MONITORING THE EFFECTS OF GLEN CANYON DAM INTERIM FLOWS ON CAMPSITE SIZE ALONG THE COLORADO RIVER IN GRAND CANYON NATIONAL PARK

FINAL REPORT: January, 1995

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ABSTRACT

Many riverside sand deposits are used as campsites in Grand Canyon National Park. Campsite number and size are of concern because they have decreased since the operation of upstream Glen Canyon Dam while campsite use has increased. Narrow reaches of the river termed "critical reaches" have a disproportionately limited number of campsites and are of particular concern. Campsite area on 93 of these deposits was measured annually from 1991-1994 to monitor area changes during a dam operation period of reduced discharges and reduced fluctuations in discharge.

Between 1991 and 1994, campsite area decreased significantly, losing an average of 9% area. However, this loss in minimal when compared to the magnitude of campsite area loss during the entire operation of Glen Canyon Dam. Also, aside from extensive tributary flood damage at some sites, area changes have had little effect on campsite carrying capacity. Half of this decreased area was lost due to river induced changes (erosion and increased slope of sand deposit), 29% was lost due to vegetation growth, and 20% was lost due to tributary flooding. Above the Little Colorado River, a major tributary to the mainstem, river-induced changes were the primary mechanism for area loss, accounting for 80% of lost campsite area. Downstream of the Little Colorado River, this mechanism accounted for only 32% of lost campsite area. Vegetation growth was responsible for a higher proportion of lost campsite area in non-critical reaches (47%) than critical reaches (8%), and campsite loss from tributary flooding occurred exclusively in critical reaches.

Year-to-year monitoring of campsite area below the 708 m^3/s stage showed an overall decrease from 1991 to 1992, an increase from 1992 to 1993, and a decrease from 1993 to 1994. The increase in area between 1992 and 1993 occurred because of an unusually large natural flood event in the Little Colorado River. This event increased the mainstem Colorado River well above its maximum dam discharge and caused sediment deposition resulting in increased area of many downstream campsites. While most of this increased area eroded a year later, some campsites remained larger than they were in their initial 1991 measurements. These effects of mainstem flooding on campsites help support proposed dam management alternatives which include periodic beach building flows.

INTRODUCTION

A primary influence of Glen Canyon Dam on downstream recreation in Grand Canyon National Park has been the dam's effect on sand deposits, many of which are used as campsites (Kearsley et al. 1994). The size, elevation above the river, abundance, and distribution of these sand deposits limit the river's recreational carrying capacity, which concerns river users and resource managers primarily because of high use intensity. River trips through the Grand Canyon became increasingly popular during the 1960's and 1970's, causing the National Park Service to limit use to approximately 22,000 people per year (National Park Service 1989). Even with this limitation, many campsites are used nearly every night during the summer and sometimes, for lack of alternative camps, by two river parties on the same night. Without open sand deposits, river trips could not be conducted because the remainder of the shoreline is too rocky or too densely vegetated to be used for camping except under extreme circumstances.

Increased campsite use intensity has coincided with a post-dam long-term decrease in campsite number and size. Three campsite inventories conducted between Lee's Ferry and Diamond Creek in Grand Canyon National Park show a decrease in the number of campsites between 1973 and 1991. The first inventory documented 333 campsites above average maximum high river level (708 m^3/s) in 1973 (Weeden et al. 1975). The second inventory, which was conducted soon after flood flows were discharged from Glen Canyon Dam, documented 438 campsites in 1983 (Brian and Thomas 1984). The increased number of campsites between 1973 and 1983 was attributed to sand redistribution during the 1983 flood releases (Brian and Thomas 1984). The most recent survey, which was not preceded by flood conditions, was conducted in 1991. This inventory documented 226 campsites, a 32% reduction in campsite number since 1973, and a 48% reduction since 1983 (Kearsley and Warren 1993).

Results from these inventories were combined with an aerial photograph size comparison of campsites from 1965 to 1990 by Kearsley et al. (1994) to produce a long-term system-wide evaluation of campsite change since construction of Glen Canyon Dam. At least 30% of all campsites decreased substantially in size due to erosion between 1965 and 1973, before the first campsite inventory, and did not subsequently recover. Campsites continued to decrease in size, but at a decreased rate over the next 18 years. Most campsites exhibited a pronounced yet short-lived increase in size resulting from the 1983 flood releases; by 1984, almost all of these sites had eroded back to their pre-1983 size. In addition to campsite erosion, many campsites were lost due to vegetation growth, since annual flooding, which used to prevent the establishment of riparian vegetation, is severely limited by Glen Canyon Dam. Forty-one percent of all campsites which were lost between 1983 and 1991 were lost due to vegetation growth on otherwise useable sand deposits.

Concern over Glen Canyon Dam's effects on sediment deposits as well as many other resources in Grand Canyon has prompted political action during the past decade. The Bureau of Reclamation's Glen Canyon Environmental Studies program was initiated in 1982 (National Research Council 1987), and a draft environmental impact statement was released in 1994 (Bureau of Reclamation 1994) to resolve management of these resources.

In August 1991, more restrictive limitations were placed on dam operations. This new discharge regime, termed "interim flows" will be in effect until the environmental impact statement's record of decision is reached in 1995 or 1996. Interim flows range from 142 to 556 m^3/s, with a maximum daily change in discharge of 142 m^3/s (U.S. Bureau of Reclamation 1994). The interim flows criteria substantially reduced the previous daily range of discharge fluctuation (43 m^3/s to 892 m^3/s with no limitations on maximum daily change) as well as the ramping rate.

