon River Guides or Grand Canyon Monitoring and Research Center, http://www.gcmrc.gov/ .

Part of the Adopt-A-Beach program is also to provide the photos to interested parties. The images are currently available as part of the Adopt-A-Beach photo gallery at https://www.flickr.com/photos/147271391@N08/collections or by contacting Grand Canyon River Guides directly.

When a volunteer requests a camera and a beach assignment, they are asked to photograph a completed datasheet (Appendix A), identifying the beach name and mile, plus the photo date and time, immediately prior to photographing the camp. This information is included in the captioning of the image, and helps to correctly place the photo chronologically during analysis. While this practice occurs most of the time, occasionally the datasheet is photographed later or, rarely, not at all. Photos without a distinct date/time attribute in the photography sequence are examined by water color, shadowing on the surrounding walls, or other common elements such as guest attire when available, to help correctly identify the proper sequential placement of the image(s). Embedded metadata in the image can also be used as reference to correctly code the image by date and time. Very infrequently, the date or time may be incorrectly recorded on a datasheet, then onto an image.

Analysis

When comparing the photos for evaluation, numerous criteria are used to gather the empirical data. After the images are sorted by camp and have been given a date and time caption, a consistent pattern of examination is conducted for every analysis. This begins with the water level determination for the first image examined in any set. This is accomplished by consulting the flow graph of one or all of the following USGS gauges: Colorado River at Lees Ferry, AZ (09380000), Colorado River Near Grand Canyon, AZ (09402500), Little Colorado River Above Mouth Near Desert View, AZ (09402300), Kanab Creek Above the Mouth Near Supai, AZ (09403850), Havasu Creek Above the Mouth Near Supai, AZ (09404115) or the Paria River @ Lees Ferry, AZ (09382000) and Colorado River Above Diamond Creek near Peach Springs, AZ (09404200). These graphs also helped determine when additional sediment may be entering the mainstem for possible deposition along beaches downstream. During comparison to each subsequent image, identification of a near-shore landmark or two and its proximity to the current shoreline was employed to help determine relative water levels. The flow graphs were also revisited if required, particularly when it appeared that the river volume and possible sediment load changed due to additional input from the Paria, Little Colorado or Kanab Creek tributaries. For the specific purpose of this report, the following additional flow graphs were consulted to better understand the flow patterns related to the HFE's. See Figures 5 – 20.

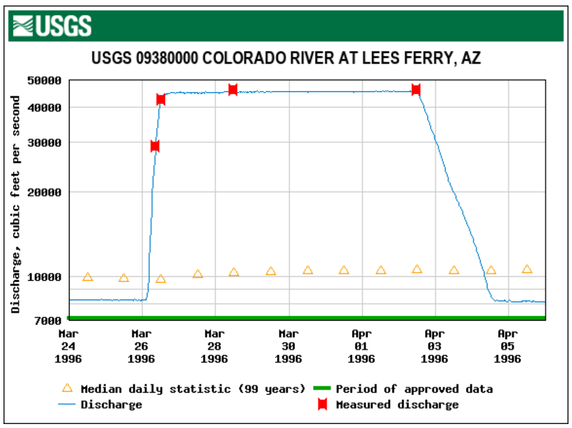


Figure 5. Flow graph for Colorado River at Lees Ferry, AZ., March 24 through April 6, 1996

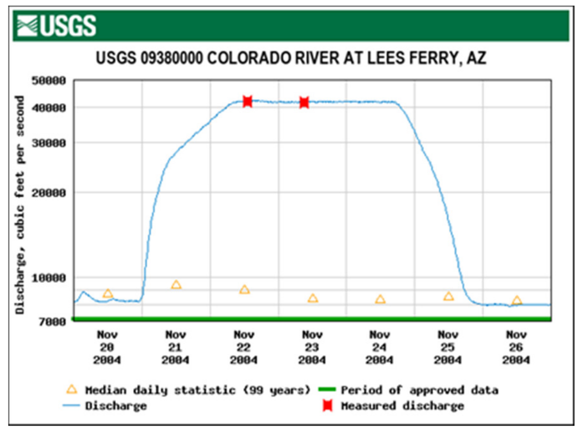


Figure 6. Flow graph for Colorado River at Lees Ferry, AZ., November 19 through November 27, 2004

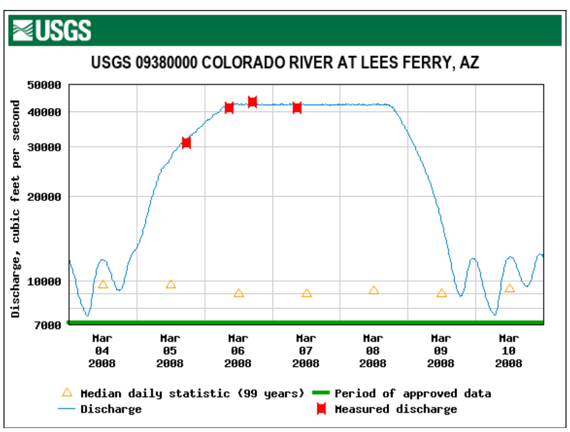


Figure 7. Flow graph for Colorado River at Lees Ferry, AZ., March 3 through 11, 2008

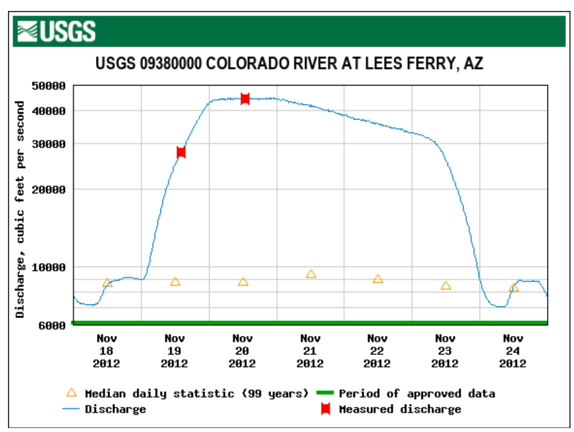


Figure 8. Flow graph for Colorado River at Lees Ferry, AZ., November 17 through November 25, 2012

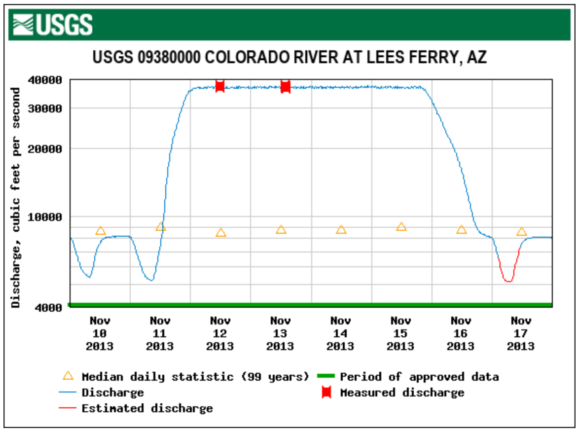


Figure 9. Flow graph for Colorado River at Lees Ferry, AZ., November 9, through November 18, 2013

