Evaluation of Campsite Studies in the Colorado River Ecosystem: Analysis and Recommendations for Long Term Monitoring

Final Report

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Abstract

The continued existence, relative size and distribution of Colorado River sand bars are of particular concern to river managers. Sand bars used as campsites for river runners and hikers are one of the principal limiting factors in determining visitor capacity in the river corridor. Campsite area is also the main metric used by Grand Canyon Monitoring and Research Center to evaluate the effects of Glen Canyon Dam on recreational resources in the Colorado River ecosystem. Over the past thirty years, Grand Canyon National Park, Glen Canyon Environmental Studies, and now the Grand Canyon Monitoring and Research Center have supported a variety of monitoring and research to examine campsite area and visitor capacity. In general, these efforts have provided valuable information. However, a lack of consistent inventorying and monitoring strategies in the different studies reviewed in this report precluded a detailed, quantitative temporal analysis of changes to campsites. A more consistent, comprehensive, and long-term approach to assessment and monitoring of campsites and visitor capacity is needed. Based on our review of past and current efforts, we recommend the following: 1) campsite area measurements should be collected using either total station or orthophoto methods, or a combination of the two; 2) conduct a comprehensive inventory of all campsites within the Colorado River corridor 3) conduct a comprehensive estimate of the visitor capacity of the Colorado River corridor; 4) develop an integrated long-term monitoring program for measuring campsite area and visitor capacity of the Colorado River corridor; and 5) convene a panel of experts in a workshop to begin the development of a long-term monitoring plan and to discuss management and institutional issues.

Introduction

Grand Canyon National Park (GCNP) is one of the best-known wildland preserves in the world. GCNP was designated for the benefit of human visitors, as well as to protect the physical, biological and cultural resources contained within its borders. Interest in recreation on the Colorado River has risen dramatically since the mid-1960's, and a 200-mile journey through the Grand Canyon by boat is now regarded as one of the world's premier wild river experiences. Recreational use of the river corridor is closely regulated by GCNP, and demand, particularly for river trips, greatly exceeds availability. Sand bars are used as campsites for river runners and hikers, and the continued existence, relative size and distribution of sand bars are of particular concern to river managers (Stewart et al., 2000). Proper stewardship of the river corridor demands that Colorado River sand bars should be monitored and maintained for social as well as ecological reasons. Recognizing these multiple values, the Grand Canyon Protection Act (1992), the Glen Canyon Dam EIS (USDI, 1995a), and the Record of Decision (USDI, 1996) explicitly mandated monitoring and conservation of sediment resources and recreation values in the Colorado River ecosystem.

To address the recreation component of these responsibilities, both GCNP and the Grand Canyon Monitoring and Research Center (GCMRC) have supported a variety of research and monitoring efforts. Recent developments within both of these agencies have increased the importance of reliable information concerning recreational resources of the Colorado River corridor. The Glen Canyon Dam Adaptive Management Program (GCDAMP) approved a strategic plan that includes goals for maintaining or improving recreational experiences for visitors to the Colorado River (GCDAMP, 2001). Concurrently, GCNP reinitiated the process for revising and updating the 1989 Colorado River Management Plan (CRMP), which focuses on recreational use of the river corridor (USDI, 2002). Unfortunately, previous research and monitoring programs have applied inconsistent methods with intermittent monitoring of sand bars used as campsites, and temporally, these efforts have been poorly coordinated across program and agency boundaries. A more consistent, comprehensive, and long-term approach to assessment and monitoring of these critical resources is needed. Such a program should address both the GCDAMP need to assess the effects of Glen Canyon Dam operations on the resource and the mandate of GCNP to manage recreational use of the river corridor.

Objectives

The overall goal of this project was to develop recommendations for long-term monitoring of sand bars used as campsites within the Colorado River ecosystem (CRE) below Glen Canyon Dam. Specific objectives were to:

1. Review previous and ongoing campsite area monitoring methodologies.
2. Present a methodology for predicting future changes to campsites due to flow releases from Glen Canyon Dam.
3. Make recommendations for long-term monitoring of sand bars used as campsites.

This report is organized in four sections. The first section includes a review of past efforts to catalog and track changes in camping sand bar parameters, and a summary of current knowledge. The second section presents a comparison of methodologies used to measure campsite area. The third provides an overview of methods used by managers to establish appropriate levels of recreation in areas where use must be constrained due to high demand, sensitivity to impacts, limited physical space or some combination of these factors and a discussion of relationships between Colorado River sand bars, recreation experience quality and visitor capacity. In the fourth section, we integrate this information to make recommendations for the long-term monitoring of sand bars used as campsites in the CRE. This study did not review investigations of human impact on camping sand bars and focused on studies specifically related to measurement of campsite area and estimates of visitor capacity.

Background

Study Area

The Colorado River flows approximately 270 miles from Glen Canyon Dam to the Grand Wash Cliffs. Our review of campsite investigations includes the portion of the river from Lees Ferry to Diamond Creek (RM [River Mile] 0 – RM 225). Lees Ferry is the launching point for river trips through the canyon and Diamond Creek is the typical takeout point. Previous campsite studies have inventoried campsites between these points.

Reach Designations of the Colorado River

The geomorphic characteristics of the river channel are controlled by the bedrock type exposed at the river level (Dolan et. al, 1978). Features of the river channel such as distribution of debris fans, channel width, depth, and the size of sand bars are all related to bedrock geology (Howard and Dolan, 1981). Based on the type of bedrock exposed at river level and other geomorphic features, Schmidt and Graf (1990) defined eleven reaches of the river corridor between Glen Canyon Dam and Diamond Creek (Table 1). Webb et. al (2000) modified these reach designations based on debris flow characteristics (Table 1). Reaches that have relatively resistant bedrock exposed at river level are typically narrow, such as the Upper Granite Gorge (RM 77.5 – 117.8) and have steep, smaller debris fans; whereas reaches that have more easily erodeable bedrock are wider, and have larger, lower sloped debris fans, such as the Furnace Flats reach (RM 61.6 – 77.4). Kearsley and Warren (1993) defined reaches of the river based on campsite availability (Table 1). Critical reaches were defined as any stretch of the river in which the availability of campsites was limited and increased competition for sites occur. Non-critical reaches were defined as stretches of the river where campsites are plentiful and little competition for campsites occur. These campsite reaches closely follow the geomorphic definitions, and critical reaches are typically similar to narrow geomorphic reaches, where there are fewer sand bars. One exception is in the Deer Creek reach, which is in a relatively wide reach with many debris fans and sand bars. However, the concentration of attraction sites within this area causes a clustering of river trips and therefore intense competition for the available campsites.

Table 1. Geomorphic and Campsite reaches of the Colorado River in Grand Canyon.

Schmidt and Graf (1990)				Webb et, al. (2000)				Kearsley and Warren (1993)		
#	**mileage**	**Name**	**width**	**#**	**Mileage**	**Name**	**Width**	**#**	**Mileage**	**type**
1	0-11.3	Permian Section	Wide	1	0-8	Upper Wide I	Wide	1	0-11	NC[1]
2	11.4-22.5	Supai Gorge	Narrow	2	8-38	Upper Narrow I	Narrow	2	11-40.8	C[1]
3	22.6-39.9	Redwall Gorge	Narrow							
4	40.0-61.5	Lower Marble Canyon	Wide	3	38-77	Upper Wide II	Wide	3	40.8-76.5	NC
5	61.6-77.4	Furnace Flats	Wide							
6	77.5-117.8	Upper Granite Gorge	Narrow	4	77-170	Middle Narrow II	Narrow	4	76.5-116	C
7	117.9-125.5	Aisles	Narrow					5	116-131	NC
8	125.6-139.9	Middle Granite Gorge	Narrow					6	131-139	C
9	140.0-159.9	Muav Gorge	Narrow					7	139-164	C
10	160.0-213.8	Lower Canyon	Wide	5	170-213	Lower Wide III	Wide	8	164-226	NC
11	213.9-225	Lower Granite Gorge	Narrow	6	213-276	Lower Narrow III	Narrow			

1. NC = Non-Critical Reach, C = Critical Reach

Physical Characteristics of Sand Bars Used as Campsites

There are 768 tributaries of the Colorado River in Grand Canyon, of which 736 produce debris flows (Webb et al., 2000). Coarse sediment is input by debris flows and forms debris fans at the tributary mouths. Debris fans constrict the main channel and increase the local bed elevation of the river (Schmidt and Graf, 1990). At most constrictions, recirculation zones, or eddies are formed and because of lower flow velocities sand bars are deposited within eddies. Eddy sand bars are used as campsites for river trip and hiking parties and are commonly referred to as beaches.

Flow patterns within an eddy define the configuration of sand deposited (Schmidt and Graf (1990). Typically, eddies contain a primary recirculating zone and often have secondary zones of separated flow where the current rotates opposite that of the primary zone or is virtually stagnant. Sand deposits are classified based upon which recirculating zone they are deposited within. Two types of deposits are the highest in elevation and are most typically associated with campsites. Separation deposits mantle the downstream part of the debris fan near the point where the main current separates to form the eddy. Reattachment deposits are located at the downstream end of the primary recirculating zone where the main channel current reattaches to the bank. Channel margin deposits are not associated with tributary debris flows and occur along the channel banks. These deposits form within small eddies associated with bank irregularities caused by talus and rock outcropping. A small number of these channel margin deposits are utilized as campsites. Within narrow reaches of the corridor, flat complexes of bedrock ledges are also utilized as campsites.

Water release patterns between 1973 and 2002

The closure of Glen Canyon Dam decreased the annual sediment load of the Colorado and greatly decreased the magnitude and frequency of flooding (Andrews, 1991). Post-dam peak discharge has generally been limited to 33,000 ft^3/s (934 m^3/s) - the maximum capacity of the Glen Canyon Dam hydroelectric power plant, or more recently, 25,000 ft^3/s (708 m^3/s), following the Record of Decision on the Glen Canyon Dam Environmental Impact Statement (USDOI, 1996). Exceptions to these peak discharge levels occur either during high inflow years or experimental flow releases.

During the pre-dam gaging record, annual flood peaks averaged about 77,000 ft^3/s (2180 m^3/s). In the post-dam era, high inflow years resulted in a 1983 peak flow at Lees Ferry of 97,000 ft^3/s (2752 m^3/s) and 1984 to 1986 peak flows that ranged from 40,000 ft^3/s (1132 m^3/s) to 60,000 ft^3/s (1698 m^3/s). In 1996 an experimental high flow, or Beach Habitat Building Flow (BHBF) of 45,000 ft^3/s (1274 m^3/s) was released. Since 1996, three experimental flow releases of 30,000 ft^3/s (849 m^3/s) were released. These near power plant capacity flows were termed Habitat Maintenance Flows (HMF) and occurred in November 1997, May 2000, and September 2000.

Water releases from Glen Canyon Dam fluctuate diurnally. These daily fluctuations were unconstrained from closure of the Dam until 1992 and typically changed from a low of 3,000 ft^3/s (85 m^3/s) to a high of 33,000 ft^3/s (934 m^3/s), depending on the month and regional hydrologic factors. Beginning in 1992 to the present, flow fluctuations were constrained due to ecological reasons from a low of 5,000 ft^3/s (142 m^3/s) to a high of 25,000 ft^3/s (708 m^3/s). The maximum daily fluctuation allowed is 8,000 ft^3/s (226 m^3/s) per day. Typically, flows are higher in the summer and winter months and lower in the spring and fall.