While the presence of high-elevation sandbars as a resource in this World Heritage National Park is important, their use as campsites in a system that is near its physical carrying capacity and that has experienced a long-term decrease of this resource makes campsite monitoring imperative. Also, since the draft environmental impact statement's preferred alternative is similar to interim flows (U.S. Bureau of Reclamation 1994), it is important to gain an understanding of campsite changes during this interim flow period. The purpose of this study is to examine changes in campsite area and causative factors since the initiation of interim flows.

During the course of this study, an unforseen event occurred which added another component to the purpose of this study. In January and February, 1993, unusually large floods occurred in the Little Colorado River (LCR), a tributary joining the mainstem at river mile (RM) 61.5 downstream from Lee's Ferry. These flooding events raised the Colorado River to 960 m^3/s in January and 849 m^3/s in February, causing a significant increase over interim flow's highest discharge of 556 m^3/s (U.S. Geological Survey, 1993). The flood events simultaneously contributed a large amount of sediment to the system. Thus, this study also measures changes in campsite area caused by flooding that substantially increases the mainstem.

STUDY SITES

River corridor campsites were measured between Lee's Ferry and Diamond Creek (RM 0-226). This distance is subdivided into reaches based on the number of campsites available in relation to recreational demand. "Critical reaches" of the river have a limited number of available campsites, and competition for sites is greater than for sites on other stretches of the river (Kearsley and Warren, 1993). Critical reaches are RM 11-40.8, 75.6-116, and 131-164, which correspond closely to the narrow reaches of Schmidt and Graf's (1990) reach classification of the river corridor. Non-critical reaches are RM 0-11, 40.8-75.6, 116-131, and 164-226. A campsite is defined as a site that has access between mooring and camping area, has sufficient space to accommodate a kitchen and 10 or more people, and is not overgrown with vegetation (Kearsley and Warren 1993).

METHODS

Initial campsite areas were established for 125 sites using enlarged color copies of June 1990 aerial photos. In March and May 1991, before the onset of interim flows, campsites were evaluated on-site, and campsite areas were delineated on the photographs.

Campsite area is defined as any area that is relatively flat (less than 9 degree slope), has few rocks or boulders, and is non-vegetated. While some areas that do not fit these criteria may be used for other recreation activities, they are not considered useable camping space because they do not contribute to the camping carrying capacity. Campsite area was measured at constant discharges of 142 m^3/s, 226 m^3/s, 425 m^3/s, and 708 m^3/s. Water's edge boundaries for 142, 226, and 425 m^3/s stage elevations were determined from aerial photographs and videos taken in 1990 and 1991. The water's edge boundary for 708 m^3/s was delineated in the field by experienced Colorado River boatmen by observing vegetation lines and cutbanks.

Area changes from the initial spring 1991 area were made using October 1992, May 1993, and May 1994 aerial photographs, and during river trips conducted at the same time. For each year campsite areas below the 708 m^3/s stage were determined and delineated at each site using the 1991 708 m^3/s stage boundary. Campsite area measured below the 708 m^3/s stage is termed "low water area" in this report. In addition, in May 1994 entire campsite areas rather than just that below the 708 m^3/s stage were reevaluated to compare with initial areas of the entire campsite. Campsite areas which were no longer useable in 1994 due to vegetation growth or tributary flood damage were delineated and measured. Tributary flood damage consisted of damage to campsites (i.e. gullies, scoured areas, cobbles deposited on top of sand) due to localized flooding from tributaries.

Delineations of campsite area for all years were superimposed onto the May 1993 photographs of each campsite to minimize measurement error between comparisons. These photographs were scanned into a map and image processing system (MIPS, Microimages, Inc.), and campsite area that was delineated in the field was then digitized to compute low water area for each year as well as the entire campsite area for 1994. Calibration measurements made between two fixed points (centers of well-defined landmarks) during site visits were used to scale the photographs. For areas that are not visible from the air, such as areas beneath overhangs, vegetation, or areas too small to be discerned on the video images (i.e. small separate sleeping areas), measurements were made in the field by taking the length and width of the area to the nearest half meter.

A total of 93 campsites was remeasured (Table 1). Because of the importance of campsites in critical reaches to the overall carrying capacity of the river, emphasis was placed on campsites in critical reaches, with 57 sites measured in critical reaches and 36 in non-critical reaches. Also, 25 of the campsites were located upstream from the LCR, and 68 were located downstream.

Changes in the entire campsite area between 1991 and 1994 were normally distributed (Lilliefors test; $p=0.345$), so the data were tested with a paired t-test ($\alpha=0.05$). Yearly changes in low water campsite area were not normally distributed (Lilliefors test; 91-92 change $p=0.016$, 92-93 change $p<0.001$, 93-94 change $p<0.001$). The Kruskal-Wallace non-parametric test was used to determine significance for these data ($\alpha=0.05$). Campsites which decreased or increased more than 5% of their initial area below 708 m^3/s were categorized as sites that had changed in size.