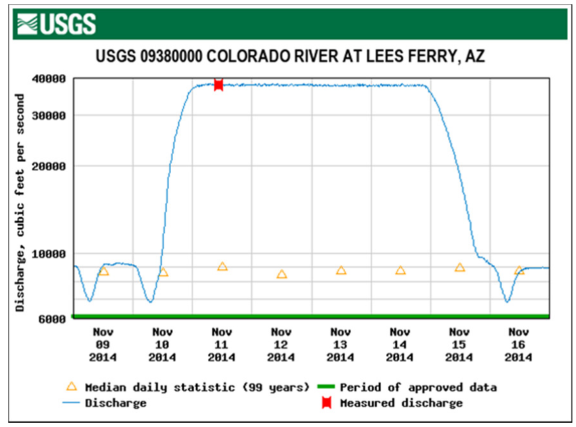


Figure 10. Flow graph for Colorado River at Lees Ferry, AZ., November 8 through November 17, 2014

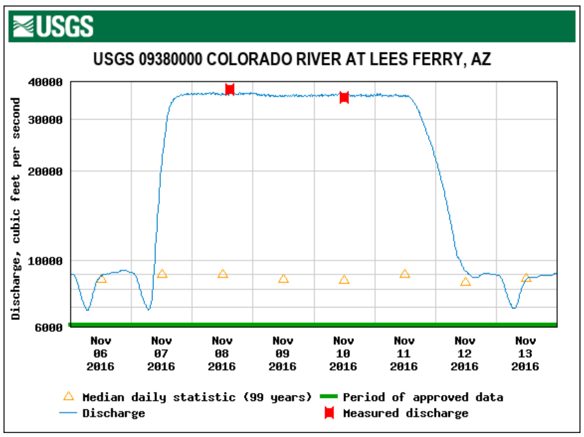


Figure 11. Flow graph for Colorado River at Lees Ferry, AZ., November 5, through November 14, 2016

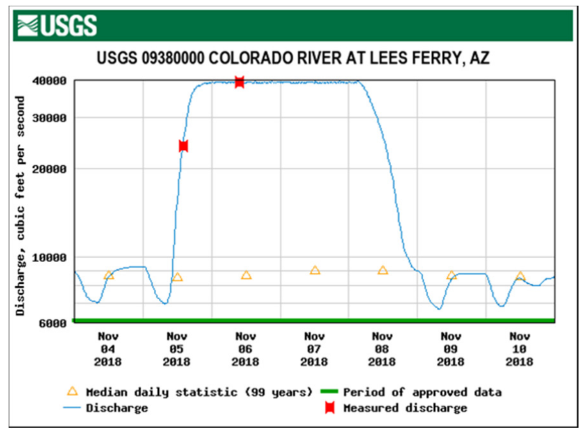


Figure 12. Flow graph for Colorado River at Lees Ferry, AZ., November 3, through November 11, 2018

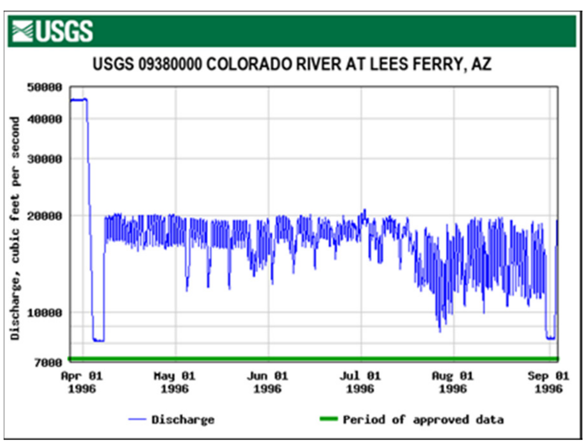


Figure 13. Flow graph for Colorado River at Lees Ferry, AZ., April 1 through September 1, 1996

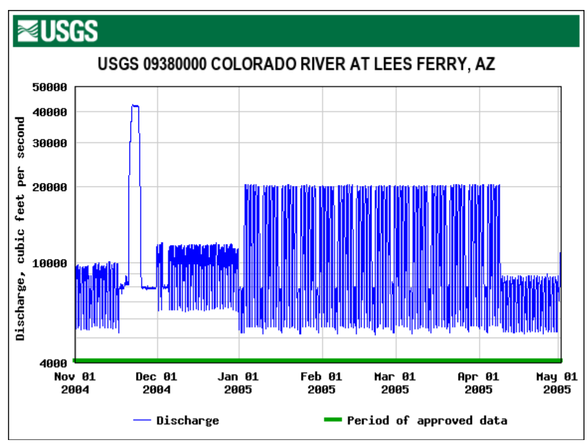


Figure 14. Flow graph for Colorado River at Lees Ferry, AZ., November 1, 2004 through May 1, 2005

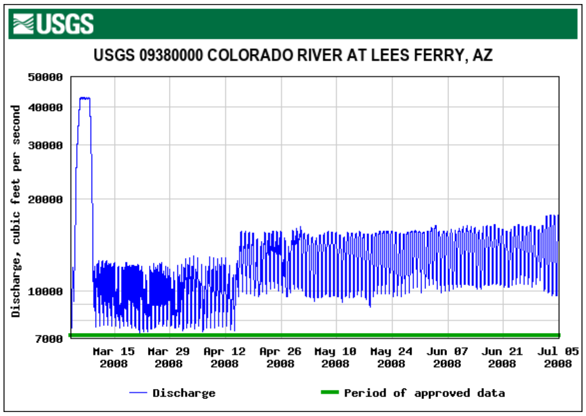


Figure 15. Flow graph for Colorado River at Lees Ferry, AZ., March 4 through July 5, 2008

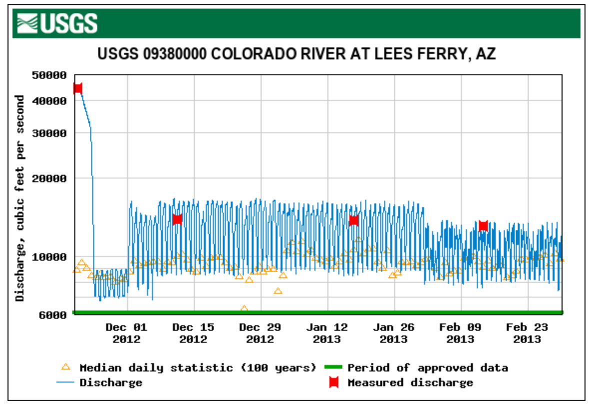


Figure 16. Flow graph for Colorado River at Lees Ferry, AZ., November 3, 2012 through March 1, 2013