Post dam patterns of sand bar change

Changes to Grand Canyon sand bars in the post-dam era follow a general pattern of erosion during "normal" dam operations, with brief periods of aggradation during flow events that are greater than power plant capacity. The largest flood event of the post-dam era was the 1983 flood which created or enlarged many sand bars that had eroded after closure of the dam (Beus et al., 1985; Schmidt and Graf, 1990). However, by 1986, many sites showed a net erosion and some sand bars used as campsites were completely eroded. Rubin et al. (1990) showed that the high releases from 1984 to 1986 deposited little sediment on sand bars. Sand bars continued to erode from 1986 until the 1996 BHBF (Kaplinski et, al., 1995). Topographic surveys before and after the 1996 BHBF show that the BHBF rebuilt previously eroded high-elevation sand bars (Hazel et al., 1999). Subsequent surveys showed that erosion rates following the BHBF were initially high, but decreased with time (Hazel et al., 1999). More recent studies have shown that sandbars continue to erode despite the release of three power plant capacity flood experiments in November 1997, May 2000, and September 2000 (Hazel et al., 2002).

These observations demonstrate that flood flows in excess of power plant capacity produce an increase in the volume of high-elevation sand deposits that are at least partially maintained for nearly a year afterward. Floods in excess of powerplant capacity are therefore not a one time "fix" of the continual erosion, rather, they can temporarily replace sediment lost to erosion and should be repeated when results from long-term monitoring show the volumes fall below a predetermined level.

Mechanisms of Campsite Area Loss

Substantial losses in area that is open and usable for camping have occurred due to erosion of sand bars, and also from colonization by vegetation of previously open areas. Kearsley and Warren (1993) found that campable area decreased primarily due to erosion in critical reaches, and primarily due to vegetation encroachment on sand bars in non-critical reaches. Although both trends reduce campable area, their effects are not identical so they are discussed separately.

Erosion of sand bar fronts is caused primarily by operations of Glen Canyon Dam. The magnitude of daily fluctuations, ramping rates and the increased ability of clear water releases to transport sediment have all been identified as contributing factors (Beus and Avery, 1992; Rubin et al., 2002). Rainfall induced flash flooding has also reduced campable area. However, flashflood impacts were transient prior to completion of the dam and erased every year or two as high spring runoff flows replenished and reworked sand bars.

Besides erosion, encroachment by tamarisk, other exotic species such as camelthorn and native species such as arrowweed and coyote willow into open sandy sections of sand bar is the other principal trend affecting campable area. Although this process has substantially reduced available space at many campsites, effects on visitor capacity are somewhat less clear than when area is lost to erosion. In some frequently used camps individual sleeping sites are cleared of, and kept free of vegetation by constant use (Philips et al., 1986). These individual sites are often separated by vegetation "screening" that may actually serve to reduce the distance that river trip participants feel they need to be separated from one another in order to achieve privacy. Clumps of mature tamarisk trees along steep river banks may serve to reduce further sand bar erosion by anchoring sediment in place, and also provide protection from sun and wind. However, in many larger and less frequently visited sites, dense patches of vegetation now make large areas of sand bar essentially unusable for camping activities.

Previous Work

With realization in the early 1970's that a more proactive strategy for managing river recreation was needed, NPS managers were faced with two issues: protecting river resources from impacts associated with rapidly rising visitation, and maintaining the quality of river recreation experiences. A critical first step in addressing these issues was acquiring knowledge about the capacity of the river to accommodate visitors, so that policies for regulating use could be developed.

Weeden et al. (1975) – the first campsite inventory

A team of researchers led by F. Yates Bordon conducted the first research concerning recreation visitor capacity in the river corridor. It was assumed *a priori* that size and availability of campsites might be principal constraints on capacity, so the first phase of this work consisted of an inventory of all sand bars in the river corridor that were suitable for camping (Weeden et al. 1975). A set of air photos was acquired on June 1973, producing about 800 prints at 1": 600' resolution. Interpretation of these photos prior to fieldwork revealed over 400 identifiable potential camping sand bars of ¼ acre or more. It was not practical to physically visit all of these, so sampling was determined by simultaneous consideration of ability to gain desired data by *posteriori* photo interpretation, rate of progress in fieldwork, and concentration of sand bars in a particular river reach.

Field data were gathered on a 16-day river trip in July 1973 by relief mapping, campsite evaluation, ecological study, and sand bar evaluation teams. The investigators noted that camps between river miles 8-40, and river miles 74-166 are scarce and small, and thus likely to present the most serious constraint on visitor capacity. Consequently, sampling was focused primarily on these reaches, where all identifiable camping sand bars were visited. No sand bars were visited in miles 0-8, four sand bars were visited in miles 40-73, and fifteen sand bars were visited in miles 166-240. Logistical difficulties prevented sand bar mapping from being accomplished for all but the first 10 sites visited. At all sand bars visited, the campsite evaluation team used the 24,000 cfs waterline to delineate the near-water boundary of campable area, and estimated campsite capacities. At sand bars visited after mapping was discontinued, one to four 35mm color slide photographs were taken from elevated vantage points of sand bar areas designated as suitable for camping. The ecological study team evaluated plant community parameters in the proximity of, and within campsites, including actual or potential vegetation encroachment.

Post inventory analysis was conducted using stereo pairs of the airphotos, to determine capacities for camping at sand bars not visited during fieldwork. Campable area was estimated by placing a template with a set of 5 graduated ovals over the airphotos, and interpolating which of the ovals best matched the flat sandy area visible in the images. Sand bar sections considered too rocky, too steep, too soft, too wet or too vegetated were eliminated, as were sandy areas deemed unsafe due to proximity to tributary canyons or imminent slides and rockfalls. Resulting estimates of net available camping area at each sand bar were then used to make capacity judgements. During the posteriori aerial photo interpretation phase, the investigators note the potential for error with this method, due to difficulties interpreting rocky conditions and that vegetation in shaded areas looked similar to sand. They suggested using higher resolution images (e.g. 1”:400’) for similar work in the future, and acquisition of false color/infrared images to increase ability to recognize vegetation.

Final products from the project were a campsite inventory available in both abbreviated and long form, 35mm slide photographs, aerial photographs and strip maps. To qualify as a camp, a sand bar had to be large enough to support at least 8 people above the 24,000 ft^3/s (680 m^3/s) water level contour, have a landing/mooring location within 50 yards of the camping area, and landing and mooring had to be possible for all types of river craft in use at the time. The investigators noted that suitability for camping is a judgement. Thus, some suitable sites may have been omitted, or unsuitable sites included in the inventory, and some sites may become unsuitable while others may become suitable, due to the dynamic nature of the system. They also stated that criteria for acceptance of an area as a campsite were applied less stringently in sections of the river where potential campsites were scarce. For these reasons they concluded that the inventory should be considered dynamic, with deletions, additions and clarifications made periodically to reflect changing conditions.

The investigators discussed in detail their criteria for designating sections of sand bars as suitable for camping, although the basis for making numerical capacity judgements was not explained. The investigators used a quantifiable indicator (campable area) upon which to base their capacity estimates, and suggested numerical limits for the number of people each camping area could hold, but did not quantitatively link the indicator and suggested standard.

Bordon (1976) - estimates of visitor capacity

Bordon (1976) incorporated knowledge gained from the campsite inventory in a study that resulted in the first and only comprehensive definition of recreation visitor capacity for the Colorado River. Bordon captured both ecological and social aspects of visitor capacity in his description of it as "…the level of river-runner use over a season that can be maintained from year to year without unacceptable impacts on the environment and that provides visitors with an overall rewarding experience consistent with the nature of the environment" (Bordon, 1976, p. 2). In stating that "…policy is the basic definer of visitor capacity" (p. 5), Bordon recognized the importance of basing capacity assessments on specific statements about what kind of experience was to be provided for. Experiential aspects of Colorado River trips were characterized by partitioning the experience into five dimensions: visual, aural, adventure, sociological, and wilderness. Although Bordon determined that all experiential dimensions were outstanding, and some were not substitutable, he concluded "…it is not any one dimension alone that accounts for the uniqueness of the over-all river running activity. Rather, it is the combination of such high, simultaneously attainable levels of the visual, aural, adventure and wilderness dimensions that make Grand Canyon river running truly unique" (p. 13). Based on this analysis of the type of experience available, and general

NPS mandates, Bordon submitted a general policy statement that guided his assessment of visitor capacity: “Float trips on the Colorado River will be conducted to allow a broad spectrum of people to participate in an adventuresome, aesthetically outstanding wilderness experience of long duration” (p. 13).

Once the type of experience was defined, an estimate of the visitor capacity of the river was developed. In developing the visitor capacity estimates, assumptions were made concerning several parameters such as user days, length of the primary season, and group size (8 person minimum, 40 person maximum). Based on an average river current speed of 4.2 miles per hour, downriver travel was assumed to average 21 miles per day, with the typical visitor using 11 user-days. Constraints imposed by campsite size and locations were derived from the Weeden et al. surveys.

Campsite size and availability in critical sections of the River Corridor were found to be the limiting parameters of visitor capacity, within the constraints of the type of experience the NPS sought to provide. Bordon recommended limiting departures from Lees Ferry to 148 people per day (three groups of 40, one group of 20 and one group of eight) and prescheduling camps in critical reaches. Based on a 182-day season and 11 user-days per visitor, he estimated visitor capacity at 296,296 user-days. Bordon stated that this system would require satisfactory scheduling of launches and progress downriver, but also acknowledged the need for flexibility in downriver travel due to variables such as weather and water level, and because some intergroup contacts are impossible to avoid, and in some cases, desirable. He noted that the regimentation of rigid but efficient scheduling would degrade experience quality, and suggested that intergroup spacing should be left primarily to the river guides.

Currently, 166 people are allowed to launch daily during the primary season, and two trips per day during the secondary season (USDI, 1989). Borden’s focus on critical sections, now known as critical reaches, has been widely adopted by subsequent researchers and river planners. Campsite prescheduling in critical reaches has not been implemented, but lack of campsite size and availability has been one of the principal drivers of policy and legislative change, and remains a key management consideration.

Brian and Thomas (1984) – campsite inventory after the high flows of 1983

Recreation visitor capacity was not re-evaluated until a survey of sand bar capacity was conducted following the record post-dam high discharge of 97,300 ft3/s event of 1983 (Brian and Thomas 1984). Campable sand bars were assessed during an NPS river trip in fall, 1983. Each investigator was responsible for assessments on one side of the river for the duration of the trip. Sand bars were classified as small (15-20 persons), medium (21-30), or large (31-40). Most sand bars were assessed from the river, but onsite inspection was made when vegetation occluded camping features. Investigators made considerable use of their river experience (~8 years) and conferred with other trip participants about evaluations. Sand bars were inventoried as camps if area above the new high water line, or the 25,000 ft^3/s (708 m^3/s) stage elevation, would accommodate 15 or more people, and there was a pathway from the mooring to camp area. Brian and Thomas identified a total of 438 campsites using these methods. In addition, Brian and Thomas directly link the Weeden et al. (1975) camp size classes of 15, 20, 25, 30, 35, and 40 with the templates of 0.27, 0.65,0.97, 2.2, 3.9 and >3.9 acres that he used for airphoto interpretation of sand bar areas. This quantitative linkage of areas with capacities is the only such linkage of which we are aware.

Acknowledging limitations to the validity of comparing data from studies by teams with different levels of contextual experience using different methodologies, Brian and Thomas state that, of 227 campsites also identified by Weeden et al. (1975), 42% were the same size, 30% increased and 28% decreased in 1983. Twenty-four campsites were lost or became unusable as a result of the 1983 flood, including 6 from Upper Marble Canyon, and 7 from Upper Granite Gorge, both of which are critical reaches. The authors list 32 campsites lost prior to the 1983 flood, including 5 not identified in 1973. Most of these were not frequently used and were not in critical reaches.

Thirty-five sand bars listed in Weeden et al. (1975) were not listed in the 1983 survey, because of vegetation encroachment, erosion, or because they were listed by Weeden but not known to have received use. Conversely, the 1983 survey included 77 campsites recognized as such prior to 1983 but not listed by Weeden. Assuming that these sand bars existed in 1973, Brian and Thomas attribute this discrepancy to the fact that half of the 1973 campsites were identified by airphoto interpretation by personnel unfamiliar with sites actually used by river runners. Many (33/77, 43%) are listed as commonly used by Stevens (1983) while the remainders are recognized as campsites by NPS personnel and river runners. Campable area on 86 pre-existing sand bars was increased in 1983 by sediment deposition or vegetation removal, primarily in Lower Marble Canyon, below Havasu Creek, and below Lava Falls (RM 179). Brian and Thomas list 50 new campsites deposited by the 1983 high flows, 38% were small, 34% medium and 28% large. Small camps were distributed in all reaches except Upper Marble Canyon, medium camps mostly below Middle Granite Gorge, and large camps equally distributed above Upper Granite Gorge and below Havasu.