Table 1. List of the 93 Campsites Evaluated

Mile	Reach	Name*	Mile	Reach	Name*
8.0 L	NC**	Jackass	119.2 R	NC	no name
8.0 R	NC	Badger	119.8 L	NC	120-mile
11.0 R	C**	Soap Creek	120.0 R	NC	upper Blacktail
12.2 L	C	below Salt Water Wash	122.2 R	NC	122-mile
17.0 R	C	lower House Rock	122.7 L	NC	upper Forster
18.0 L	C	upper 18-mile	125.4 L	NC	below Fossil
19.0 R	C	upper 19-mile	126.2 R	NC	Randy's Rock
19.1 L	C	lower 19-mile	131.1 R	C	below Bedrock
19.9 L	C	20-mile	131.8 R	C	Galloway
20.4 R	C	upper North Canyon	132.0 R	C	Stone Creek
21.5 L	C	22-mile Wash	133.0 L	C	133-mile
21.9 R	C	22-mile	133.5 R	C	Racetrack
23.0 L	C	23-mile	134.6 L	C	Owl Eyes
23.7 L	C	Lone Cedar	136.0 L	C	Junebug
26.3 L	C	above Tiger Wash	136.2 L	C	opposite Deer Creek
30.4 R	C	below 30-mile	136.3 L	C	below Deer Creek
31.6 R	C	South Canyon	136.9 L	C	Football Field
33.6 L	C	below Redwall	137.0 L	C	Backeddy
37.7 L	C	Tatahatso	137.9 L	C	Doris
39.0 R	C	Redbud Alcove	139.0 R	C	Fishtail
44.2 L	NC	Eminence	139.8 L	C	140-mile
47.2 R	NC	Lower Saddle	145.1 L	C	above Olo
53.0 R	NC	Main Nankoweap	145.6 L	C	Olo
56.2 R	NC	Kwagunt	148.4 L	C	lower Matkat
59.8 R	NC	60-mile Canyon	148.5 L	C	below Matkat
61.7 R	NC	below LCR Island	155.7 R	C	Last Chance
66.8 L	NC	Espejo	157.7 R	C	First Chance
74.1 R	NC	upper Rattlesnake	158.5 R	C	Second Chance
74.3 R	NC	lower Rattlesnake	160.0 L	C	160-mile
75.6 L	NC	Nevilles	160.7 R	C	161-mile
75.8 R	NC	Papago	164.5 R	C	Tuckup
76.6 L	C	Hance	166.6 L	NC	lower National
81.3 L	C	Grapevine	168.0 R	NC	Fern Glen
84.0 R	C	Clear Creek	174.3 R	NC	upper Cove
84.4 L	C	above Zoroaster	174.4 R	NC	lower Cove
91.1 R	C	lower 91-mile	177.7 L	NC	Vulcan's Anvil
92.3 L	C	92-mile	184.5 L	NC	no name
94.3 R	C	94-mile	188.0 R	NC	upper Whitmore
96.0 R	C	96-mile	188.2 R	NC	lower Whitmore
96.1 L	C	Schist	202.0 R	NC	202-mile
98.0 R	C	upper Crystal	211.7 R	NC	Fall Canyon
102.8 R	C	no name	212.9 L	NC	Pumpkin Springs
103.8 R	C	Emerald	219.8 R	NC	upper 220-mile
107.8 L	C	Ross Wheeler	219.9 R	NC	middle 220-mile
108.0 R	C	Parkins' Inscription	220.0 R	NC	lower 220-mile
114.3 R	C	upper Garnet	222.0 L	NC	222-mile
114.5 R	C	lower Garnet			

*** Names are not official and are listed to help others know which sites were measured**
**** NC=non-critical, C=critical**

RESULTS

Changes in Campsite Area Between Years

Measurements of entire campsite area showed a slight overall decrease between 1991 and 1994. Campsite area was significantly smaller in 1994 than in 1991 ($t = 2.326$, $n=86$, $0.02<p<0.05$), with a mean loss of 9% of their original 1991 area. There was a trend for campsites upstream from the LCR to lose a higher percentage of area than downstream from the LCR (15% versus 7%) and for campsites in critical reaches to lose a higher percentage of area than non-critical reaches (14% versus 2%) between 1991 and 1994, but neither of these differences was significant ($t = 1.584$, $n=86$, $0.1<p<0.2$, and $t = 1.608$, $n=86$, $0.1<p<0.2$ respectively). Changes in campsite area occurred primarily below the 708 m^3/s stage, with area changes in 65% of the sites attributed to low water changes.

Year-to-year changes in low water campsite area reveal a more complex pattern due to the contrasting effects of interim flows and the January and February 1993 LCR floods (Table 2). Low water campsite area was different between the years 1991, 1992, 1993, and 1994 ($T_F=12.345$, $p=0.006$). This difference in area between years occurred below the LCR ($T_F=14.415$, $p=0.002$) but not above the LCR ($T_F=5.57$, $p=0.134$). This is caused by the 1993 floods which increased campsite area in many sites below the LCR.

Campsites exhibited a general decrease in low water area between spring 1991 and October 1992. During this time, more than twice as many campsites decreased as increased in size, resulting in a mean loss of 117 m^2 from a mean 1991 campsite area of 1215 m^2 (Table 2). Campsites in critical reaches had a significantly smaller percentage of their original 1991 low water area than those in non-critical reaches (Kruskal-Wallis $u=540$, $p=0.024$) (Figure 1). Differences in sites above versus below the LCR were not significant ($u=493$, $p=0.326$).