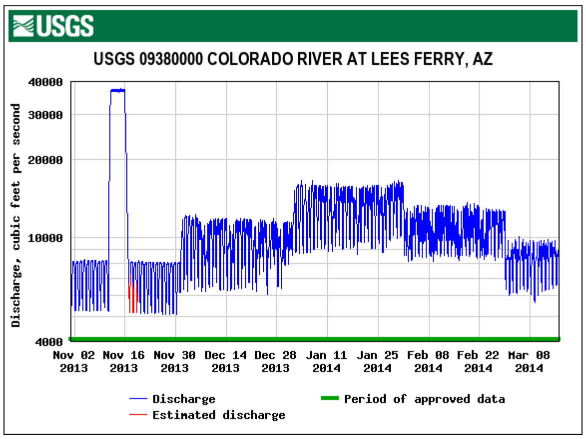


Figure 17. Flow graph for Colorado River at Lees Ferry, AZ., November 1, 2013 through March 10, 2014

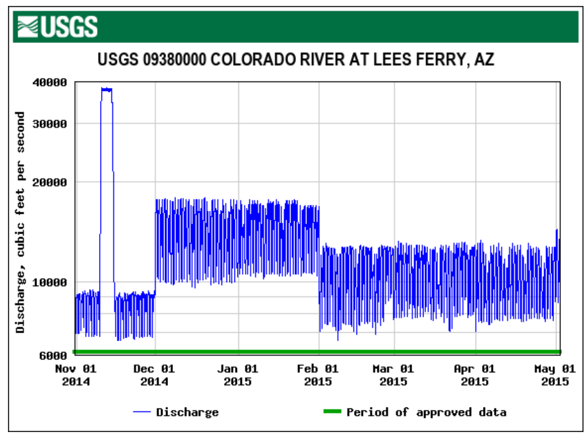


Figure 18. Flow graph for Colorado River at Lees Ferry, AZ., November 1, 2014 through May 1, 2015

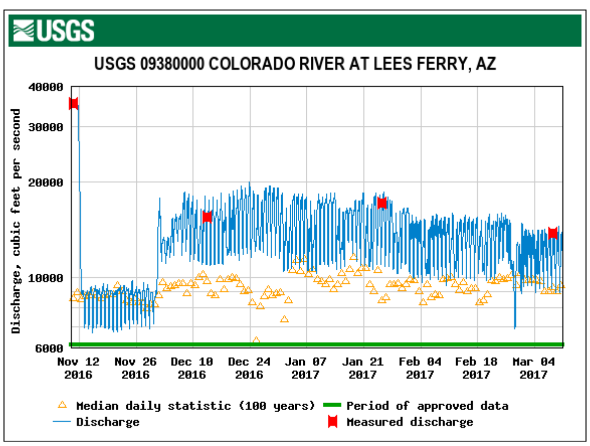


Figure 19. Flow graph for Colorado River at Lees Ferry, AZ., November 10, 2016 through March 5, 2017

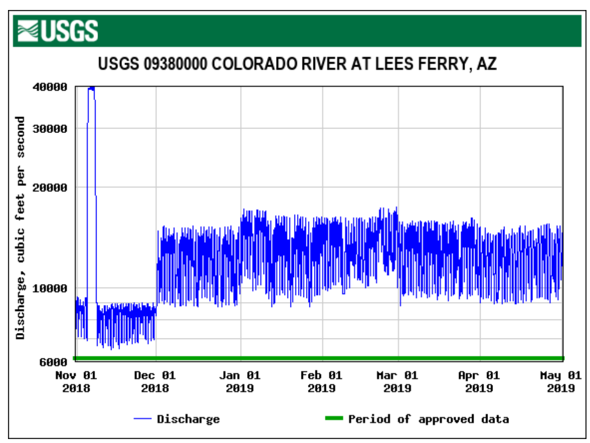


Figure 20. Flow graph for Colorado River at Lees Ferry, AZ., November 1, 2018 through May 1, 2019

Prior to visual analysis, each set of datasheets for that particular beach is consulted to identify the photographers' impressions and to note any factor or event that should be evident during the analysis.

The images were viewed for evaluation using the Adobe Photoshop v7.0 and Windows 11 Photos Viewer software viewed on a Dell 24" monitor. Beginning at the front, or shoreline of the beach, the images were examined and compared. The presence/absence of rocks or debris, either hindering or enhancing boat parking, were noted. Due to the variety of river flow levels between the comparison photos, change in the 'parking' at a particular beach is often difficult to evaluate, and, when covered at higher flows, is considered only when recorded by the AAB observer. Any beach front cutbanks that would affect unloading/loading of boats at similar flow levels, or which indicated erosion of the beach by the river flow were also noted. Conversely, the absence of a cutbank or smoothing of an access slope helped determine the possible addition of sand by sediment augmentation or other river action that benefited the camping desirability of the beach.

The images being compared were then examined progressively from beach front to back to note the absence or addition of rocks or other debris that would impact the total area being used as a camp. The location and visual extent of emerging rocks can usually indicate the physical action that occurred to reveal the rocks. As an example, rocks that were covered in image "A" by sand, covered by river flow in image "B" and subsequently revealed as the water level receded, are noted as indicators of river flow erosion. Conversely, the reverse action would be noted as an indicator of sediment deposition.

Figure 21. An example of an Improved camp following an HFE. Stone Creek, RM 132.5 R, April 11, 2012.

The same kind of visual clues can also be used to determine aeolian impact, particularly when the exposed and/or covered rocks and shelves are higher than any possible river flow level during the time period being examined.

Determining whether a beach was uncomfortably steep for access was easily assessed if one of the photos was taken across the front, either looking up or downstream. But beaches with only head-on photos are more difficult to discern. Well-trodden paths, leading to and from obvious access points, creating easily eroded channels, are the primary clues. Human caused erosion is usually noted by the volunteer photographer and can be correlated with the images.

Beach images acquired from various viewpoints were the easiest to determine changes in vegetation. When this was not possible, such as head-on only shots, a systematic comparison from one end of the beach to the other was used. Baccharis species, arrow-weed (*Pluchea sericea*), Russian thistle (*Salsola tragus*), coyote willow (*Salix* species) and camelthorn (*Alhagi* species) were usually identifiable when noted moving into a previously open sand area, or were missing from subsequent images.

Figure 22. An example of water draining from beach immediately following an HFE, undermining the sediment deposition. Crystal RM 98.7 R, March 12, 2008.

Because of varying photo locations from one beach to the next, some agents of change are more readily apparent than others. Deposition/erosion across a beach front at waterline is always more prominent in the images than perhaps vegetation incursion or loss. Aeolian activity on a beach is more apparent when the photograph is acquired from an angle slightly higher than the beach itself, and vegetation changes are more readily denoted when there are images of the beach in addition to the beach front itself. Not all beach photos include areas where human impacts would most likely be found.

While every effort is made to ensure an even, consistent analysis of the beaches, the patterns of photo acquisition on any particular beach may bias the evidence of an agent of change. Conversely, some bias towards a No Change determination may be present in other photo acquisition sets. The final determination is sometimes dependent on the patterns of photo acquisition established for a particular beach and, to a lesser extent, the effort exerted by the volunteer photographer.