Brian and Thomas noted a net movement of sediment downstream, reflected in the general decrease in size and number of sand bars from Lees Ferry to Kanab Creek (RM 143), and increase in size and number from Kanab Creek to Granite Park (RM 209). They suggested that sediment stored in the river bed since closure of Glen Canyon Dam had contributed to the increase, and that without substantial sediment input, high flows in the near future would result in greater loss of campsites, particularly in the upper reaches. They recommended resurveying of campsite capacities using their methodology when river managers noticed a substantial change in number or capacity of camps or following flow events of 35,000 ft^3/s (990 m^3/s) or greater, and at intervals determined by NPS personnel observations. They also recommended monitoring campsites at four-year intervals, using vegetation maps for vegetation encroachment and human use patterns.

Kearsley et al (1991-1997) – campsite inventories and visitor capacity estimates in the 1990's

The next effort to assess changes in camping sand bars was that of Kearsley and others in the 1990's. This work consisted of an inventory of camping sand bars and airphoto comparisons (Kearsley and Warren 1993, Kearsley et al. 1994), annual measurement of campsite area at 93 sand bars from 1991-1994 (Kearsley 1995) and sand bar assessment before and after the 1996 Sand bar-Habitat Building Flow (Kearsley and Quartoroli, 1997). Camping sand bars were inventoried in 1991 by interviewing professional river guides to develop a draft list of sites, which was refined by onsite visitation and assessment by the investigators and professional guides. Physical carrying capacities were estimated by consensus of interviewed guides and onsite evaluations of the number of sleeping sites to categorize each sand bar by size class: small (10-12 persons), medium (13-24 persons) and large (25 or more persons). Campsites listed in 1973, 1983 or 1991 inventories were evaluated using aerial photographs from 1965, 1973, 1984 and 1990. Area of exposed sand above a river flow reference stage of 25,000 ft^3/s (708 m^3/s) was estimated at each campsite. Because of limitations in interpreting aerial photographs, physical visitor capacity of sites was not estimated in this phase of the study; instead changes were recorded as a substantial increase or decrease from the initial 1965 condition.

Kearsley and Warren (1993) found that campsites had decreased dramatically in both number and size since Weeden's team completed its initial survey in 1973. Reaches designated as critical because of limited availability of suitable campsites (Marble Canyon, RM 11-40.8; Upper Granite Gorge, RM 76.5-116 and Muav Gorge, RM 139-164) are nearly the same as the critical sections identified by Weeden et al. (1975). Campable area decreased primarily due to erosion in critical reaches, in non-critical reaches, decrease in campsite area was primarily due to vegetation encroachment (Kearsley and Warren 1993). An overall trend of increased campsite size and number between 1973 and 1983 was attributed to the 1983 high discharge, but the change was temporary, with sand bars significantly decreasing in size and number less than one year later. Moreover, campsites in the Upper Marble Gorge and Upper Granite Gorge decreased between 1973 and 1983 and between 1983 and 1991. The inventory documented 226 campsites above the new highwater zone (25,000 ft^3/s [708 m^3/s]), a 32% decrease in campsite number between 1973 and 1991. This included a 51% decrease in large camps, resulting in a 44% decrease in campsite area between 1973 and 1991. Campsite area decreased an average of 9% between 1991 and 1994, with disproportionately larger decreases at camps in critical reaches (Kearsley 1995). River induced changes accounted for 80% of lost campsite area above the Little Colorado River, but only 32% of loss below the Little Colorado River confluence.

Kearsley et al. (1994) concluded that loss of Colorado River campsites was an ongoing process after nearly 30 years, but that the rate of decline had slowed. The overall pattern of change was one of initial system-wide decrease in sites (1965-1973), variable change during years of regulated high flows (1983-1986) and a system-wide decrease in campsites between 1984 and the mid-1990's. They noted that not all sand bars in Grand Canyon respond in the same manner to high flows, fluctuating flows, or vegetation encroachment, and that campsite availability in critical reaches had decreased the most. They recommended that managers focus on long-term responses of campsites in critical reaches by implementing strategies that create new or increase the size of sand deposits there. Strategies that lead to net aggregate deposition along the river but which cause net campsite loss in critical reaches will only exacerbate problems associated with current use at the few remaining campsites.

As part of efforts to monitor changes resulting from the 1996 Sand bar Habitat Building Flow, 53 camping sand bars were randomly selected from the 218 remaining from the 1991 inventory, and physically measured two weeks before, two weeks after and six months after the 45,000 ft^3/s (1274 m^3/s) flow reached during this flood experiment (Kearsley and Quartaroli 1997). Float-by assessments (i.e. Brian and Thomas, 1984 method) were made of 200 sand bars, including the 53 that were also measured. Results showed a system-wide increase in campsite area. Half (100/200) of the sites assessed were at least 10% larger, 39% (77/200) were the same, and 12% (23/200) were smaller than prior to the high flow. For sites directly measured, 62% (33/53) increased in size, 17% (9/53) were the same, and 21% (11/53) decreased in area. Float-by assessments were less sensitive to measuring change, but not biased toward increase or decrease. At many sites, sand was deposited directly on top of existing campable areas, and did not increase campsite size. At some sites, new sand was deposited as a mound over previously usable space and the increase in slope angle resulted in decreased camping area.

Eighty-two new sites were created, in the sense that these were not usable just prior to the high flow. However, although 33 of these were included in previous campsite inventories, all had degraded to being unusable by 1996. Many new sites consisted of deposition on low elevation sand bars that jut out into the river, with little sun or wind protection. These were theoretically usable but not highly valued as camps, and were subject to rapid erosion. Forty of the new sites were between RM 40-65. More than twice as many sites were created in non-critical reaches as in critical reaches. Six months after the high flow, only 55% (45/82) of the new sites were still considered usable. The high flow obliterated 3 previously inventoried campsites. Overall, the BHBF increased the number, size, capacity and aesthetic qualities of campsites. These benefits were substantial, but degradation occurred quickly- within 6 months, nearly half the new campsites were unusable, remaining new sites were half their initial size, and most of the increased area on measured established sites had eroded. Relatively high flow releases immediately following the 1996 Sand bar Habitat Building Flow in 1996 and 1997 probably exacerbated erosion.

Grand Canyon River Trip simulator Project

The Grand Canyon River Trip Simulator Project (GCRTSim) is a computer program designed to predict visitor use dynamics on the Colorado River, developed for planning purposes with support from GCNP (O'Brien and Roberts, 1999; Roberts and Bieri, 2001; Roberts et al., 2002). To model campsite use, a database of campsite visitor capacity was derived from research sources from 1973 to 1996, and visitor capacity was examined to see how it pertained to application of the computer simulator (Roberts et al. 2002). Changes to previous visitor capacity estimates due to subsequent changes in sand bar morphology were analyzed by an on-river survey of twenty sand bars in October 1999 (O'Brien and Roberts, 1999). The entire inventory was scrutinized for potentially erroneous capacity estimates. A list of 24 camps was provided for which capacity was thought to have changed since 1996, based on Adopt-A-Beach (reviewed below) repeat photography and onsite observation, including 8 that were deemed essentially unusable at any water level. A second list of 20 campsites was presented, selected based on significant change in size, use frequency and proximity to attraction sites and visited in 1999 to estimate current capacity. O'Brien and Roberts (1999) found that visitor capacity had decreased at 50% of the sites, and by 10 or more persons at 30% of sites.

The investigators noted that small, medium and large campsite categories are important for characterizing individual sand bar capacity in general, but groups do not choose a campsite by size distinctions alone. Other physical and aesthetic characteristics, trip logistics such as time of day and proximity to attraction sites, and lack of options also affect campsite choice. Capacity estimates were based on basic *ability* to use a site, while the simulator was intended to predict *decisions* to camp at a particular site, a process that is more complex than simply matching a visitor capacity value to a group size. For modeling purposes, capacity estimates may be most useful when considered as maximum values (i.e. the maximum number of people that could camp at a given site).

While acknowledging that many campsites had eroded, the analysis deemed the 1996 data sufficiently accurate for use in the simulator, but the authors also recommended updating campsite inventory information. They note that an important question remains unanswered: "How does visitor capacity relate to degree of change, specifically, how much change must occur before capacity is affected?"

O'Brien and Roberts (1999) recommended developing a method of converting camping area, a measurable quantity, to visitor capacity of a site and suggest addressing this key information need by developing a standardized method of estimating visitor capacity for a sand bar, so that on-site estimates are performed consistently. They state that an interdisciplinary team of a statistician, a sociologist, a geologist and surveyors should be included in order to develop an empirically verifiable and repeatable method of measuring and interpreting the campsite area, location and abundance in relation to other variables such as trip length, attraction sites, number of people, and social aspects of visitor use.

Grand Canyon River Guides Adopt-a-Beach program (1996 – 2002)

The Adopt-A-Beach (AAB) program is an ongoing qualitative effort by the Grand Canyon River Guides (GCRG) to monitor changes in parameters that affect the quality of Colorado River sand bars for camping. Individual commercial river guides, science trip participants and NPS staffers volunteer to "adopt" a particular sand bar for the spring through fall season. Periodically, adopters stop at their chosen sand bar to note changes and take photographs from a pre-established location that provides a view of the sand bar front and as much of the camp as possible. To date, five AAB administrative reports have been completed. Three summarize results for one year (Thompson et al., 1997; O'Brien et al., 1999; Thompson, 2001) and one summarizes results for two years (O'Brien et al., 2000), and the other summarizes six years of the program (Thompson, 2002). Current data are integrated with that of prior years. Each report includes appendices with adopter comments and a brief description of changes shown in photographs, allowing changes over the course of a season to be tracked for each camp monitored. Photographs and narratives are archived at the Grand Canyon River Guides office in Flagstaff, Arizona.

Forty-three sites in critical reaches were adopted during the 1996 season, when the AAB program was initiated in response to announcement of the BHBF experiment. The AAB program defined critical reaches as river sections where camps are in high demand, few in number or small in size; this differs slightly from those used by Kearsley and Warren (1993): Marble Canyon, RM 9-41; Upper Gorge, RM 71-114 and Muav Gorge, RM 131-165. Principal conclusions from the 1996 effort were that the BHBF deposited large amounts of sand on highly used sand bars, and that while new sand bar fronts were initially steep, many graded to gentler and more stable slope angles as a result of human use during the river running season. It was suggested that relationships between sand bar stability and human use needed to be explored. Guides noted considerable erosion as the season progressed, but felt sand bars were still larger in the fall than before the BHBF (Thompson et al., 1997).

Of the forty-three sand bars adopted in 1996, forty were studied in 1997 and twenty-one in 1998. The 1999 AAB report synthesized data gathered in 1996, 1997 and 1998 to look at four time periods: the 1996-7 winter season, 1997 summer season, 1997-8 winter season and 1998 summer season (O'Brien et al., 1999). In general, sand bars eroded during this period. Some aggradation took place during the November 1997 test flow (31,000 ft^3/s [877 m^3/s]) but was mostly eroded by 1997-98 winter flows. High constant flows during 1997 were observed to increase erosion of sand bars at higher stage levels, while depositing sand at lower elevations. Fluctuating river flows appeared to be the biggest factor in sand bar erosion, but it was unclear whether the higher but steadier flows of 1997 or lower flows with larger fluctuations in 1998 caused erosion at a faster rate. Guides noted the disappearance of remaining 1996 BHBF deposits at many camps, but a majority was still larger than prior to 1996. A significant percentage of sand bars showed little change over both years, possibly due to increased vegetation above fluctuating flow levels, increased stability within campable areas due to visitation, and quasi-equilibrium of sand deposits resulting from compaction and infilling of gullies by wind. It was suggested that more research is needed to identify factors that contribute to stability of sand bar deposits over time.