TABLE 2. Changes in Campsite Area Below the 708 m^3/s Stage

	DECREASE	INCREASE	SAME	MEAN CHANGE
SPR 91-OCT 92 n = 87	55%	20%	25%	- 117 m^2
OCT 92-MAY 93 n = 87	27%	52%	21%	+ 97 m^2
MAY 93-MAY 94 n = 90	47%	24%	29%	- 63 m^2
SPR 91-MAY 94 n = 86	45%	34%	21%	- 70 m^2

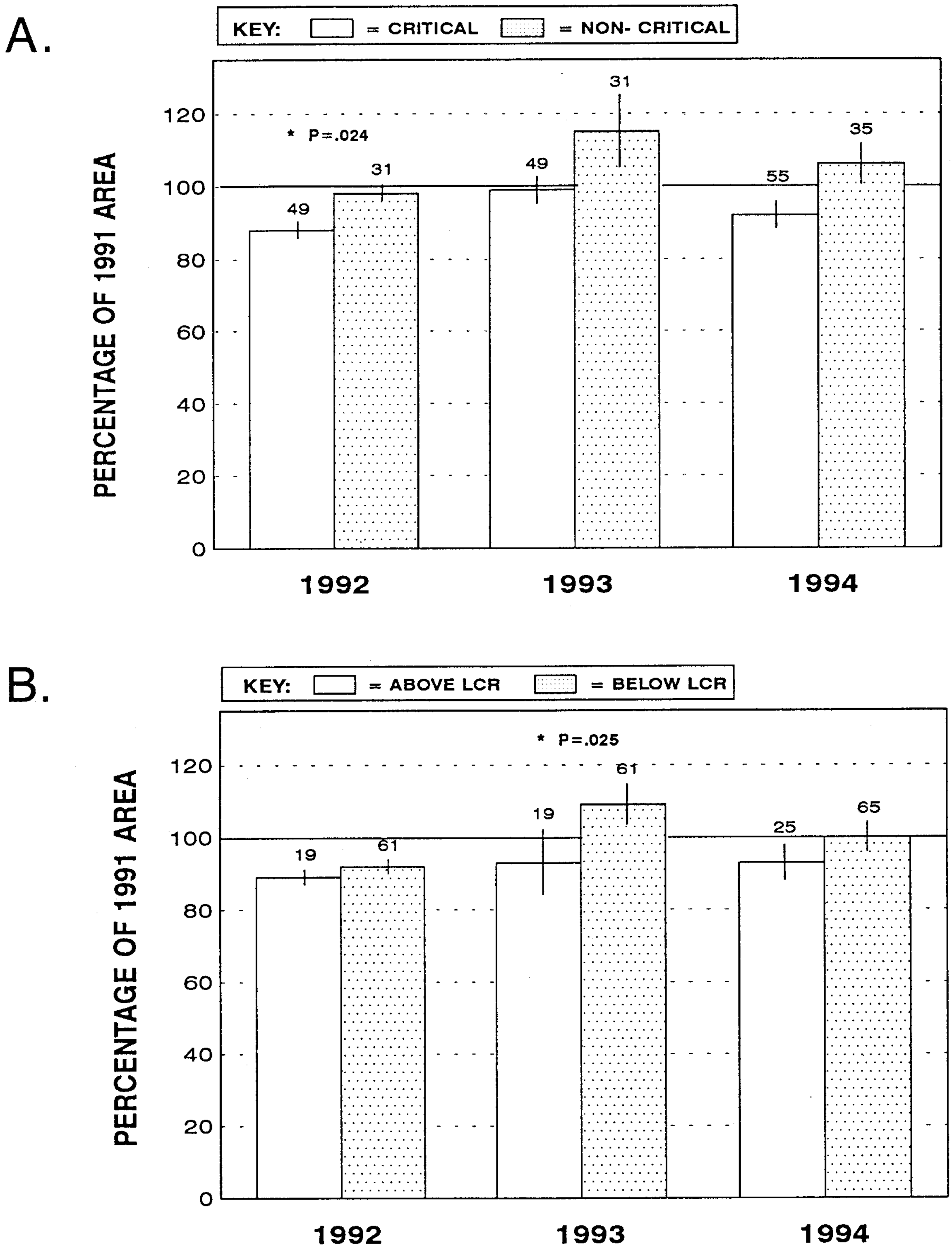


Figure 1. Percent of 1991 campsite area remaining in 1992, 1993, and 1994 due to changes in campsite area below 708 m^3/s a) in critical versus non-critical reaches, and b) above versus below the LCR. Standard error is shown for each bar. Significant differences are indicated with an asterisk.

Between October 1992 and May 1993, this trend was reversed because of the January and February 1993 LCR flooding events. Twice as many sites increased as decreased in size, resulting in a mean increase of 97 m^2 per campsite (Table 2). While there was a trend for campsites in non-critical reaches in 1993 to have a higher percentage of their original 1991 low water area, these differences were not significant (Kruskal-Wallis u=682, p=0.398) (Figure 1). Campsites below the LCR in 1993 did have a significantly higher percent of their original low water 1991 area than those above the LCR (Kruskal-Wallis u=381, p=0.025). This was expected since campsites downstream from the LCR confluence were affected by the 1993 flooding events.

Even near the LCR, however, these changes were variable. Two campsites approximately 15 km downstream from the LCR (RM 74.1 and 74.3R) gained little to no low water area in 1993, while sites 2 km further downstream (RM 75.6L and 75.8R) gained large areas. Sites which gained the greatest area were near the LCR. The first campsite downstream from the LCR (RM 61.7R) gained the most area, 1774 m^2, tripling the campsite's low water area. However, a number of campsites far downstream from the LCR also increased substantially in area. Most notable are RM 94.3R, which had lost all its low water campable area due to tributary flooding in 1992, but which gained more campable area in 1993 than when first measured in 1991. RM 108.0R, 125.4L, 155.7R, and 220.0R also acquired considerable campsite area in 1993, with a mean increase of 496 m^2.