Prior knowledge of the study sites by the investigator was also considered, though this did not determine the final classification used for any particular beach. Using these analysis criteria, the beaches are given classifications indicating desirability as camping beaches, stated as Improved, Degraded or Unchanged. While the designations of Unchanged, Improved and Degraded are inherently subjective, the results are reflective of the stated evaluation purpose of determining the beach as a useable camp for river trips. No photogrammetry techniques were employed and this should not be interpreted in any way that results were obtained using anything other than objective evaluation.

Figure 23. Beach being undermined by water drainage after HFE due to quick downramp. Bass Camp, RM 109.1 R, March 14, 2008.

This paper specifically addresses the instances when a beach was Improved, Degraded or remained Unchanged through the action of an HFE. Although the factors determining classification are always consistent, regardless of year, season, etc., emphasis on one or more of the following criteria was used following an HFE. To be considered an Improved beach an expanded camping area, which is most readily identified by previously exposed rocks being covered, gullies and access trails being filled with new sediment deposit, and the leveling of depressions or mounds often associated with wind scour, are the highest priority. Secondly, easier access from boat to camp interior, usually identified by a gentle slope across the beach front, with little or no cutbank "step" and a broad space for multiple boat parking. Equally important, better parking, including safer/friendlier conditions for both people and craft as identified by the presence of sand or absence of rocky conditions is considered. Little or no vegetation to impair access is also important, though this factor weighs less than the previous criteria. Changes in vegetation by either removal or covering with sand would be a contributing indicator.

Figure 24. Documentation of beach access Degraded (Nonexistent) after HFE due to quick downramp and fluctuating flows. Tatahatso Camp, RM 38.6 L, April 3, 2015

Some negative impacts are more readily 'remedied' than others or can be interpreted in degrees of "improvement". Filled gullies in camp or rocks covered on a beach are ready examples, and expansion of the campable area will usually qualify as "Improved" for the purposes of the study. However, discernable improvement of a beach as a campable area is weighed against any factors that may have simultaneously degraded the beach.

An increase in the height of the beach above river level due to sediment deposition would warrant careful consideration for Improvement, but sediment deposition alone would not necessarily justify this classification if it is strongly offset by negative factors. Restated, beneficial results, most notably the filling and leveling of camp surfaces, would be considered of greater importance than improved parking or vegetation removal, resulting in an Improved classification. However, a shear cut bank, taller than a large step for most people and requiring assistance to unload equipment, making camp access more difficult, would counter other beneficial positive effects of an HFE, resulting in a Degraded classification.

Over the eight years, 278 instances of beach impacts by HFEs were evaluated and classified, an average of 35 included in each year of study.

It is important to note that the results of the floods that occurred in the springs of 1996 and 2008 were usually photographed within days or a few weeks of the event, whereas it was almost always 5 to 6 months before photographic evidence of the impacts were recorded for the Fall floods. It is not clear how this may have affected the resulting classifications. However, as will be discussed, differences in this time lapse may be significant in the evaluation of the event results. The 1996 and 2008 years were initially evaluated separately to avoid any bias built in to these timeframes, but the resulting classifications were considered as being equal with all years and were combined with the other 6 years for final comparison.

Figure 25. Documentation of beach access seriously hindered after HFE due to quick downramp and fluctuating flows. The campable area did increase significantly and had good access (behind photographer), so received an Improved rating.
Shinumo Camp, RM 38.6 L, April 3, 2015

Figures 26. Documentation of mounded sand deposition followed by beach front shear, March 2008 High Flow Experiment resulting in a Degraded classification.
Lower National Camp, RM 167.11 L, June 17, 2008.

Figure 27. Documentation of a successfully Improved camp. Lower Tapeats, RM 134.5 R, March 15, 2008

Results

Per Classification

There were 278 useable data points spread across the 8 years in the study. This averages to slightly less than 35 beaches per year being evaluated. Overall, 189 (68%) were classified as having Improved thanks to the HFE, with a low success of just 41% in 2004 and a high of 86% during the first event in 1996. A total of 31 beaches Degraded after the HFE across the 8 years , or 11% of the instances. The lowest year for this classification was 2004 with 6% of the beaches suffering degradation. The highest was during the next event in 2008 at 20% of the reporting beaches. Beaches that remained Unchanged for all years totaled 58, 21% of the study and an average of 7.25 beaches per year.

Camp name	Rvr mile	1996	2004	2008	2012	2013	2014	2016	2018
Soap Creek	11.3 R		X					X	
12.4 Mile	12.4 L	X		X		X		X	
Hot Na Na	16.6 L		X					X	x
19.4 Mile	19.4 L	X		X			X	X	
Upper North Canyon	20.7 R	X	X		X	X		X	x
23 Mile	22.7 L	X		X	X	X		X	
Shinumo Wash	29.5 L	X	X	X	X	X	X	X	x
Nautaloid	35 L	X	X	X	X			X	
Tatahatso	37.9 L	X							
Martha's	38.6 L	X	X	X			X		x
Buck Farm	41.2 R	X				X			
Total MC	11	9	6	6	4	5	3	8	4
Nevills	76 L	X		X		X		X	x
Hance	77.1 L								
Grapevine	81.7 L			X	X	X		X	x
Clear Creek	84.6 R	X		X	X		X	X	x
Zoroaster	85 L	X		X		X	X	X	
Trinity Creek	92.1 R	X		X	X	X	X	X	
Schist	96.6 R	X			X	X	X		
Boucher	97.3 L	X		X					x
Crystal	98.7 R				X				x
Lower Tuna	100.2 L	X	X						x
Ross Wheeler	108.3 L							X	
Bass	109 R	X			X				x
110 mile	110 R			X				X	x
Upper Garnet	114.9 R	X	X	X	X	X	X	X	x
Lower Garnet	115.1 R	X	x	X	x	X	X	X	x
Total UGG	15	10	3	9	8	7	6	9	10
Below Bedrock	131.7 R	X		X				X	
Stone Creek	132.5 R	X		X	X	X	X	X	x
Talking Heads	133.7 L	X	X	X	X	X		X	x
Racetrack	134.2 R	X			X			X	x
Lower Tapeats	134.5 R	X		X		X	X		
Owl Eyes	135.2 L	X	X	X	X	X	X	X	x
Backeddy	137.8 L	X	X	X	X				
Kanab	144 R	X		X	X	X		X	
Olo	146.1 L	X		X		X			
Matkat Hotel	148.9 L	X	X	X	X		X	X	x
Upset Hotel	150.9 L			X	X	X			x
Last Chance	156.3 R	X				X	X	X	x
Tuckup	165.2 R	X	X	X	X	X	X		x
Upper National	167 L				X	X	X	X	x
Lower National	167.2 L	X			X				
Total MG	15	13	5	11	11	10	7	9	9
Travertine Falls	230.6 L							X	
Gneiss	236.1 R			X	X			X	
250 Mile	250.0 R					X	X	X	
Total LGG	3	0	0	1	1	1	1	3	0
Totals	44	32	14	27	24	23	17	29	23
Total eval'd this year		37	34	40	29	33	29	44	32
percent Improved		86%	41%	68%	83%	70%	59%	66%	72%

Table 2. Side by side yearly comparison of camps Improved by HFE 1996 - 2018.