The 2000 AAB report presented findings from data collected in 1999, and cumulative observations from 1996-1999 (O'Brien et al., 2000). Twenty-nine sand bars were adopted in 1999. Over 1000 repeat photographs had been archived at the time the report was completed, documenting changes over a 4-year period. Sand bars continued to degrade system-wide, but the number of sand bars showing no change was greater than the number decreasing in size, and the number of sand bars degraded due to fluctuating flows was lower than the number degraded by flashflood induced gully formation. It was also noted that rate of sand loss had declined annually since the 1996 BHBF. Concern was expressed that several camps had become essentially unusable since 1996, due to excessive loss of sand to erosion by rainfall, flash flooding and cutbank formation, including Upper Garnet (RM 114.3), Lower Tapeats (RM 132), and First Chance (RM 158). It was concluded that the net effect of controlled flows from Glen Canyon Dam is the continued erosion of sand bars. The ongoing loss of sand from camp areas is also exacerbated by the effects of visitation, wind and rain. It was suggested that continuation of the AAB program would help differentiate the processes contributing to sand bar area loss.

The 2001 AAB report again presented data for the preceding season and integrated this with cumulative data (Thompson, 2001). Thirty-four sites were adopted in 2000; twenty-seven of these are in continual high demand and have been adopted most years. These were identified as higher priority in order to assure continuity of data. It was noted that encroachment by tamarisk has necessitated relocation of many photo locations since inception of the AAB program. It was also noted that the AAB methodology was particularly useful for the 2000 season, where short-term changes resulting from the 8000 ft^3/s (226 m^3/s) Low Steady Summer Flow and two four-day flows of 31,000 ft^3/s (877 m^3/s) were assessed. Results showed that sand bars continued to decrease system-wide from 1996 until May 2000, when the initial 31,000 ft^3/s (877 m^3/s) flow started the Low Steady Summer Flow experiment. During this initial high flow event, sand bars gained a relatively small amount of volume (Hazel et al., 2002).

The September, 2000 31,000 ft^3/s (877 m^3/s) high flow restored sand bars approximately back to their condition following the May 2000 31,000 ft^3/s (877 m^3/s) flow event. The Low Steady Summer Flows opened up several camps that are under water and unusable at higher flows. Many guides felt low steady summer flows yielded better camping than in the 3 previous years, but some problems were noted, including increased rockiness in boat mooring areas and longer, steeper slopes for accessing camps. Overall, the Low Steady Summer Flow experiment offered some improvements in camping, but these were very small when compared to the benefits resulting from the 1996 BHBF.

Kaplinski et al. (1998-2001) - NAU Campsite Area Measurements

The next campsite monitoring study was initiated in 1998 by a team of researchers at Northern Arizona University primarily involved in geomorphic studies measuring changes in sand bar area and volume (Kaplinski et al., 1998, 2001). The NAU team developed new, more precise techniques for monitoring campsite area changes at a selected number of sites. The NAU method involves measuring campsite area at thirty-one of the long-term study sites used for the geomorphic investigations using standard total station survey techniques, rather than aerial photographic mapping. The NAU team used the same criteria for identifying campsite area as Kearsley et al., but improved on the accuracy and precision of the measurements, incorporated detailed stage-discharge relationships into the area calculations, and integrated geomorphic changes at the site into interpretations of change. Kaplinski et al (1998) also conducted simultaneous measurements of their sites using the Kearsley method of aerial photographic mapping in order to provide an assessment of the relative accuracy and precision of the two methods. The results of this comparative analysis are presented in the next section of this report. Kaplinski et al (2001) reported on three years of annual campsite area monitoring. Their results show that high elevation (above the 25,000 ft^3/s [707 m^3/s] stage elevation) camp area decreased between each survey. From October 1998 to October 1999 high-elevation camp area decreased by 25% and from October 1999 to October 2000, campsite area decreased by 10% (Kaplinski et al., 2001). Kaplinski et al. (2001) also reported that campsite area above the 25,000 ft^3/s (707 m^3/s) stage elevation had decreased at a greater rate than sand bar volume above this level. This indicates that other factors, such as vegetation encroachment, wind deflation, erosion from precipitation runoff, and human traffic have contributed to the loss of high elevation camping area. In addition, high-elevation camp area has continued to decline despite the release of two near-powerplant capacity floods in 2000, which suggests that near-powerplant capacity floods are not of sufficient magnitude to replenish high-elevation campsite area (Hazel et al., 2001).

Summary of campsite area and visitor capacity studies

Availability and size of sand bars used as campsites in critical reaches have long been recognized as limiting factors in the amount of recreational use that can be accommodated on the Colorado River. In the early 1970's, when it became apparent that limits on recreational use were needed, Weeden et al. (1975) made a valuable contribution by developing the first scientific inventory of Colorado River campsite number, size and capacity. Estimates were provided in the form of numerical limits for the number of people each camping area could hold. Criteria for designating sections of sand bar as suitable for camping were discussed in detail, although the specific basis for making numerical capacity judgments was explained simply as professional judgment. Nancy Brian, principal investigator for the Brian and Thomas surveys (Brian and Thomas 1984) indicated that Weeden et al. (1975) directly converted capacity estimates from the area templates used to estimate area (N. Brian, pers. comm., 2002), thus providing an important link between a measurable quantity (campsite area) and the reported capacity estimates, that was not reported by Weeden et al. (1975). Weeden et al. (1975) did note that for simplicity, most of the photo interpretations were of capacity instead of area. Bordon (1976) used the Weeden inventory to develop recommendations for visitor capacity on the river.

Brian and Thomas (1984) assessed campsite number and size following the high flows of 1983. A system-wide increase in sand bar size and number was offset by loss of 13 campsites in critical reaches, a general decrease in size and number of sites above RM 143, especially in critical reaches, and rapid erosion of new sediment, even after only one year (Brian and Thomas, 1984). Despite limitations resulting from the qualitative methods employed, and differences between these methods and those utilized by Weeden et al. (1975), the 1983 inventory provides valuable interim data during a 20-year period in which no other recreation visitor capacity related studies were conducted.

In the early and mid-1990's, Kearsley and associates inventoried campsites, analyzed campsite size and distribution trends, and monitored selected campsites for several years (Kearsley and Warren 1993; Kearsley et al., 1994; Kearsley 1995; Kearsley and Quartaroli 1997). Qualitative and quantitative methods were used, but methodologies were again mostly different from those used in prior studies. This effort was more rigorous than the 1983 inventory, and results showed conclusively that sand bar size and number had declined dramatically since 1973, especially in critical reaches. Increases in campsite size and number after the 1983 flood and 1996 BHBF were largely short-lived, with campsite degradation beginning almost immediately after cessation of high flows in both cases. An attempt was initially made to inventory and monitor changes in visitor capacity, but focus later shifted to campable area, a parameter that is easier to quantify and less subjective than visitor capacity judgments. Campsite area has since become the preferred parameter for monitoring campsite quality, but no attempt has been made to link recent changes in campsite area to visitor capacity.

Kaplinski et al. (2001) conducted annual campsite monitoring from 1998 through 2000. Their surveys indicate that high-elevation (above 25,000 ft^3/s [708 m^3/s]) campsite area declined approximately 25% during this period. The campsite area decline was greater than the loss of sediment from the high-elevation areas of the sand bars and indicates that factors such as vegetation encroachment, surface runoff, and human-induced impacts, are also responsible. They concluded by noting that flood flows above power plant capacity are needed to maintain campsite area at high elevations.

Since 1996, the AAB program has provided more or less continuous observations of frequently used campsites for several months each year, rather than once per year or every few years. Although qualitative, such information enables sand bar changes to be closely linked to particular timeframes and flow regimes, and thus provides a valuable counterpoint to more rigorous, but less temporally robust monitoring efforts. To some extent, AAB information also enables sand bar degradation from rainfall to be distinguished from river flow related impacts and provides a measure of campsite quality indices such as mooring, vegetation encroachment, etc. Results from 5 years of AAB data show that camping sand bars have largely returned to their pre-1996 sizes, and continue to erode, albeit at a slower rate each year.

Based on the review of previous studies, we have constructed a time series plot of what we term the campsite availability index. The campsite availability index was derived from the percent change in the number of campsites between campsite inventories conducted through 1996, then combined with measurements of campsite area at specific sites post-1996. Because the campsite availability index combines different metrics, it should be interpreted as a qualitative view of the changes to campsites in the post-dam era.

The campsite availability index time series plot shows that Grand Canyon campsites have declined in number and/or area in the post-dam era. In addition, the availability index time series shows that the present condition of campsites in Grand Canyon is at an all time low. Two increases in the time series correspond to sand deposition during the high flows of 1983 and 1996. Despite these increases, erosion of the sand deposits and vegetation encroachment above "normal" dam operations in years without high flows decrease the availability of campsites in Grand Canyon.

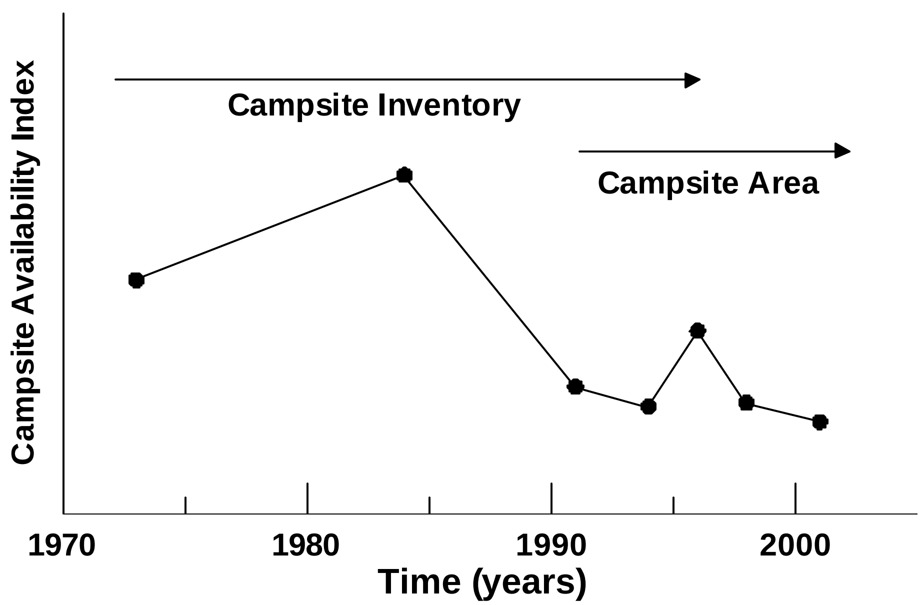

Figure 1. Graph showing changes in campsite availability index. The campsite availability index is a qualitative measure of change that was constructed by combining changes in the number of campsites with changes in campsite area.

Comparison of recent campsite area methodologies

We conducted an analysis of three different methods for measuring campsite area in order to assess which method provides the best solution for future monitoring. Two of the methods have been used previously for monitoring and the third was developed to take advantage of new mapping technologies that are now available through the GCMRC remote sensing initiative. The three methods analyzed are: 1) aerial photographic mapping conducted by Kearsley and Warren (1993), Kearsley (1995), and Kearsley and Quartoroli (1997), hereafter referred to as the aerial photo method; 2) total station campsite area mapping conducted in an ongoing study by Kaplinski et al. (1998, 2001); and 3) mapping directly on to orthophotos using field tablet computers, referred to here as orthophoto method. The GCMRC Remote Sensing Program is currently developing an automated mapping procedure using the orthophoto database to place polygons around open areas of sand. This technique holds promise as a monitoring tool, but was not evaluated for this report due to the preliminary status of the project. Total station mapping techniques provide the highest level of spatial accuracy and precision. Therefore, in our analysis, we compared measurements made using the other two techniques to total station measurements made at the same time. We collected measurements using the total station and aerial photography during monitoring trips in October of 1998 and 1999. Ortho photo mapping and total station measurements were collected during a monitoring trip in October 2001 survey trip. All three of these techniques utilized the same definition of campsite area; a relatively flat (less than 8 degrees of slope), non-cobbled, non-vegetated, non-marshy area (Kearsley and Warren, 1993) and mapping was completed while on-site.