Between May 1993 and May 1994, the percentage of sites which increased versus decreased in size was similar to that between 1991 and 1992 (Table 2). In response to deposition from flooding the previous year, antecedent conditions strongly affected change in campsite area. Sixty-seven percent of the campsites that increased in area below 708 m^3/s in 1993 decreased in area by 1994, while only 21% of those that decreased or remained the same size in 1993 decreased in 1994. Differences in the percent of 1991 area remaining due to low water area changes between campsites in critical versus non-critical reaches and above versus below the LCR were not significant (Kruskal-Wallace u=621, p=0.148, and u=467, p=0.202 respectively); (Figure 1).

Factors Causing Decreased Campsite Area

Lost campsite area between 1991 and 1994 was categorized into three causative factors. 1) Vegetation growth accounted for 29% of lost area, 2) localized tributary flooding accounted for 20%, and 3) river-induced erosion and increases in the slope of sand deposits accounted for 51% (Figure 2). The latter factor predominated throughout the river corridor, particularly above the LCR, where it accounted for 80% of lost campsite area above the LCR, versus only 32% below the LCR. Critical and non-critical reaches showed similar levels of loss due to erosion and slope changes.

Vegetation growth continued to be a substantial factor in loss of campsite area, causing nearly one third of lost area. Also, vegetation growth was strongly related to distance downstream and reach type. A much higher percentage of the area lost below the LCR between 1991 and 1994 was due to vegetation growth (41%) than above the LCR (11%); (Figure 2). The differences in vegetation growth between critical and non-critical reaches are even more pronounced. Nearly half (47%) of the loss in campsite area in non-critical reaches between 1991 and 1994 was caused by vegetation growth, compared with only 8% in critical reaches. Also, over half (56%) of the area lost due to vegetation growth was below the 708 m^3/s stage.

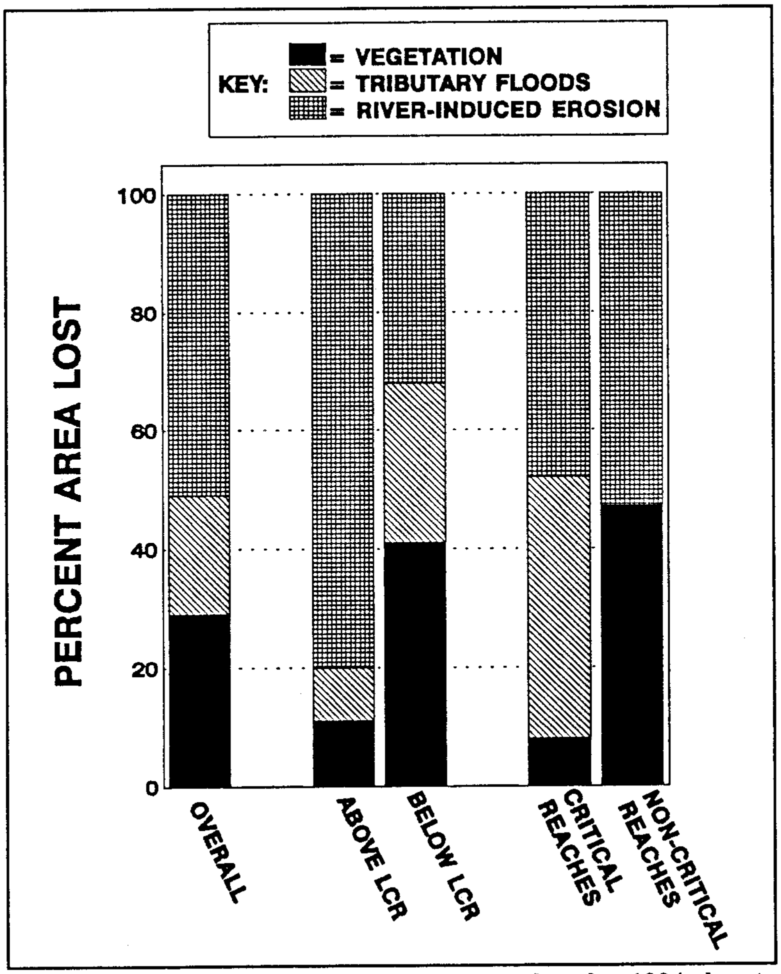


Figure 2. Percent of 1991 campsite area lost by 1994 due to vegetation growth, tributary flooding, and river-induced erosion. See text for details.