Camp Name	Rvr mile	1996	2004	2008	2012	2013	2014	2016	2018
Soap Creek	11.3 R			X	X	X			X
12.4 Mile	12.4 L								
Hot Na Na	16.6 L								
19.4 Mile	19.4 L				X	X			
Upper North Canyon	20.7 R			X					
23 Mile	22.7 L								
Shinumo Wash	29.4 L								
Nautaloid	35.0 L						X		
Tatahatso	37.9 L			X			X		X
Martha's	38.6 L					X		X	
Buck Farm	41.2 R		X	X	X			X	X
Total MC	**11**	**0**	**1**	**4**	**3**	**3**	**2**	**2**	**3**
Nevills	76.1 L								
Hance	77.1 L								
Grapevine	81.7 L								
Clear Creek	84.5 R					X			
Zoroaster	84.9 L								
Trinity Creek	92.0 R								
Schist	96.5 L								
Boucher	97.2 L								
Crystal	98.7 R			X					
Lower Tuna	100.1 L								
Ross Wheeler	108.3 L	X							
Bass	109.0 R		X	X				X	
110 mile	109.9 R	X			X				
Upper Garnet	114.9 R								
Lower Garnet	115.1 R								
Total UGG	**15**	**2**	**1**	**2**	**1**	**1**	**0**	**1**	**0**
Below Bedrock	131.7 R								
Stone Creek	132.4 R								
Talking Heads	133.6 L								
Racetrack	134.1 R								
Lower Tapeats	134.5 R								
Owl Eyes	135.1 L								
Backeddy	137.7 L						X		
Kanab	144.0 R						X		
Olo	146.0 L								
Matkat Hotel	148.9 L								
Upset Hotel	150.7 L								
Last Chance	156.2 R								
Tuckup	165.1 R								
Upper National	167.0 L	X		X					
Lower National	167.1 L			X					
Total MG	**15**	**1**	**0**	**2**	**0**	**0**	**2**	**0**	**0**
Travertine Falls	230.6 L								
Gneiss	236.0 R								
250 Mile	250.0 R								
Total LGG	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Totals	**44**	**3**	**2**	**8**	**4**	**4**	**4**	**3**	**3**
Total eval'd this year		**37**	**34**	**40**	**29**	**33**	**29**	**44**	**32**
percent Degraded		8%	6%	20%	14%	12%	14%	7%	9%

Table 3. Side by side yearly comparison of camps Degraded by HFE 1996 - 2018.

Camp name	Rvr mile	1996	2004	2008	2012	2013	2014	2016	2018
Soap Creek	11.3 R								
12.4 Mile	12.4 L		X						X
Hot Na Na	16.6 L						X		
19.4 Mile	19.4 L		X						
Upper North Canyon	20.7 R								
23 Mile	22.7 L		X						
Shinumo Wash	29.5 L								
Nautaloid	35 L								X
Tatahatso	37.9 L							X	
Martha's	38.6 L								
Buck Farm	41.2 R						X		
Total MC	**11**	**0**	**3**	**0**	**0**	**0**	**2**	**1**	**2**
Nevills	76 L		X				X		
Hance	77.1 L	X						X	
Grapevine	81.7 L		X						
Clear Creek	84.6 R								
Zoroaster	85 L								
Trinity Creek	92.1 R								
Schist	96.6 R		X	X				X	
Boucher	97.3 L					X		X	
Crystal	98.7 R	X	X			X		X	
Lower Tuna	100.2 L							X	
Ross Wheeler	108.3 L		X	X		X			X
Bass	109 R								
110 mile	110 R						X		
Upper Garnet	114.9 R								
Lower Garnet	115.1 R								
Total UGG	**15**	**2**	**5**	**2**	**0**	**3**	**2**	**5**	**1**
Below Bedrock	131.7 R		X		X	X	X		
Stone Creek	132.5 R		X						
Talking Heads	133.7 L						X		
Racetrack	134.2 R		X	X		X	X		
Lower Tapeats	134.5 R		X					X	
Owl Eyes	135.2 L								
Backeddy	137.8 L							X	X
Kanab	144 R		X						
Olo	146.1 L						X	X	X
Matkat Hotel	148.9 L								
Upset Hotel	150.9 L							X	
Last Chance	156.3 R		X	X					
Tuckup	165.2 R							X	
Upper National	167 L		X						
Lower National	167.2 L		X					X	X
Total MG	**15**	**0**	**8**	**2**	**1**	**2**	**4**	**6**	**3**
Travertine Falls	230.6 L		X	X					
Gneiss	236.1 R		X			X			
250 Mile	250.0 R								
Total LGG	**3**	**0**	**2**	**1**	**0**	**1**	**0**	**0**	**0**
Totals	**44**	**2**	**18**	**5**	**1**	**6**	**8**	**12**	**6**
Total eval'd this year		**37**	**34**	**40**	**29**	**33**	**29**	**44**	**32**
percent Unchanged		**5%**	53%	**13%**	3%	18%	28%	27%	19%

Table 4. Side by side yearly comparison of camps Unchanged by HFE 1996 - 2018.

Classification Per Reach

The Marble Canyon (MC) reach had a total of 45 Improved data points spread across the 8 years, which is 24% of the overall classification and 63% of that reach. There were a high of 9 Improved beaches in 1996 and the low was in 2014 with 3. The Upper Granite Gorge (UGG) contained 33% of this classification, with 62 total, an average of 7.75 per year. This accounted for 69% of this reach. Two years had 10 Improved beaches, 1996 and 2018. The low year was 2004 with only 3 beaches displaying benefits of the HFE. The Muav Gorge (MG) had 75 Improved beaches, 40% of the total for all years and 71% of that reach. The highest number of Improved beaches in this reach occurred in 1996 with 13 while 2004 only had 5. The Lower Granite Gorge (LGG) contains the smallest number of beaches in the study and many of those were not incorporated into the early years of the project. It is also the least visited stretch by volunteers and therefore has the least number of data points. Only 7 instances were recorded as having Improved through the years. This was only 4% of the total for this classification, but a full 64% of that reach.

The 31 beaches with a Degraded classification were distributed through three of the reaches. The MC accounted for 18, which is 58% of the overall classification total and 25% of that reach. In the UGG, 8 beaches qualified as Degraded, 26% of the 31 holding this classification and 9% of this reach. The other reach with Degraded beaches was the MG. It contained 5 of these beaches, 16% of the total classification and 5% of the reach. No beaches in the LGG were recorded as Degraded.

For the Unchanged classification, there were 58 data points total for the 8 years. Most of these were located in the MG with 26 instances, 45% of the total and 25% of the reach. The reach with the lowest number was the LGG at 4. This accounts for a low of 7% of the 8 year total, but the highest percent of reach amount at 36%. The UGG had 20 in this classification, 34% of the 58 data points and 22% of the reach. Marble Canyon contained an eight year total of 8 Unchanged beaches, 14% of the total and accounts for 11% of the reach.