Campsite area mapping involves a certain degree of subjectivity when selecting areas at a given sand bar to map as campsite area. Due to the subjectivity of the mapping, Kaplinski et al. (2001) considered area changes greater than 10% between surveys as significant, even though total station surveys have been shown to be precise to within 3% (Kaplinski et al., 1998). However, for the method comparison, conducting the aerial photographic and orthophoto mapping concurrently with total station mapping effectively removes the operator-specific subjectivity. While the selection of which area to map is still subjective, all mapping crews selected the same areas for mapping.

Aerial Photography mapping (Kearsley et al.)

The campsite area mapping technique used by Kearsley and Warren (1993), Kearsley (1995), and Kearsley and Quartoroli (1997) involved mapping campsite area at a selected number of sites by outlining camp spots on 400% Xerox copies of 1:4800 aerial photographs, then digitizing the polygons and calculating areas in a Geographical Information System (GIS) environment. Ticks marks for registering the photographs were either taken from common points identified on orthophoto base maps (Werth et al., 1993), or using a conversion factor between digitizer units and actual ground distances. This conversion factor, derived by measuring the distance between recognizable features on the aerial photograph during the on-site visit and dividing the digitizer units between the same features, was used to convert digitizer units to square meters. During their October 1998 and 1999 survey campaigns, the NAU team used this method to outline campsite areas while simultaneously conducting total station campsite area surveys.

Total Station Mapping (Kaplinski et al.)

Kaplinski et al. (2001) conducted campsite area mapping at their study sites using standard total station survey techniques (USACOE, 1994). Survey crews consisted of an instrument operator, one to two rodmen and a crew chief. At each site, the crew chief would direct the rodman to points that outline the perimeter of camping areas, as well as points that outline the perimeter of exclusions to the camp, such as trees and rocks. The crew chief also mapped the areas following the methods of Kearsley and others. These sketch maps proved valuable on return visits to reduce subjectivity and enable duplication of the camp area on subsequent surveys by different personnel and to assist in the interpretation of variables causing campsite area change (i.e. vegetation encroachment, runoff, bank erosion, etc.). Not all possible camp areas were mapped at every site. Instead, representative camp spots were selected across a range of stage elevations. Camping areas not represented in the mapping were typically far (>100 m) from the main mooring/cooking areas.

Survey points for each site were downloaded from field data collectors and checked for proper control coordinates and elevation. Digital elevation models (DEMs) were formed within the area boundaries. The elevations of the various stage elevations were derived from an empirically derived stage discharge relationship at each site. The plan area within different ranges of stage elevation was calculated from the DEMs and tabulated in a spreadsheet.

Ortho photography mapping (Kaplinski et al.)

During the October 2001 campsite area mapping campaign, a methodology was developed to outline camping areas directly on to a digital ortho photo basemap. Digital ortho photos, collected annually by the GCMRC starting in March of 2000, are spatially referenced digital aerial photographs. The ortho photos were downloaded onto ruggedized Fujitsu Stylistic pen tablet computers and mapping was conducted using GIS software (ArcView v. 3.2). Survey crews consisted of one person equipped with the computer tablet and reference maps from previous years.

Evaluation of Methods

Using the methods of Palmer (1990), the performance of the aerial photo and orthophoto methods relative to the total station mapping was evaluated by the mean deviation, mean square deviation, mean square proportional deviation, percent overestimates, and the correlation between the two methods and total station mapping. The mean deviation (MD) is a measure of bias, and is calculated as follows:

$$MD = \sum_{j=1}^{P} (E_j - O_j) / P,$$

Where E_j is the ortho photo or aerial Photo area value and O_j is the total station area value, and P is the number of comparisons. MD will be positive if the method measures more area and negative if it measures less. The magnitude of MD measures the poorness of fit. The mean square deviation (MSD) measures the closeness to the total station measurements and is calculated as follows:

$$\text{MSD} = \sum_{j=1}^{P} (E_j - O_j)^2 / P.$$

Measurements with smaller MSDs are more precise than those with larger MSDs. An estimate with a high MSD may nevertheless have a MD close to zero. Such an estimator is accurate, but not precise. Both MD and MSD measure the absolute deviation of Aerial photo or ortho photo measurements from total station measurements.

The percentage of over measurement is another measure of bias. If this value is close to 100 or 0%, the method is very biased. An ideal measurement should overestimate 50% of the time. The correlation coefficient, or r^2, between aerial photo or ortho photo and total station mapping values measures the adequacy of measurements for comparison purposes.

Results and Discussion

The performance of the aerial photo and ortho photo methods are displayed in Figure 2 and Table 2. Both the Ortho photo and aerial photo methods are negatively biased. Both methods have negative Mean Deviations and percent over measurements below 50%. The Mean square deviations values show that the ortho photo method is more precise than the aerial photo method. The ortho photo method is also more highly correlated with the total station mapping.

Table 2. Performance of methods versus total station mapping

Method	MD	MSD	% over measurement	r^2
Ortho Photo	-25.92	4408.55	38.46	0.979
Aerial Photo	-46.38	7795.46	30.77	0.941

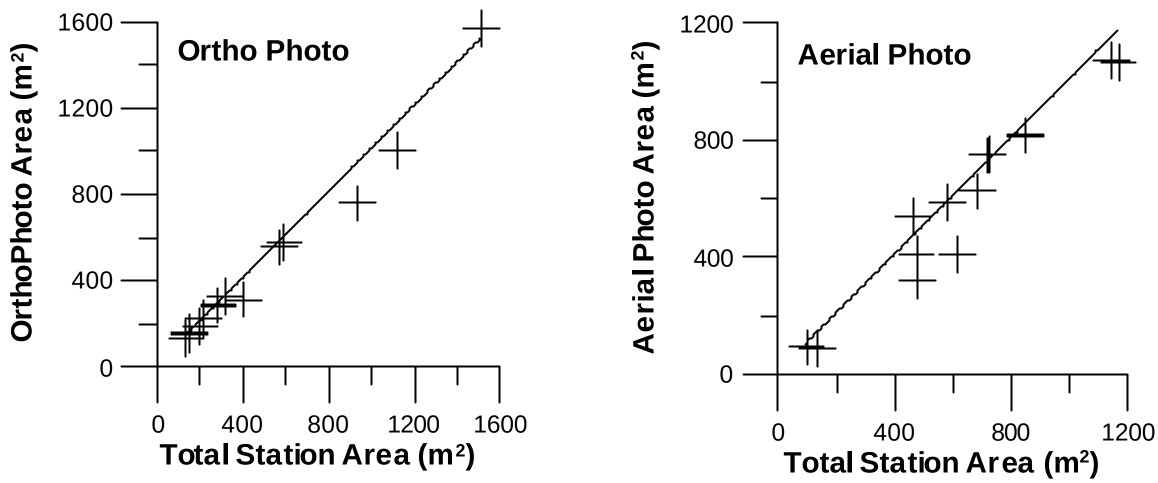

Figure 2. The relationship between total station mapping and photographic-based mapping methods. Points that fall above the diagonal line are over measurements; those below under measurements.

These results show that the ortho photo method is the most precise and least biased. However, while both methods are negatively biased and under measures are common, each technique provides a good estimate of camp area. This suggests that results from historical aerial photo analysis can be compared to current and future measurements with a reasonable level of confidence.

All three of the methods discussed above have advantages and disadvantages. The most precise and accurate method, total station mapping, is fairly time-consuming and only allows approximately forty sites to be mapped on a given sampling trip. However, this method documents the campsite area at the time of the measurement and links camp area to morphology through topographic surveys of the sand bars conducted at the same time. In addition, these sites have accurate stage-discharge relationships that allow campsite area changes to be divided across a range of dam releases. The ortho photo method provides a quick and efficient way to map campsite area directly into a GIS. This allows more sites to be visited on a single river trip when compared to total station mapping. The ortho photo method also has the practical advantage of being more efficient and less work than the aerial photo method. Ortho photo mapping results are instantly georeferenced and available for analysis in the field, while aerial photo mapping must be brought back to the office and digitized, which introduces additional error into the measurements.

One of the disadvantages of photography-based technique for mapping in the field is that the photographic product may not be available for three to six months after the data were collected. In this study, the available photography at the time of the mapping trips was at least one year old. For the ortho photo mapping, one-year-old products were used above Phantom Ranch and two year old ortho photos were used below. Daily and seasonal changes in sand bar morphology (river-based deposition and erosion, wind deflation and deposition, runoff gullies) and vegetation growth since the photography is collected can make on-site assessments difficult or even useless. Additionally, mapping a slope-dependent feature such as campsite area from photographs can be difficult because the slope is not discernable on the photography, which can be particularly troublesome along the top of exposed sand bars.

Discussion – Visitor Capacity, Experience Quality and Campsite Change

What is Visitor Capacity?

Because demand for recreation on the Colorado River is high and camping area limited, campsites along the river have received a considerable amount of attention. Heavy demand, and mandates to facilitate visitation while protecting park resources and provide for a certain type of recreation experience, converge into one of the most important questions managers face: *how many people should be given the opportunity to experience the Colorado River ecosystem*?

Questions like this are usually addressed in terms of *recreation carrying capacity.* The concept of carrying capacity originated in wildlife and range management, where it is usually interpreted using biological, chemical, and physical resource parameters, and defined as the number of animals that an area can support before unacceptable ecological impacts occur. With increasing recognition that this approach could also be used in places where it becomes necessary to establish limits for the number of humans, such as wildlands used for recreation, carrying capacity began to be applied in national parks during the 1960's (Manning et al., 1996). The working hypothesis was that a park can only accommodate a certain level of visitor use before unacceptable impacts to resources occur, and that biological and physical indicators of these impacts could be used to establish carrying capacities for humans, just as they could for wildlife or livestock. With rapidly rising visitation to parks and wilderness areas, attention to recreation carrying capacity management issues increased. In recreation contexts, carrying capacity is now referred to as *visitor capacity*, defined recently as "…a prescribed number and type of people that an area will accommodate, given the desired natural/cultural resource conditions, visitor experiences, and management program" (Haas, 2001a) or, more succinctly as "…the supply, or prescribed number of visitor opportunities that will be accommodated in an area" (Haas, 2002).

Biophysical aspects of visitor capacity usually relate to cumulative ecological impacts, but in places such as Colorado River campsites, actual physical space available (impacted or not) is also a critical factor. These categories have been referred to as *ecological* capacity, e.g. plant, animal, soil impacts, and *physical* capacity, e.g. people per unit area of flat sleeping area, camping parties per beach (Shelby and Heberlein, 1986). This distinction is useful for understanding visitor capacity for the Colorado River, where physical space available and resource impacts are both important management considerations.

In addition to resource protection, primary objectives for recreation management include enhancing, preserving, and minimizing impacts on the quality of recreation experiences. Experience quality is complex and affected by an array of factors, some of which are social rather than ecological or physical, so visitor capacity also has *social* component. Social variables that affect experience quality include the number of people visible at one time, number of encounters with other parties, or with groups of a particular type or size (Shelby and Heberlein, 1986). Resource protection will always be a fundamental concern in highly sensitive areas, where even moderate human activity may cause ecological impacts, and in settings where heavy use produces damage. However, for a broad range of less sensitive areas, or those that receive less intensive visitation, social variables that affect recreation experience quality may limit visitor capacity at levels below those at which unacceptable resource impacts occur. This is especially true in wildland settings, where interaction with nature and solitude are essential to the experience visitors are seeking.