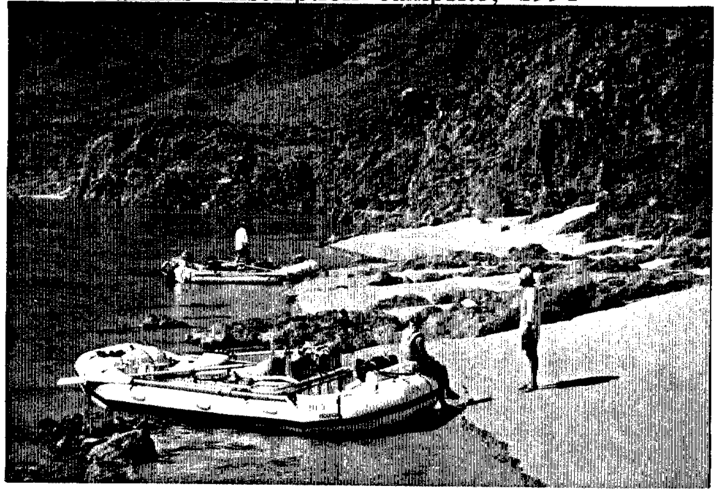
The amount of campsite area destroyed by localized tributary flooding was strongly influenced by one storm on August 20, 1993 that caused debris flows and severe flooding, drastically affecting campsites between RM 155 and 161 (Melis et al. 1994). Flooding of this magnitude had not occurred in that area for more than 30 years according to aerial photographs and for more than 55 years according to historical accounts (Melis, oral comm. USGS, 1995). These debris flows destroyed two campsites, RM 157.7R and 160.9R, and flooding from this event severely limited the size of two campsites, RM 155.7R, and 158.5R. These campsites lie near Havasu Canyon, an area that has the largest discrepancy between campsite supply and demand in the Grand Canyon. If this event had not occurred, tributary flooding would have been responsible for 6% rather than 20% of lost campsite area between 1991 and 1994.

The extent of tributary flood damage was substantial, and differed in relation to distance downstream and reach type. The percentage of lost area below the LCR due to localized tributary flooding (27%) was three times higher than that above the LCR (9%, Figure 2). Tributary flood damage occurred exclusively in critical reaches, causing no lost campsite area in non-critical reaches between 1991 and 1994 and 44% in critical reaches. These percentages, however, are also affected by the August 1993 flooding event. If that event had not occurred 4%, rather than 27%, of lost area below the LCR would have been attributed to tributary flooding; and 16%, rather than 44%, of the lost area in critical reaches would have been attributed to tributary flooding between 1991 and 1994. Tributary flooding caused the loss of an additional 936 m^2 to the total 1991-1994 campsite area loss of 3696 m^2 from tributary flooding, but both aggradation during the 1993 LCR flooding events and flattening out of flood gullies allowed this additional area to be useable for camping by 1994.

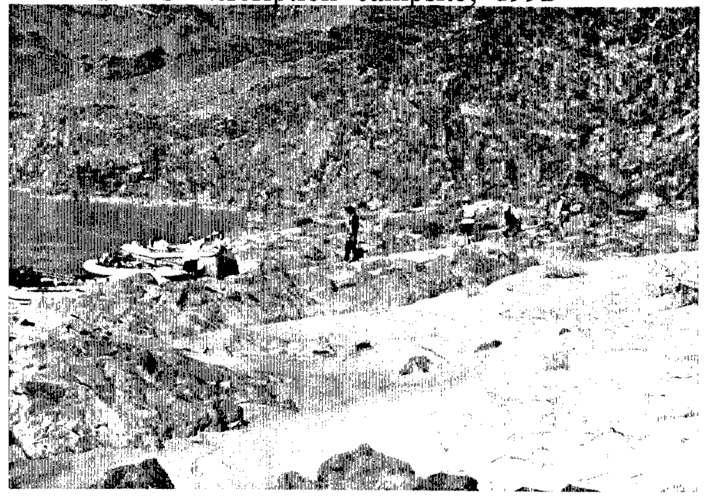
Spatial Patterns of Change

Several spatial patterns of change in campsite area were noted in this study. While responses of individual campsites to interim flows varied widely, there was a trend of increased area just above 226 m^3/s during one or more years at 52% of the sites. However, 35% of the sites exhibited a decrease in this low water area. Many of these changes occurred in response to the 1993 LCR flooding events with an increase in 1993 and a decrease in 1994 of low water area. Yearly photographs taken of Parkins' Inscription campsite (RM 108.0R) provide a visual example of one of the more dramatic changes in campsite area which followed this yearly pattern (Figure 3). Also, at 13 sites, terraces at the approximate 708 m^3/s stage became narrower as they eroded along the river's edge. Aerial changes in response to the 1993 flooding event, and as terraces narrow, can be seen in maps showing campsite area below 708 m^3/s during each year of the study (Figure 4).