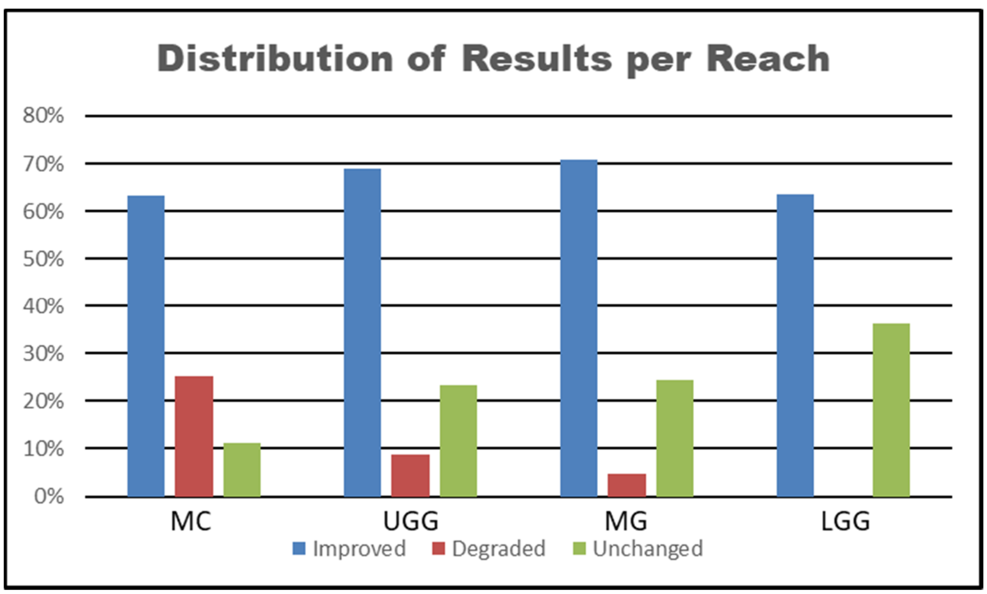


Figure 28. Distribution of results for HFE per Reach.

Discussion

The Per Reach comparison graph (Figure 28) displays a fairly consistent distribution of Improved beaches regardless of geomorphic setting, distance downstream from Glen Canyon dam, release rates or suspended sediment load. The number of beaches Degraded by the events peaks in the Marble Canyon reach and tapers to null in the Lower Granite Gorge reach. Why did the beaches furthest upstream suffer the most? Supposing that the sediment load is being transported further downstream to farther reaches due to the duration of the HFE, therefore scouring beaches after initial deposition, can be countered by the high number of beaches that did Improve within the same reach. Closer examination of the photos taken that resulted in a Degraded classification for these years reveals that two specific situations occur on some beaches here that do not allow for improvement. The first is the presence of multiple beaches that are low lying and unprotected from the 40,000 cfs flows. When an HFE of that magnitude arrives at one of these beaches, the water simply flows over the commonly used area, which is usually at an elevation of 25,000 cfs or less, and scours the beach. Upstream rocks near the beach front create turbulence that exacerbates the scouring action. High flows at these beaches tend to expose more rocks as well as removing sand, leaving a Degraded camp.

Another situation found in this reach are beaches were exceptional sediment load is lifted in the eddy, settles, and then the downramp of the river post HFE is so rapid that the face of the beach is undermined and shears, leaving, in some cases, a huge camp that is almost inaccessible. This abrupt downramp, combined with moderately high fluctuating flows closely following the HFE, combine to undermine the newly deposited sediment and it calves back into the river. This situation has been observed and reviewed anecdotally by the river running community, including the author. One private boater, a registered geotechnical engineer, commented in writing *"Some of the steeply sloped beaches suffered damage due to calving as seepage had not had enough time to adjust to the receding water level during the ramp down portion of the experiment. As a result, the material that was deposited was lost."* (GCPBA, 2016). Additionally, the Southwest Biological Science Center, noted that *"The lower downramp rate used in 2012 resulted in sandbar topography that was less steep compared to the downramp rate used in 2008. However, because the adjusted hydrograph with lower downramp rate was tested in only one year and because topographic surveys were only available for three sites, it is uncertain whether this response would be consistent among many sites or repeatable in future HFEs."* (SBSC, 2016). This begs the question, why wasn't this tried again in the following three HFEs?