Among the social aspects of recreation experience quality, perhaps the most widely studied is crowding. Crowding in recreation contexts is defined as a negative evaluation of a particular density of people. The density of people that results in perceptions of crowding varies with situation. A particular number of other people in an urban park are less likely to make people feel crowded than the same number of people in a wilderness area. People are also less likely to feel crowded by others perceived as similar to them, and engaged in similar activities. Recreationists may respond to crowding by: 1) changing their definition of the experience; 2) by rationalizing, or consciously reevaluating it in a more positive direction (most common in high expenditure activities, e.g. Colorado River trips); or 3) by being displaced. Displacement occurs when visitors leave an area, or choose not to visit because of unacceptable social, managerial or resource conditions (Schneider and Hammitt, 1995).

Crowding indisputably affects recreation experience quality, especially in wildland settings. However, relationships between density and crowding are not simple and linear. Visitor expectations, preferences, prior experience in the area, commitment to the activity, the characteristics of other visitors encountered, and an array of situational variables also affect perceptions of crowding (Graefe et al., 1984; Manning, 1999). Despite this complexity, use level is an easily measured and to some extent manageable indicator of recreation quality, particularly where activity types are relatively homogeneous. Crowding and visitor capacity can be monitored using the Limits of Acceptable Change (LAC) framework (Stankey et al., 1985). Originally developed to track ecological impacts in wilderness areas, LAC is also readily adaptable to social indicators of recreation experience quality (McCool and Cole, 1997). Indicators such as visitors per unit area, or contacts with other people are monitored, and management action is triggered when a predetermined “acceptable” threshold or standard for the indicator is exceeded. The amount of camping area per visitor was a key indicator used to assess visitor capacity on the Colorado River, as will be explained in more detail in a subsequent section.

When developing recreation visitor capacity guidelines in areas with heavy demand, managers must first define types of experiences that are appropriate. This is a critical step, because ecological and social aspects of visitor capacity, and strategies to manage them, will vary widely with the type of visitor experience being targeted. Once policies for appropriate types of activities and experiences are established, the biggest challenge in applying the visitor capacity approach is defining acceptable thresholds or standards for indicators of quality. This is where decisions are made regarding use levels and visitation limits that correspond to the experiences being managed for. Limits and standards are typically based on some combination of legal mandates, agency policies, historic precedent, expert judgment, interest group politics, and public opinion (Manning, 1999; Haas, 2002). Defining appropriate experiences and setting standards for quality are difficult because of the variable and contextual nature of human perceptions. These definitions are also contentious because they directly affect who gets to do what, when and where. Nevertheless, for lack of a better alternative, variants of the recreation visitor capacity concept continue to be widely used by all major land management agencies, including the National Park Service, to guide policies for recreation use.

In summary, recreation visitor capacity is the number of humans that can be accommodated in an area before standards for resource conditions or experience quality are exceeded. Recreation visitor capacity has physical, ecological and social components, each of which can be affected by management actions (Manning et al., 1996). Minimizing ecological impacts of wildland recreation remains an important management goal, but social variables such as solitude and crowding can also strongly influence visitor capacity. Before visitor capacity can be established, managers must consider how ecological constraints and management actions affect these social variables. Guiding policies about the kinds of recreation experiences managed for, and measurable indicators and standards of quality for these experiences, are also critical.

What kind of experience? The Colorado River as Wilderness

As part of the widespread increase in adventure travel and river running during the late 1960's and early 1970's, the Colorado River emerged as one of the most highly valued river trip destinations in the world. Recreation on the river exploded in popularity during this time. The GCNP was soon forced to address questions about the capacity of the river corridor to accommodate the increase in use.

On the Colorado River in Grand Canyon, legal guidelines stipulate and the general public expects that undeveloped, uncrowded, wilderness-type experiences should be available. It is clear that on the Colorado River, outstanding opportunities for wilderness experiences were indeed a key factor in the river's popularity. This was confirmed during the initial phase of river recreation research (Shelby, 1976), and in subsequent studies (Bishop et al., 1987; Hall and Shelby, 2000).

In 1993, the NPS updated its 1980 recommendation for designating 980,088 acres within Grand Canyon National Park as wilderness, and proposed an additional 131,814 acres of potential wilderness, much of this along the river corridor. Although Congress has yet to act on this recommendation, the Glen Canyon Dam EIS noted that "the NPS is mandated by the Wilderness Act to protect wilderness values in the park, including those along the river, and to take no action that would potentially compromise future wilderness suitability" (USDI, 1995a, p.154). The 1995 GCNP General Management Plan lists a management objective to "provide a wilderness river experience on the Colorado River" (USDI, 1995b, p. 11).

The Glen Canyon Dam EIS noted "wilderness is both a legal and philosophical concept - an area that appears to be influenced primarily by the forces of nature" (USDI, 1995a, p. 154). The Wilderness Act of 1964 defined wilderness legally as "an area where the earth and its community of life are untrammeled by man…retaining its primeval character and influence, without permanent improvements…" and instructed managers to "administer wilderness areas for the use and enjoyment of the American people in such a manner as will leave them unimpaired for future use and enjoyment as wilderness" (USDI, 1998).

The exact meaning of wilderness varies among individuals. In addition to obvious *experiential* aspects (the direct value of wilderness experiences) managers must also consider scientific and symbolic wilderness values (Hendee et al., 1990). The opportunity to enjoy a wilderness experience is one of the attributes of an excellent or perfect trip most frequently mentioned by river runners, including those on motorized trips (Bishop et al., 1987; Hall, 1999).

Maintaining wilderness qualities and providing wilderness experiences have been cornerstones of river management since the inception of river-based recreation. Glen Canyon Dam itself does not render the Colorado River in Grand Canyon unsuitable for wilderness designation, but dam operations can influence wilderness attributes downstream (USDI, 1995a). Despite the influences of the dam, and ongoing debate about the appropriateness of motorized rafting, the concept of wilderness provides the primary baseline for decisions regarding recreation visitor capacity in the river corridor.

Wilderness River Experiences and Campsites

As noted above, the GCNP has explicitly expressed the intention to manage for wilderness type experiences for Colorado River visitors. In addition to the opportunity to experience natural ecological conditions, one of the most important attributes of a wilderness experience is solitude (Hendee et al., 1990). The area available for camping in the river corridor has declined significantly since construction of Glen Canyon Dam (Kearsley et al., 1994). This decline is correlated with the amount of solitude available to river visitors in two ways: 1) by reducing the ability of separate river trips to camp out of sight and earshot of one another. This serves to increase the occurrence of what might be termed *intergroup* crowding, or crowding related to the proximity of two or more separate trips; and 2) by reducing the ability of individuals or small groups *within a particular trip* to camp out of sight and earshot of one another. This increases the occurrence of *intragroup* crowding, or crowding related to the proximity of individuals or groups within a particular trip.

Recognition of these linkages, and the need for quantifiable parameters with which to track changes in recreation resources and experience quality, have resulted in the area of camping space available being used as a preferred metric for recreational monitoring programs in Grand Canyon. This is not to say that campsite area is the only parameter of Colorado River recreation that affects experience quality, but rather that it is a very salient parameter, and also the one that has, arguably, changed more than any other facet of the river experience.

As Colorado River managers revise the CRMP, they will have to decide whether visitor capacity guidelines should be updated to reflect changes in environmental and social conditions that have occurred in the River Corridor since the last plan. In the next section, relationships between campsite changes, and changes in experience quality and visitor capacity are discussed in greater detail.

Campsite Changes: Visitor Use, Sand Bar Erosion and Vegetation Encroachment

For decades it has been recognized that availability, size and condition of camping sand bars affect experience quality and visitor capacity on the Colorado River (Bordon 1976, Kearsley et al., 1994). Changes in sand bar availability, size and condition due to visitor use or dam operations may, in turn, change experience quality and visitor capacity. Recreational use of sand bars can cause impacts (such as downslope movement of sand) which can be difficult to isolate from effects resulting from the presence and operations of Glen Canyon Dam. There is also increasing evidence of recreation-related ecological impacts beyond the old high water zone at heavily used campsites. As sand bars erode, people are concentrated in smaller areas, which increase the degree of impact. At some sites, visitors have expanded the rear perimeter of the camp by clearing native vegetation, following losses of usable area closer to the river. Closure of sites to let them recover is a common mitigation strategy in wildernesses and parks when use related impacts reach unacceptable levels. Closure of heavily used and impacted campsites on the Colorado River could affect overall visitor capacity, because the most impacted sites are typically those in critical reaches where campsites are scarce.

Differentiating between visitor and dam related impacts to sand bars may be irrelevant, because annual high spring runoff flows that would erase most recreation impacts have been eliminated by the presence and operation of the dam. In other words, visitor related impacts to sand bars would probably be mitigated to large degree each spring if the river were still controlled by natural processes, so any perceived need to address these impacts can be ultimately attributed to the dam. Moreover, impacts from visitor use along the Colorado River are probably not significant compared to impacts related to dam operations.

Campsite change and experience quality

Logic and anecdotal evidence suggest that reduction in Colorado River campsite number and size over time has been accompanied by several ongoing trends that can affect visitor experiences. These trends have not occurred in a linear fashion, may be partly attributable to changes in use patterns, and can be complicated by river flow level and other factors. Nevertheless, it is probably safe to say that the following have and continue to happen, and are strongly related to campsite degradation:

- *Increasing frequency of river trips camping in proximity to one another in critical reaches where camps have been lost. This includes a rise in frequency of two groups having to use the same camp.*
- *Visitors on the same trip camping in closer proximity to one another at sites that have declined in campable area*
- *Increasing frequency of trips altering their itinerary and/or foregoing stops at attraction sites because of fewer options for camps in the area*

A recreation experience on the Colorado River is multi-dimensional and complex (Bordon, 1976, Arnould and Price, 1993) so it is difficult to establish direct linkages between these trends and changes in river experience quality. However, to the degree that wilderness dimensions of river recreation experiences such as solitude are linked with the ability of trips to camp out of sight and earshot of one another, and individual trip participants to achieve privacy while in camp, wilderness experience quality has also been negatively impacted. The extent of these impacts is difficult to specify, but research and monitoring efforts offer some support for the conclusion that they have occurred. After monitoring daily contacts between river trips, and visitor densities at attraction sites during primary and shoulder seasons in 1989 and 1990, Jalbert (1991) found that objective standards for river contacts were not being met consistently. These problems were exacerbated in “set up corridors”, or reaches just upriver or downriver from attraction sites where trips camp before or after visits to the site, and were most acute for motorized trips launching from Saturday through Tuesday. Jalbert (1991) also found that standards for objective contact levels at attraction sites were exceeded 14% of the time during primary seasons, and 29% of the time during secondary seasons. This suggests that manager assumptions concerning the degree of difference between actual crowding levels in primary and shoulder seasons may be inaccurate. Unfortunately, monitoring in subsequent years (which could have shed light on these issues by acquiring comparative data from which trends could be discerned) was curtailed due to resource limitations.

Hall and Shelby (1999) conducted a repeat study using the same methodology as Shelby (1976). They found that motor and commercial oar passengers mostly agreed (~90 %) that the canyon could be considered a wilderness, and that this perception had not changed over time. However, there was a large decrease in the number of private trip participants who felt this way, with 87 % agreeing that the canyon was a wilderness in 1975, and only 56 % agreeing in 1998. It is important to note that this question referred to overall conditions encountered over the course of the trip, so the degree to which responses reflect opinions about campsites is hard to discern. Interestingly, the percentage of commercial passengers who preferred to camp alone versus near another group, while still a majority, dropped markedly between 1975 and 1998. Interpreting such a result with any degree of confidence is difficult, but it may reflect changes in campsite availability and more frequent in-camp encounters in 1998, which respondents were rationalizing as acceptable. In other words, it is possible that fewer respondents preferred to camp alone because they had camped near other groups on their trip and accepted that it was occasionally necessary.