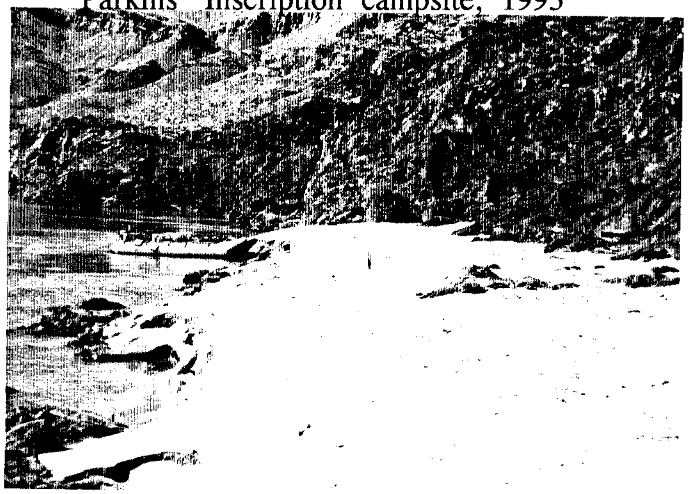
Parkins ' Inscription campsite, 1991



Parkins ' Inscription campsite, 1992



Parkins ' Inscription campsite, 1993



Parkins ' Inscription campsite, 1994

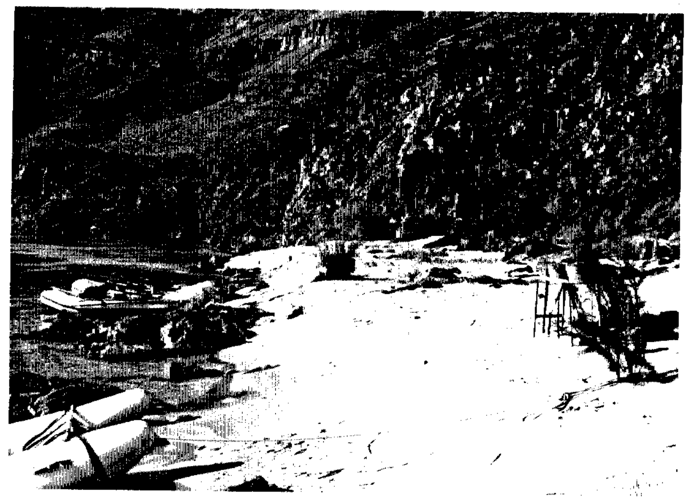


Figure 3. Yearly photographs of Parkins ' Inscription campsite (RM 108.0R) showing a decrease in campsite area between 1991 and 1992, an increase in area between 1992 and 1993, and a decrease between 1993 and 1994.

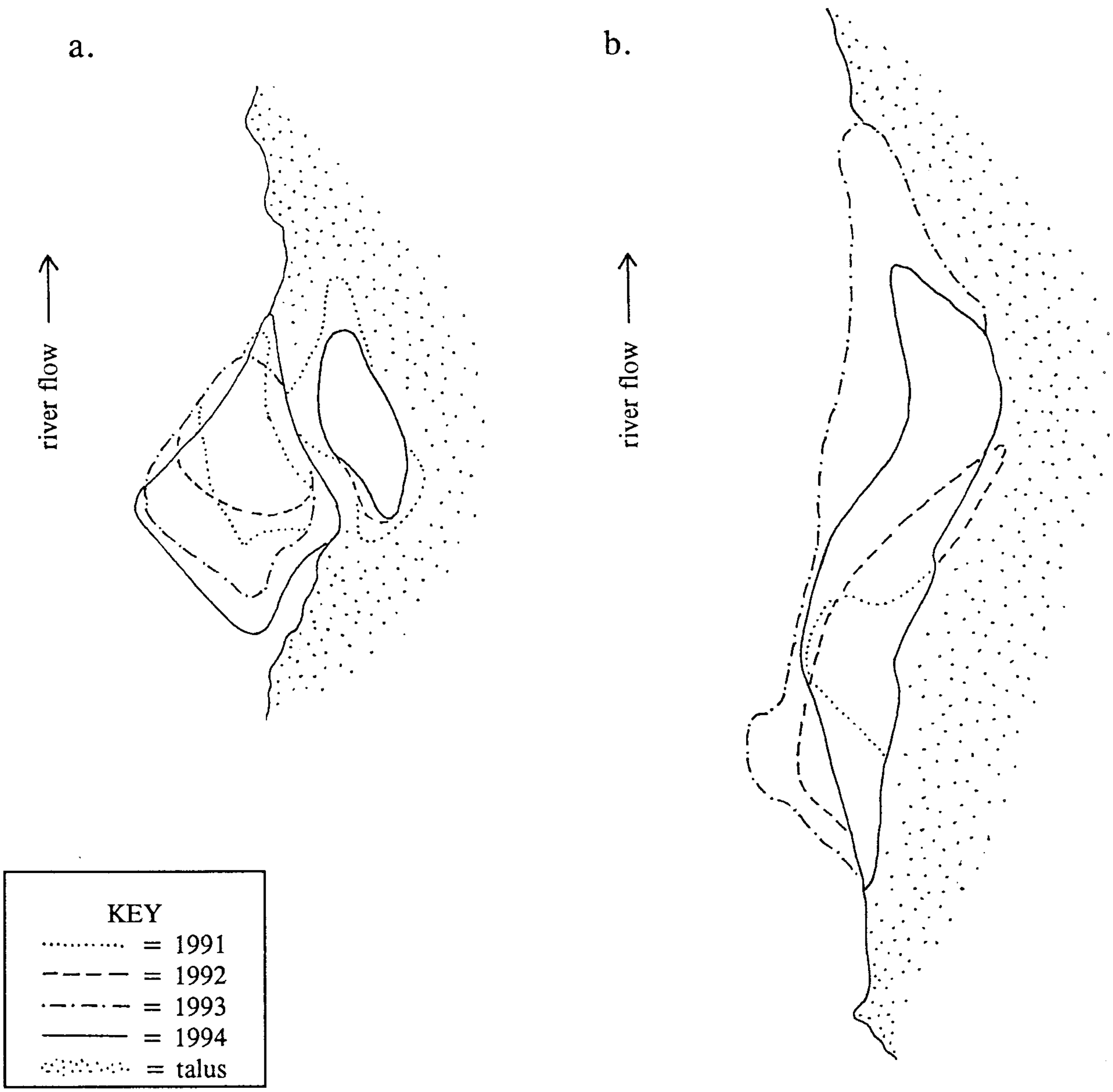


Figure 4. a) Campsite at RM 21.9R showing changes in campsite area below 708 m^3/s between years. Low water area increased with each year, and higher terraced area decreased as river's edge of terrace migrated shoreward. b) Campsite at RM 61.7R, just downstream from the LCR, showing effects of 1993 flooding events on campsite area below 708 m^3/s, with a large increase in 1993 and a substantial decrease in 1994.