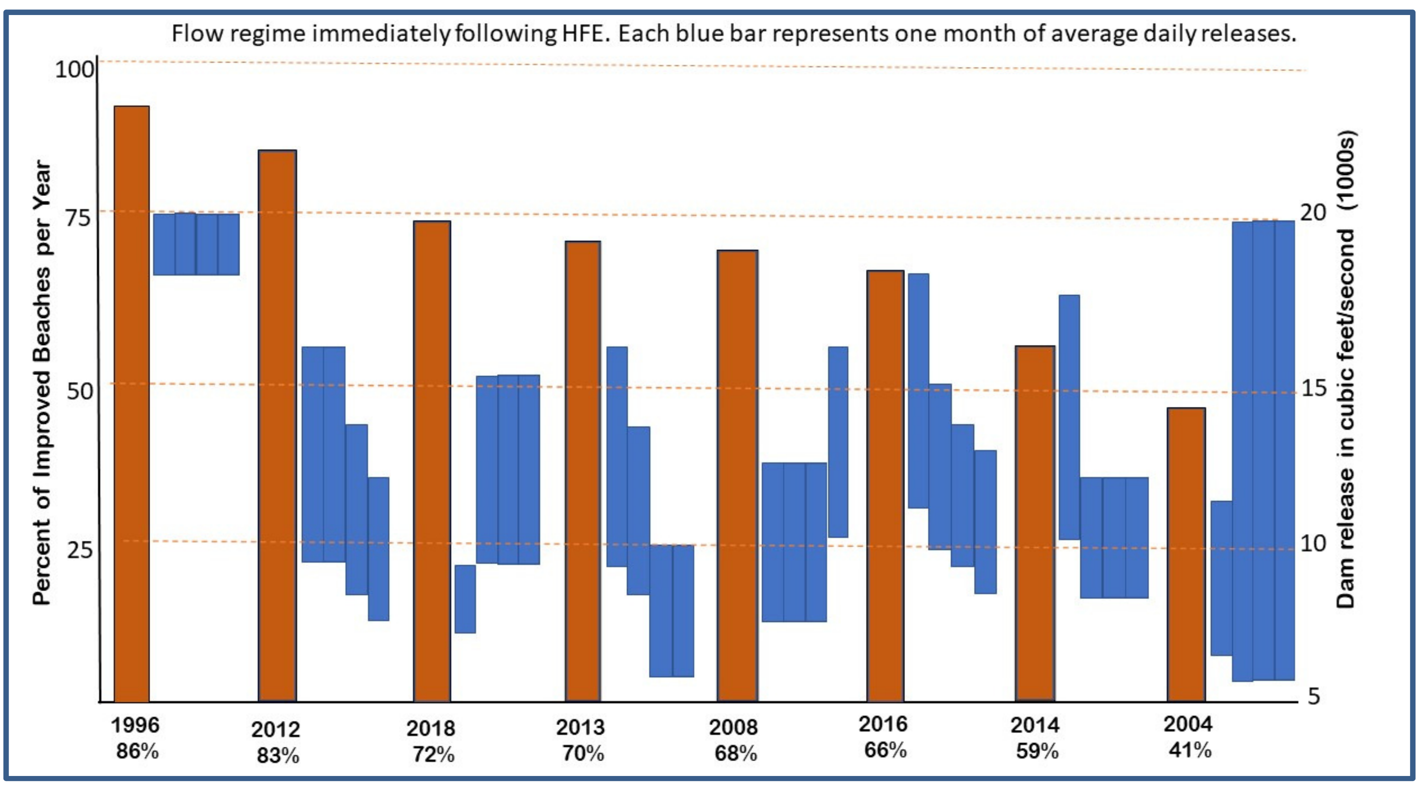


Figure 28. Distribution of Improved results and the approximate daily fluctuating flows for the four months immediately following the HFEs.

Fluctuating flow releases have been proven to degrade beaches (Mueller, 2018). And the higher the flow rate, coupled with an increase in the daily minimum to maximum cubic feet/second, the greater the negative impact on beaches. As shown by the graph in Figure 28, it may be possible that there is an inverse correlation between the observed success of each HFE, as expressed by percent of Improved beaches for that year, and the flow regime closely following the event. The lowest rate of success years are generally the same ones that have the highest flow releases and greatest fluctuations between the end of the HFE and the acquisition of the photos. The lowest rate of success, 41% in 2004, had the highest releases and greatest fluctuations in the 3 months preceding the photo dates at 5500 to 20000 cfs daily, 14000 cfs plus/minus in a twenty-four hour period. The next two lowest percentages, of 59 and 66, for 2014 and 2016, had periods of releases topping at 18,000 cfs, with daily fluctuations between 6000 and 8000 cfs. As has been stated, high flows and wide fluctuations have been proven to degrade beaches rapidly no matter how substantial the deposition. The 86% success for the 1996 event, although followed by the extremely high daily release rate of 20000 cfs, can be explained by the facts that the high release was consistent for the five months following the HFE when the beach photos were being taken, and that the fluctuation was only 2000 cfs daily, down to 18000. Additionally, the lower part of the beaches were never exposed for evaluation until late in the season. It also is significant that this was the first HFE and any increase in sand deposition recorded was probably considered as a positive outcome.

The three years with Improvement percentages clustered between 68, 70 and 72, in 2008, 2013 and 2018 respectively, had reduced maximum releases of 16000 cfs, and a low daily fluctuation of 3-5000 cfs. Two of these years, 2008 and 2018, had steady, medium daily fluctuations for the months following the event, which undoubtedly helped slow degradation of the camps during the photo acquisition period. Second only to 1996, 2012 had an 83% success rate. It also saw a high flow of 16000 cfs with medium fluctuation rates for the two months after the fall HFE, then the high flows and fluctuations were reduced twice before the early season photo period, ending with a daily high release of 12000 cfs and a fluctuation of 4500 cfs or less in the month prior to photo acquisitions. It is possible that the beach fronts had time to settle and grade by early summer to present more favorable conditions for boaters.

The primary reason beaches receive a Degraded classification following an HFE is easily identified. The beach has been rendered unusable (temporarily) because of access issues. Either the camp shore, the parking area for boaters, is lower in elevation than the elevation of the HFE release and is less protected from the downstream current such that the sand is stripped, exposing rocks or otherwise making parking, loading and unloading of the boats difficult and dangerous or, the beach front has been left so precipitous that camp is indeed perched above the shoreline. Again, the sudden down ramp after the event undermines the beachfront, or during the subsequent high fluctuating flows, reclaiming the sediment back into a starved system. Evidence indicates that it is a simultaneous combination of the two. The latter issue is eventually resolved as the sand angle lowers, through slumping or reduced collapse events, and access is gained over steep inclines.

Although there was considerable variation in the number of beaches that remained Unchanged through all of the years, the beaches that displayed this trait were consistently the same. Through protection by vegetation or simply their geomorphic location, these deposits are less susceptible to the effects of the HFEs. It's unclear as to why the percent of these beaches within a reach would gradually increase as you go downstream.

Conclusion

HFEs, as they have been conducted up to 2018, have been highly successful restoring camping beaches vital to recreational use. Slower down ramping post HFE should greatly benefit not only the immediate results but also the longevity for the beaches. After an HFE, beaches that have lower grade slopes across the front shore as a result of a slower down ramp post event will not only evaluate as Improved and are indeed preferred by recreationist, but should also maintain their favorable state for a longer period.

Reduced fluctuating flows, especially in the first months after an HFE, would be a priority for the success of these events and the subsequent longevity of the camps. The results compiled by other researchers, and documented by the post-flood photos described in this report, strongly suggest that minimizing post-peak flow fluctuations is likely a crucial element in HFE strategies aimed at successful and durable beach improvement. As stated in numerous other reports, the floods effectively rebuild sandbars, but the sandbars often erode in the months following the floods. Sandbars are largest following controlled floods and decay toward a minimum size during normal dam operations (Mueller, 2018).

There is some bias in this study because the delay in acquiring photos after a Fall experiment does not represent the immediate condition following an HFE. However, this was very revealing regarding the rapidity of the sand loss due to high fluctuating flows, negating some benefits of the event.

ACKNOWLEDGEMENTS

Grand Canyon River Guides, Inc. would like to thank all of the adopters for volunteering the time to pull over and photograph their beaches and for their valuable observations and written comments. It takes time and effort to do this, and the dedication shown by guides has literally kept this program alive for over twenty years. The result is the most comprehensive collection of repeat photographs of critical camping beaches in the Grand Canyon. An added benefit is the public outreach fostered by the volunteers' actions. By taking time to include guests as active participants and by answering their questions, volunteers can further explain how this resource in Grand Canyon is enhanced, degraded or maintained by the influence of man and technology.

Special thanks to Lynn Hamilton, GCRG Director, for exhaustive work in support of this project.

Special thanks also to the members of the guide staff and participants in the Grand Canyon Youth program for incorporating the Adopt-A-Beach program into their river trips.

This material is based on work supported by the U.S. Geological Survey under Grant/Cooperative Agreement No. G18AC00125. Without their generous assistance, this program would not be possible. And finally, our sincere thanks to those individual GCRG members who believe that the Adopt-A-Beach project worthy of their support.