Hall and Shelby (1999) found that while use had increased dramatically between 1975 and 1998, numbers of on river intergroup encounters had risen only slightly. They found evidence to suggest that trip leaders are more sensitive to the effects of encounters, attempt to avoid them and seem able to control them fairly well while traveling downriver. Small increases in encounters between 1975 and 1998 may also indicate that NPS efforts to schedule launches efficiently to control congestion have been fairly effective. Hall and Shelby (1999) also found that commercial passengers had become less sensitive to encounters over time, while private boaters had become more sensitive, particularly to conditions at attraction sites. They found that commercial oar and private trips were within NPS management standards for encounters per day, while commercial motor trips were slightly out of standards. For encounters per trip, they found that 41 %

of commercial motor, 0 % of commercial oar, and 13 % of private trips exceeded NPS encounter standards.

Using visitor survey data to assess experience quality

As discussed previously, the indicators and standards approach to managing recreation experience quality underlies the LAC management framework, which was implemented on the Colorado River under the 1989 CRMP. Visitor surveys are the most common method of assessing change in experience quality over time, especially regarding social variables. Results from such surveys are important decision criteria for assessing capacity and comprise one aspect of public input, which is required by law in many instances of public land management policy-making including the forthcoming revision of the CRMP. To find out about experience quality, a good place to start is to ask those who have had the experiences. As Hall and Shelby (1999) note:

> "Recreation experiences, including wilderness-like experiences and solitude, are subjective, and visitors are the best judges of what conditions affect their experiences and of whether they actually experience feelings such as solitude. Managers must try to identify the objective setting factors within their control that are conducive to desired experiences, but visitors are the ultimate experts on the quality of the experience itself" (p. 158).

It is important to note that focused, close-ended questions about encounters and other measurable indicators of experience quality address only a small subset of parameters that comprise the overall experience. Open ended questions asked of visitors and river guides could also offer valuable contextual information about experience quality.

Despite its utility and widespread use, visitor survey data also has several limitations, and should be seen as only one of a range of decision criteria for assessing visitor capacity. Hall and Shelby (1999) offer this discussion on the limitations to using visitor opinions to implement the indicators and standards approach to managing for recreation experience quality, in the context of responses to questions about encounters:

> "An important consideration and matter of current debate in questioning visitors about personal standards is the specific nature of the question[s] asked. It seems well-established that there are differences between what visitors prefer and what they will tolerate, and that preferences are usually for fewer encounters than are tolerable. Furthermore, we have begun to

> recognize that the term ‘tolerate’ is poorly defined in much previous research: does it refer to the point at which a visitor will no longer return to a site? Does it entail any position about what management should do if conditions exceed standards? Such matters are important because the contextual factors and tradeoffs involved in real management and visitation decisions are difficult to convey in survey [questions], which jeopardizes the confidence we may have in the…results. The more specific the question asked (e.g. ‘what is the maximum number of encounters with different groups – where encounters are defined as any visual contact of any duration with any other boating party, either on the river, at attraction sites, or at camp – that you consider to be acceptable for a wilderness-type trip – where wilderness is defined as the most primitive type of setting – on any given day of a Colorado River trip, knowing that if that standard is imposed, 20% of the visitors who now go on the river will not be able to go, and that waiting times will double, but at the same time your chances of seeing other visitors on the river will drop to 50% from 70% and at attraction sites from 90% to 50%, the more confidence (perhaps) in the results, but the more difficult it becomes for visitors to answer. Apart from the unwieldy nature of the question itself, recreational users simply do not interact with the environment and other parties in reductionist, quantitative terms such as these. However, the more general the question, (e.g. ‘How many encounters is too many?’) the more vague and imprecise it is; we cannot know what assumptions visitors make when they answer such questions, and therefore it becomes difficult to know how to use their input in meaningful ways” (p. 157-8).

Using normative visitor survey data to assess capacity issues on the Colorado River is challenging for other reasons. When exposed for the first time to a unique and exotic recreation setting such as the Colorado River, most visitors tend to be happy with what they find. A large majority of river visitors are on their first trip, and thus have limited pre-existing norms about what to expect in such a place, or comparative bases for encounters, wilderness attributes or campsite quality and may be unaware of adjustments made by their guides in response to campsite issues (Shelby, 1976). Availability of camps is taken for granted, but beyond this expectations are often vague. Issues of decreasing sand bar number, size and quality are masked from commercial passengers by the ability of guides to find them adequate camping sand bars, even though camps used in prior years are avoided because they are no longer suitable, and sand bars that are used may be much smaller, and more vegetated than they were ten or twenty years ago. Private boaters may be concerned primarily with access issues (i.e., acquiring a launch permit) and to a lesser extent with sand bar issues, as long as there are usable camps available.

Asking visitors how satisfied they are with their experience, and defining capacity as the point at which aggregate satisfaction declines is also problematic (Shelby, 1976). If use continually increases or wilderness qualities deteriorate, visitors who desire a wilderness-type experience may simply be displaced by others who are less discriminating; with little indication to managers that capacity for wilderness-type experiences has been exceeded. While it is theoretically possible that experience quality could be impacted enough to displace visitors from the Colorado River, it is unclear if crowding-related displacement is major concern for such a highly valued, high commitment, unique and non-substitutable experience, especially for visitors who only take one trip in their lifetime. Nevertheless, managers should be aware that satisfied visitors are usually not displaced, and displaced visitors are not present to be sampled about how satisfied they are.

Some current visitors, especially repeat visitors, are probably displaced to shoulder seasons by knowledge of high visitor density levels during the primary season. The NPS has recognized this and tries to manage for fewer contacts during shoulder seasons (USDI National Park Service, 1989). However, monitoring evidence has shown that standards for contacts are exceeded twice as often in shoulder seasons as in primary seasons. (Jalbert, 1991), indicating that visitors who desire less crowded conditions may not be able to find them even in the spring and fall. Visitors also respond to crowding with several different coping mechanisms that serve to mitigate its negative effects, particularly in high commitment or high expenditure activities, of which Colorado River trips are an excellent example (Schneider and Hammitt, 1995).

Perhaps the biggest impediment to detecting camping sand bar-related changes in experience quality from visitors themselves is that overall quality remains very high by most standards, even for repeat visitors, because of the unique and extremely high quality of other experience attributes. Most of these, e.g. whitewater, diverse and unique scenery, side canyon hiking and the extended duration of the experience in relation to other rivers have changed very little over the time period Colorado River trips have been popular. The fact that a large majority of visitors are still highly satisfied with their experience makes identification of any *relative* decline in experience quality over time by way of visitor responses problematic.

Despite limitations discussed above, visitor survey responses can provide useful information about how experience quality relates to the capacity of the river to support recreation and must be a component of any future capacity assessment. Monitoring of visitor perceptions using a standardized set of questions and sampling methodology at specified intervals (e.g. 2-4 years) could provide trend data that might allow detection of changes by comparing the number of people saying they felt crowded across successive years (Hall and Shelby, 1999). Surveying river guides about changes in their perceptions and use of Colorado River camping sand bars through time could also provide valuable information because guides visit repeatedly, in many cases over the course of several years or even decades. Although information gathered from guides would be qualitative and anecdotal, this group is in the best position to notice changes and has a comparative basis on which to assess them.

All available survey data should be considered when establishing visitor capacity for the Colorado River, and new visitor survey information would be useful in that questions could be tailored specifically for current management issues. However, visitor survey data is only one of many decision criteria that should be considered when making visitor capacity decisions.

Linking campsite change, experience quality and visitor capacity

Although detecting changes in experience quality is difficult, and most visitors still rate the trip in very positive terms (Hall and Shelby, 1999), it is reasonable to conclude that campsite changes continue to degrade the quality of Colorado River trip experiences. Our review suggests that social parameters (e.g. solitude and crowding) are the principal factors by which visitor capacity for the Colorado River has been set, but that physical capacity, or the actual amount of campable area, is increasingly what limits use of Colorado River sand bars for camping. Physical, ecological and social parameters are to some degree inter-related, and are not discrete constructs. However, there is evidence of a general trend away from lightly impacted campsites with enough space for separate trips and individual visitors to achieve privacy, to a somewhat smaller number of campsites that have less campable area. Some campsites have become unacceptable and unusable for most groups due to loss of campable area (O'Brien and Roberts, 1999), a trend that is likely to continue.

Because demand for access to the river remains very strong, NPS managers have thus far chosen not to adjust visitor capacity policies in response to decreases in camp number and area. Nevertheless, there are probably limits to the ability of river trips to adapt to ongoing decline in area available for camping in critical reaches before physical space becomes the limiting factor regardless of solitude considerations, and ecological and social impacts become unacceptable for managers and rising numbers of visitors. Sand bar degradation is now a major issue for river managers because it has gone on for several decades. This suggests that some visitor capacity-related policies (e.g. group size, overall visitation, scheduling parameters) may need to be revised.

Unfortunately, despite the large body of research on sediment and campsite issues and irrefutable evidence of substantial losses in sediment volume and campable area, definitive conclusions about how these changes have affected visitor capacity remain somewhat elusive. This is partly due to the lack of detailed campsite area measurements from the early 1970's with which current data could be compared, but more importantly because visitor capacity is to a significant degree a management decision rather than a scientifically measurable quantity (Haas, 2002). Complicating matters further is that while visitor capacity on the Colorado River is strongly related to campsite area, this relationship is not linear. Reductions in campsite area may not translate directly into the same percentage reduction in visitor capacity, because factors other than available space may affect people's willingness to camp in close proximity to one another. Physical and aesthetic characteristics such as available shade and weather, trip logistics such as time of day and proximity to attraction sites, and lack of options also affect campsite choice and assessment of campsite quality (O'Brien and Roberts 1999). Decisions to use a particular camp and evaluations about it may vary considerably between summer and fall when finding shade is less of an issue, or even by day depending on the weather. On stormy days protection from wind and anchor points for tents might be the most important criteria for assessing whether a camp is "good" or "bad", whereas room to spread out and achieve privacy may be what people care most about when conditions are clear and calm.

Despite the complexity of these relationships, the amount of relatively level, rock and vegetation-free area available for use in Colorado River campsites has been used implicitly as an indicator for experience quality and visitor capacity. It is recommended that this linkage be made explicit by including campable area as a monitored indicator of experience quality. Weeden (1975) appears to have used different amounts of campable area per person to establish campsite capacities, according to different campsite size classes. The amount of campable area per person deemed sufficient was smallest at small camps, and greatest at large camps. Weeden (1975) probably recognized that river trips use less stringent criteria for camp selection in critical reaches because camps are generally smaller here, and the option of choosing a large camp often does not exist. The *relative* differences in sand bar size between critical and non-critical reaches are a function of geomorphic differences in the canyon walls (Kearsley et al., 1994), and are thus part of the natural landscape. Weeden's (1975) approach is thus reasonable, and experience quality may not suffer by using a variable standard for per capita campable area, depending on whether the camp is in a critical or non-critical reach. River trips will likely be able to camp at *some* larger sand bars over the course of their trip, affording visitors greater opportunities for privacy at these camps.

The limitations of visitor survey data and the difficulties involved with linking campsite change, experience quality and visitor capacity discussed above suggest that generating viable alternatives for river management over the next decade will require analysis and information from many different perspectives. Updated visitor capacity standards are necessary because demand for access to the river probably exceeds what can be provided under any realistic management scenario that adheres to park policies for resource protection and experience quality, and because law requires the NPS to specify and implement them. New information, synthesis and interpretation of existing data, and ecological, social and managerial considerations are all necessary to generate capacity guidelines that are defensible and accepted by the public. Fortunately, the salience of capacity issues across the United States has generated renewed interest in the topic and recent interagency efforts have resulted in refinement and definition of workable strategies for capacity decisions (Hass, 2002).