DISCUSSION

Campsite area decreased significantly between 1991 and 1994, with a trend for more loss in critical reaches. River-induced erosion was the predominant causative factor, accounting for half of the campsite loss between 1991 and 1994, and for 80% of the area loss upstream of the LCR. This system-wide loss occurred in spite of the 1993 increase in campsite area of many sites caused by mainstem flow increase during the LCR flooding events. During this monitoring period, interim flow rules were in effect, thus interim flows did not prevent erosion of Grand Canyon's campsites.

The magnitude of this campsite area loss, both in the context of previous loss of campsite area and of recreational impacts, is minimal. When the 1991-1994 loss is compared to the system-wide gross decreases in campsite size between 1965 and 1991 (Kearsley et al. 1994), most of the size decreases since 1991 (with a mean loss of 9% area) are too small to be discerned in that study's context. This finding further validates that study's assertion that while large-scale decreases in campsite area due to erosion have occurred since dam operations, the rate of decrease has diminished. Also, the impacts to overall carrying capacity of the river corridor were minimally affected, except in the few sites eroded by localized tributary flooding. While changes in campsite area at low river stage have been dynamic at some sites, most of the campsite area above high river stage remains relatively unchanged, and approximately the same number of people can be accommodated at most sites.

One must be careful in interpreting the causes of changes in campsite area since the initiation of interim flows. This study establishes a rate of change in campsite area between 1991 and 1994, along with the relative influences from different causative factors. However, since annual measurements of campsite area were not made before interim flows, we cannot compare the rate of decrease in area during interim flows to a pre-interim flow rate of decrease. Also, half of the campsite area lost during interim flows was due to tributary flood damage and vegetation growth, changes only partially related to interim flows. While tributary flooding is a process unrelated to the mainstem, recovery from tributary flood damage primarily occurs when river stage rises above the scoured area. Since interim flows do not exceed 556 m^3/s, scoured areas on these higher terraces remain unreplenished. Also, interim flows are not the causative factor for vegetation growth above 708 m^3/s since these areas were normally above river discharges prior to interim flows. Campsite area between 556 and 708 m^3/s, however, is inundated much less frequently during interim flows, and is available for new vegetation growth (Stevens and Ayers 1994).

There are several limitations to this study. Other than low water area measurements, there is no relationship between discharge and campsite area in this study. As long as campsite area remained above the 226 m^3/s stage and could be used for camping, erosion of high elevation area to low elevation area was not discerned in these campsite measurements. Also, in order to have the same baseline of 226 m^3/s for all campsites, there is a discrepancy adjacent to the river between measured area and area that would be used for camping. Area measured as "campable" just above 226 m^3/s, while substantial at some campsites, would not be used for camping if river discharge fluctuated. This area would be and has been used during constant flows. Even during constant flows, though, if access is not difficult, campsite space near or within large patches of vegetation (above 708 m^3/s) is preferred for reasons of protection, aesthetics, and privacy.

Other research has documented rapid changes in portions of sandbars due to cycles of bank failure and rebuilding that may occur several times annually (Cluer and Dexter, 1994). These asynchronous episodes of erosion and deposition would not be discerned in annual monitoring. Some of these events occur along the low river stage of campsite area and may have contributed to the non-significant findings in differences in campsite area between years and reaches. However, this study of system-wide campsite change consists of analysis of a large number of sites (93), with abundant representation in critical and non-critical reaches. In this context, rapid changes may increase the variation in area measurements, which would make significant findings all the more robust. A finding of significant differences between years and between reaches in spite of the short-term erosion/deposition events demonstrates that patterns of change are discernable through annual monitoring.

This study demonstrates the benefits of main channel flooding under conditions similar the 1993 LCR flooding events on campsite area. Not only did many campsites increase substantially in area, almost all campsite area downstream from the LCR that had been lost due to tributary flooding prior to this event was reusable in 1993. Also, while area changes between 1991 and 1994 had little effect on the carrying capacity of most sites, the short-term size increases in 1993 were large enough to increase carrying capacity at many sites. The 1993 LCR events deposited more sediment than is discerned in this study because campsite area rather than sand volume was measured. There were numerous instances where new sand created higher terraces after the 1993 LCR flooding events enabling these areas to be used at higher flows, but where campsite area remained the same. The effects of this flooding event on campsites are important since planned beach building flows are proposed in the alternatives of the Glen Canyon Dam Environmental Impact Statement.

CONCLUSIONS

Campsite area was significantly smaller in 1994 than it was in 1991, losing a mean of 9% area. There was a trend for a higher proportion of campsite area to be lost in critical reaches than in non-critical reaches. Fifty-one percent of this lost area was river-induced (caused by erosion and increased slope of sand), 29% was caused by vegetation growth, and 20% was caused by tributary flooding. Loss by vegetation growth occurred primarily in non-critical reaches, and loss by tributary flooding occurred almost exclusively in critical reaches. Campsite area below 708 m^3/s decreased overall between 1991 and 1992, increased between 1992 and 1993, and decreased between 1993 and 1994. The increased area resulted from 1993 flooding in the LCR, which substantially increased downstream river stage, resulting in sediment deposition on many campsites. Mainstem flooding events under certain conditions do augment campsite area and would be beneficial from a recreation perspective to incorporate into future dam operation criteria.

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