DISCLAIMER

REFERENCES

Grams, Paul, Buscombe, Daniel, Gushue, Tom, Hamill, Dan, Hazel, Joseph, Kaplinski, Matt, Kohl, Keith, Mueller, Erich, Ross, Robert, Tusso, Robert, 2018. Sandbars and Sediment Storage in Marble and Grand Canyons: Response to Recent High-flow Experiments and :Long Term Trends. Grand Canyon Monitoring and Research Center Project B, PowerPoint presentation 17 p. Retrieved from https://www.usbr.gov/uc/progact/amp/twg/2018-01-25- twg-meeting/AR03.pdf

Grams, Paul, Tusso, Robert, Kohl, Keith A., December 8, 2016. *Grand Canyon Sandbar Monitoring* Southwest Biological Science Center. https://www.usgs.gov/centers/southwest-biological-science-center/science/grand-canyon-sandbar-monitoring

Grand Canyon Private Boaters Association. December 19, 2016. Letter from Wally Rist.

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, Arizona: implications for sediment storage and sand bar maintenance: EOS Fall Meeting Abstracts, vol. 74. 43 p.

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, Northern Arizona University, Department of Geology. 62 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.H., 1995. Monitoring the effects of Glen Canyon Dam interm flows on campsite size along the Colorado River in Grand Canyon National Park. Final Report. CA8022-8-0002, National Park Service, 16 p.

Kearsley, L.H., 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.

Lauck, Paul, 2016. Adopt-A-Beach Long-Term Monitoring of Camping Beaches in Grand Canyon: Summary of Monitoring Observations for Year 2015

Lauck, Paul, 2010. Adopt-A-Beach Long-term Monitoring of Camping Beaches in Grand Canyon: Summary of Results for Year 2009.

Lauck, Paul, 2009. Adopt-A-Beach: Long Term Monitoring of Camping Beaches In Grand Canyon Summary of Results for Years 2007 - 2008.

Melis, T.S., ed., 2011. Effects of three high-flow experiments on the Colorado River ecosystem downstream from Glen Canyon Dam, Arizona: U.S. Geological Circular 1366.

Mueller, E.R., Grams, P.E., Schmidt, J.C., Hazel, J.E., Alexander, J.S., Kaplinski, M., 2014. 014. The influence of controlled floods on fine sediment storage in debris fan-affected canyons of the Colorado River basin. Geomorphology 226, 65–75.

Mueller, E.R., Grams, P.E., Hazel, J.E., Schmidt, J.C., 2018. Variability in eddy sandbar dynamics during two decades of controlled flooding of the Colorado River in the Grand Canyon. Sedimentary Geology 363, 181-199.

Mueller, E. R., & Grams, P. E., 2021. A morphodynamic model to evaluate long-term sandbar rebuilding using controlled floods in the Grand Canyon. Geophysical Research Letters, 48, e2021GL093007

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: submitted to Glen Canyon Environmental Studies by Northern Arizona University, Department of Geology, 22 p.

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., Burke, K. and Potochnik, A., 1997. Effects of the Beach-Habitat Building Flow and Subsequent Interim Flows from Glen Canyon Dam on Grand Canyon Camping Beaches, 1996: A Repeat Photography Study by Grand Canyon River Guides (Adopt-A-Beach Program).

Thompson, K.S., 2004. Long Term Monitoring of Camping Beaches in Grand Canyon: A Summary of Results from 1996 – 2003. Annual Report of Repeat Photography By Grand Canyon River Guides, Inc. (Adopt-A-Beach Program), 14 p.

Turner, R. M. and Karpiscak, M. 1980. Recent Vegetation Changes along the Colorado River between Glen Canyon Dam and Lake Mead, Arizona: U.S. Geological Survey Professional Paper 1132, Washington, D.C.

U.S. Department of the Interior, 1987. *River and Dam Management*: A review of the Bureau of Reclamation's Glen Canyon Environmental Studies: National Academy Press, Washington, D.C., 203 p.

U.S. Department of the Interior, 1996. Record of Decision (ROD) on the Operation of Glen Canyon Dam Final Environmental Impact Statement (EIS): Bureau of Reclamation, Salt Lake City, Utah.

U.S. Geological Survey, 2013, Grand Canyon Monitoring and Research Center, Colorado Mileage System [Spatial Database, GIS.BASE_GCMRC_TenthMile], 1st revised edition: U.S. Geological Survey database, accessed September 18, 2013, at http://www.gcmrc.gov/gis/silveratlas1.aspx

Webb, Robert H., 1996. Grand Canyon, a Century of Change. Rephotography of the 1889-1890 Stanton Expedition. University of Arizona Press, Tucson, AZ.

Webb, R.H., Boyer, D. E and Turner, R. M., 2010. Repeat Photography: Methods and Applications in the Natural Sciences. Island Press, Washington, D.C.

Wiele, S.M., Andrews, E.D., and Griffin, E.R, 1999. The effect of sand concentration on depositional rate, magnitude and location in the Colorado River below the Little Colorado River: in *The Controlled Flood in Grand Canyon:* Geophysical Monograph Series, vol. 110, p. 113-145.

Web

Geanious, Chris. Website gallery for Adopt-A-Beach images
https://www.flickr.com/photos/147271391@N08/collections

Glen Canyon Adaptive Management Program WIKI, 2016. Retrieved from
http://gcdamp.com/index.php?title=GCDAMP-_HFE_2016

Appendix A

Adopt-A-Beach Data Sheet
Used by Volunteers to Record Comments

Adopt a Beach Data Entry Form

Guide s Name ______________________

Camp Name ______________________

Camp Mile ______________________

Date ______________________

River Flow (circle one) Low (5-12K) Med (12-18K) High (18-25K)

Photo Numbers: ______________ (remaining)

Any Comments about Beach Change? (describe in this space)

Change in Beach Size from Previous Visit (circle one): Increase Decrease Same

Dominant Cause of Change (circle one):

Spike	Daily/Monthly Flow	Rain	Wind	People	Don't Know

Supporting Observations for Dominant Cause (check any that are appropriate):

- ☐ New cutbank
- ☐ Change of slope
- ☐ Bench in eddy
- ☐ Gully
- ☐ Trib/Debris flow
- ☐ Scour from wind or people
- ☐ Mounded sand

Secondary Cause of Change (circle one):

Spike	Daily/Monthly Flow	Rain	Wind	People	Don't Know

Supporting Observations for Secondary Cause (check any that are appropriate):

- ☐ New cutback
- ☐ Change of slope
- ☐ Bench in eddy
- ☐ Gully
- ☐ Trib/Debris flow
- ☐ Scour from wind or people
- ☐ Mounded sand

Do you find evidence of tamarisk beetles currently in/near this beach? YES NO

Campsite Quality Compared to Last Visit (circle one): Same Better Worse

Supporting Observations for Campsite Quality (check any that are appropriate):

- ☐ Boat parking
- ☐ Rockiness
- ☐ Vegetation encroachment
- ☐ Steepness
- ☐ Trail erosion
- ☐ Open sand area
- ☐ Human impacts- ants, pee spots, litter (circle those that apply)

Any Comments about Campsite Condition? (describe in this space)