Strategies for assessing visitor capacity for the Colorado River

In a discussion of applying judicial doctrines to visitor capacity decisions, Haas (2001b) submits the doctrine of *decision ripeness* as a useful tool, and characterizes three stages of ripeness for making capacity decisions. The premature stage is characterized by few apparent capacity problems or indications that use limits are needed, vague management direction and little available information about use or demand. The mature stage represents a window of opportunity in which the decision maker is operating in an atmosphere of sufficient time for deliberation, consultation, research and analysis and little controversy or political pressure. In the post-mature stage, the window of opportunity has degenerated and decision making has become problematic because of strong indications that capacity has been reached or exceeded, controversy surrounding the situation and capacity decisions being directed largely by political or judicial processes.

Recent legal actions, ongoing controversy concerning access and appropriate experience types, and increasing evidence that capacity may have been reached strongly suggest that Colorado River managers in GRCA are now facing the post-mature stage for visitor capacity decision making. There are several possible reasons for this. GRCA representatives in the Glen Canyon Dam Adaptive Management Program may not have lobbied effectively or strongly enough for adequate research and monitoring of how Glen Canyon Dam operations affect visitor capacity. This has been exacerbated by the lack of will and institutional capability within the GCMRC to support and direct such research. The result is a paucity of up to date information concerning campable area/capacity relationships at a time when such information is critically needed (Behan 1999, Kaplinski et al. 2001). Lack of human and financial resources for river recreation management and planning within GRCA (a reflection of system-wide deficiencies throughout the NPS) are also contributing factors. But the principal reasons GRCA is faced with such a difficult situation regarding visitor capacity are the diametrically opposed trends of ever-increasing demand for access to a wilderness river experience that is now world famous, and ongoing loss of campable area, the primary constraint on capacity to accommodate these experiences.

Principles and decision criteria for capacity decisions

Developing river management policies under the circumstances outlined above will challenge river managers, but despite the shortened timeframe for decision making and post-mature stage of ripeness that GRCA faces regarding visitor capacity decisions for the Colorado River, defendable alternatives can be developed if certain guidelines are followed. Preparation of an Environmental Impact Statement under NEPA guidelines represents the best available framework for developing a preferred river management alternative that is accepted by the public. Haas (2002) states that decisions must be principled and reasoned, arbitrary decisions are a violation of federal law. Among the principles that Haas suggests contribute to logical, reasoned and defensible visitor capacity decisions are these:

- The visitor capacity should help sustain the integrity of natural and cultural resources, as well as the important recreational and non-recreational benefits they afford to local, regional and national publics

- Visitor capacity is a complex decision based on sound professional judgment, i.e. gives full and fair consideration to all appropriate information, based on principled and reasoned analysis, best available science and expertise, and complies with applicable laws

- Visitor capacity quantifies the supply of available recreation opportunities that an area can accommodate, and may also address allocation of opportunities across a variety of affected visitors- types of recreationists, commercial operators, educational programs, scientists and others

- Visitor capacity should consider the larger regional landscape and system of recreation opportunities affecting a particular area of recreation concern

- Visitor capacity provides clarity for focused dialogue and analysis of consequences across the proposed management alternatives under consideration in a planning process

- Visitor capacity needs to be adaptable to new science, information, uses, technology, trends, conditions and other circumstances of importance

- The effectiveness of a visitor capacity depends on an adequate program of monitoring that is commensurate with the level of potential consequences, risk and uncertainty

Because visitor capacity decisions are complex, Haas (2002) suggests identifying an explicit list of *decision criteria* early in the planning process using public input. This helps make the process transparent and trackable to stakeholders by establishing ground rules- the rationale or pieces of the puzzle that will eventually comprise the decision. Decision criteria aid in development of management alternatives by identifying important content areas that will be described, contribute to an administrative record for the process, improve communication with the public and aid in adaptive management. Haas (2002) suggests several categories and examples of criteria that might be included. Among these are:

- ***Effects on ecological integrity.*** The degree to which each alternative:

-affects unique or sensitive resources
-affects the ecological integrity of the site, local vicinity or bioregion
-impact desired future conditions or quality standards (i.e. physical or audible footprint, duration, timing, reversibility, cumulative effects)
-affects the important or priority resources or values the area is being managed to protect
-has irreversible effects on resources

- *Supported by science.* The degree to which each alternative:

-is supported by scientific study and expert consensus
-is supported by agency professionals, advisors and consultants
-has a level of analysis that is commensurate with potential consequences
-is based upon reasonable assumptions and trends
-may involve highly uncertain risks or consequences
-is based on unavailable or incomplete scientific information
-will secure needed scientific information in the future
-has an adequate monitoring program involving resource, social and managerial attributes

- *Level of public support.* The degree to which each alternative:

-is controversial among visitors, local, regional and national publics
-is supported by visitors, locals, regional and national publics
-contributes to the desired welfare of stakeholders (e.g. local communities, tourism industry, adjacent landowners, educational/research institutions, private operators, concessionaires, and special interest groups)
-build meaningful and appropriate partnerships with collaborators
-causes harm or a unfair negative consequences to less advantaged people
-allow for options and opportunities for future generations

- *Effects integrity of recreation experience.* The degree to which each alternative:

-affects the integrity of the recreation experience that the area is being managed for
-is appropriate and consistent with management objectives for the area
-may compromise desired future conditions or quality standards (i.e. extent of physical/audio footprint, duration, timing reversibility, cumulative effects)
-affects unique or rare recreation opportunities locally, regionally or nationally
-provides for unique or rare recreation opportunities locally, regionally or nationally
-contributes to a large regional system of recreation opportunities
-is based upon reasonable future social trends and assumptions
-makes recreation opportunities more available to less advantaged publics
-attracts visitors who would otherwise not visit
-considers latent or unmet demand of those publics not visiting
-provides an appropriate recreation experience by the least intrusive means

- *Management sustainability/capability.* The degree to which each alternative:

-addresses consequences of delaying or not taking action
-can be changed or adapted, given new science, information or circumstances
-complements other important resource uses, users or values (e.g. educational, restoration)
-establishes a precedent for future action
-has cumulative effects that are likely to be significant
-requires re-allocated or increased resources in services, personnel, facilities
-affects other management programs

Haas (2002) points out that not all of these criteria need to be included in a planning process and that they should be tailored to the situation, but the more important the decision and its consequences, the greater the number of criteria that should be considered. Many criteria are applicable to Colorado River planning and the high-profile nature of recreation here suggests that a diverse number of them will need to be included. Refining these principles and criteria for application to the Colorado River can provide a useful "roadmap" for the river planning EIS, but the process is still certain to be contentious. No matter how exhaustive the analysis and alternative development effort, the necessity of balancing resource and experience integrity with high demand for access make it likely that some stakeholders will be dissatisfied with the outcome. Decisions about appropriate experience types, commercial/private allocation and visitor capacity will be the most difficult. Capacity is ultimately a management decision rather than scientifically measurable quantity. Nevertheless, a detailed understanding of the overall amount of campable area currently available will be needed before managers can decide how much is appropriate per person or a given group size, and by extension maximum group size and overall capacity.

Recommendations for long-term monitoring of sand bars used as campsites

Lack of consistent inventorying and monitoring methods in the studies we reviewed hindered our ability to quantitatively track changes in Colorado River campsites and visitor capacity. Additional research would provide more clarity about trends in campsite number, size and distribution along the river. At the same time, methodological diversity reinforces conclusions that the resource continues to decline by showing trends of ongoing campsite area loss from several different perspectives. Overall, it is clear that direct and indirect impacts of dam operations on campsites and river recreation visitor capacity are an increasing concern for river managers, and mitigation of these impacts should be a priority if experience quality for river recreation is to be maintained.

Based on our review and analysis of campsite area and visitor capacity research and monitoring, we developed the following recommendations:

Recommendation #1: Campsite area measurements should be collected using either total station or ortho photo methods: Both ortho photo and total station mapping methods provide the appropriate level of accuracy and precision necessary for quantifying campsite area changes. New mapping technology currently under development by the GCMRC Remote Sensing group utilizes an automated technique to develop polygons surrounding areas of exposed sand and within appropriate slope parameters. If this procedure proves reliable, a field-based program of ground-truthing should be developed. This program would integrate the ortho photo mapping procedures outlined in this study with the automated mapping. Field crews would be deployed with tablet computers loaded with the ortho photo base maps overlain with the automatically generated sand area polygons. At selected camp areas, field crews would simply edit the automated polygon features to match the on-site observations. We also recommend that a backup plan include hardcopy maps of the camping areas, so that in the event of any number of potential technical problems, the mapping could still be completed.

Recommendations #2 – Conduct a comprehensive inventory of all campsites within the Colorado River ecosystem: A complete inventory of all campsites within the Colorado River ecosystem (i.e. a repeat of the Weeden et al., 1975 inventory) should be initiated. This study should be conducted using the orthophoto method of measuring campsite area using an up-to-date set of orthophotos. The inventory should include preliminary GIS mapping of campsites followed by river trips to verify and/or adjust a reasonable number of sites in the field, then subsequent development of the inventory. Repeating the Weeden et al. (1975) surveys will allow an accurate and complete inventory to be completed within a reasonable time frame – approximately one year.

Recommendation #3 – Conduct a comprehensive estimate of the visitor capacity of the Colorado River ecosystem: Once the campsite inventory is completed, it should be utilized to develop a revised estimate of the visitor capacity of the Colorado River corridor (i.e. a repeat of the Bordon, 1976 study). A standardized metric for estimating visitor capacity should be developed that incorporates the social dynamic of river party decision making, as well as physical changes to a site. A more accurate representation of campsite area, plus other resources such as the river trip simulator project (O'Brien and Roberts, 1999), would provide an accurate and up to date visitor capacity estimate. An update of these important databases are necessary due to the substantial changes that have occurred since the last estimates were made in 1976 and the crucial nature of the information to both Grand Canyon National Park planning activities and Glen Canyon Dam Adaptive Management Program objectives.

Recommendation #4 – Develop an integrated long-term monitoring program for measuring campsite area and visitor capacity of the Colorado River corridor: A long-term monitoring program should be developed that includes a standardized, repeatable method for measuring changes to campsite area and visitor capacity. Long-term monitoring requires long-term stability in the study design, sampling protocol, analysis and reporting requirements. We support the recommendations of O'Brien and Roberts (1999) that efforts should be made to develop a standardized method of linking campsite area measurements to visitor capacity of the site. The program should also include the development of a campsite database that includes ongoing descriptions of changes to camping quality, area, and capacity through time. This program should be developed and implemented through integrated and cooperative efforts incorporating both ecological and social perspectives and consist of natural scientists, social scientists, and river managers.

Recommendation #5 – Convene a panel of experts to begin the development of a long-term monitoring plan and discuss managerial and institutional issues: In order to foster interagency cooperative efforts and coordinate development of plans for research and long-term monitoring, we recommend that a workshop be held to discuss the information needs outlined above. The workshop should include managers from agencies involved in river planning, physical, biological, and social scientists, as well as representatives of existing research and monitoring groups. The goal of the workshop would be to develop an outline for an integrated long-term monitoring program and develop a framework for a cooperative recreation research program. The timeframe developed by Grand Canyon National Park for revising the Colorado River Management Plan by December 2004, adoption of management objectives for recreation within the Glen Canyon Dam Adaptive Management Program, and proposed experimental flows have increased the urgency for recreation research and monitoring that is on par with that of other resources.

The projects described above will require a greater level of cooperation and integration between Grand Canyon National Park and the Grand Canyon Monitoring and Research Center than currently exists. The National Research Council review of the GCMRC is very critical of the socio-economic component of the program (NRC, 1999). They noted that suggestions made in a previous review (NRC, 1987) were not addressed and that attention to this important resource has, in fact worsened (NRC, 1999). Sufficient funding and institutional support needs to be allocated to support the research, administration, and management of socio-economic research. Both entities (GCNP and GCMRC) should be jointly involved in the process of developing proposals, conducting the study, archiving the information, and incorporating the knowledge into management decision.

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