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Colorado River Campsite Monitoring, Grand Canyon National Park, Arizona, 1998–2012

Open-File Report 2014-1161

U.S. Department of the Interior
U.S. Geological Survey

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SALLY JEWELL, Secretary

U.S. Geological Survey
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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square foot (ft^2)	0.09290	square meter (m^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Volume	
cubic meter (m^3)	35.31	cubic foot (ft^3)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).
Elevation, as used in this report, refers to distance above the vertical datum.

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Abstract

River rafting trips and hikers use sandbars along the Colorado River in Marble and Grand Canyons as campsites. The U.S. Geological Survey evaluated the effects of Glen Canyon Dam operations on campsite areas on sandbars along the Colorado River in Grand Canyon National Park. Campsite area was measured annually from 1998 to 2012 at 37 study sites between Lees Ferry and Diamond Creek, Arizona. The primary purpose of this report is to present the methods and results of the project.

Campsite area surveys were conducted using total station survey methods to outline the perimeter of camping area at each study site. Campsite area is defined as any region of smooth substrate (most commonly sand) with no more than an 8 degree slope and little or no vegetation. We used this definition, but relaxed the slope criteria to include steeper areas near boat mooring locations where campers typically establish their kitchens.

The results show that campsite area decreased over the course of the study period, but at a rate that varied by elevation zone and by survey period. Time-series plots show that from 1998 to 2012, high stage-elevation (greater than the 25,000 ft^3/s stage-elevation) campsite area decreased significantly, although there was no significant trend in low stage-elevation (15,000–20,000 ft^3/s) campsite area. High stage-elevation campsite area increased after the 2004 and 2008 high flows, but decreased in the intervals between high flows. Although no overall trend was detected for low stage-elevation campsite areas, they did increase after high-volume dam releases equal to or greater than about 20,000 ft^3/s. We conclude that dam operations have not met the management objectives of the Glen Canyon Adaptive Management program to increase the size of camping beaches in critical and non-critical reaches of the Colorado River between Glen Canyon Dam and Lake Mead.

Introduction

Approximately 25,000 river runners and hikers visit and camp along the corridor of the Colorado River in Grand Canyon National Park every year (National Park Service, 2006). Because the banks are dominated by bedrock cliffs, rocky talus, and boulder-covered debris fans (Howard and Dolan, 1981), suitable locations for camping are limited in many places. Most campsites are located on sandbars because these alluvial deposits are relatively flat and easily accessible from the river. Sandbars occur intermittently along the shorelines, and campsites are abundant wherever sandbars are abundant. As the number of visitors to the Colorado River corridor in Grand Canyon National Park (GCNP) has increased since the mid-1960s, the distribution and quality of campsites have become an increasingly important concern to river managers (U.S. Department of Interior, 1995; National Research Council, 1999; Stewart and others, 2000; Bureau of Reclamation, 2001; National Park Service, 2006).

Because most campsites are located on sandbars, management of the two resources is intimately linked. Sandbars are dynamic landforms deposited in eddies at times of high streamflow and high suspended-sediment concentration. Sandbars may be eroded by streamflows that have low suspended-sediment concentration (Hazel and others, 1999), and sandbars also may be eroded by hillslope runoff (Melis and others, 2004), wind deflation (Draut and Rubin, 2007), and human activity (Phillips and others, 1986).

The completion of Glen Canyon Dam (GCD) in 1963 caused a 95 percent reduction in the delivery of fine sediment to the Colorado River in Marble and Grand Canyons (Topping and others, 2000). High suspended-sediment streamflows are now rare, and sandbar erosion has generally outpaced deposition (Rubin and others, 2002; Schmidt and others, 2004; Wright and others, 2005). Flow regulation also reduced the magnitude and frequency of floods that reorganized the configuration of sandbars and scoured riparian plants from the banks of the river. The number and size of plants increased after 1965, colonizing formerly open sandbars that had been used as campsites (Turner and Karpiscak, 1980; Kearsley and Ayers, 1996; Webb and others, 2002). The rate of increase in riparian vegetation along the river margins has increased greatly since the early 1990s (Sankey, written commun., 2013). Because of the combined impacts of sandbar erosion and invasion by riparian plants, the number and size of campsites has decreased dramatically in the post-dam river (Kearsley and others, 1994; Kaplinski and others, 2005; Kaplinski and others, 2010).

Purpose and Scope

Improving the condition of campsites along the Colorado River in Grand Canyon National Park is a priority management objective of the Glen Canyon Dam Adaptive Management Program (GCDAMP). The GCDAMP Strategic Plan management objective 9.3 calls for an increase in the "…size, quality, and distribution of camping beaches in critical and non-critical reaches…" of the Colorado River between Glen Canyon Dam and Lake Mead (Bureau of Reclamation, 2001). To address this objective, the U.S. Geological Survey, in cooperation with Northern Arizona University, conducted an integrated program of sandbar and campsite monitoring that was aimed at understanding the effects of Glen Canyon Dam operations on sandbars and campsites. This report describes the methods used to monitor 37 sandbar campsites and the changes that occurred to those campsites between 1998 and 2012. A companion report describes the monitoring program for the sandbar component of the study.

Study Area, Place Names, and Units

The study area is the 225-mi (362 km) segment of the Colorado River between Lees Ferry and Diamond Creek, Arizona (fig. 1). The study area is subdivided into Marble Canyon, which extends between Lees Ferry and the confluence with the Little Colorado River, and Grand Canyon, which extends from the Little Colorado River to Diamond Creek. Locations along the river corridor are referenced by convention as river mile (RM), which is distance, in miles, along the channel centerline downstream of Lees Ferry (U.S. Geological Survey, 2013). Lees Ferry (RM 0) is located 15.5 mi (25 km) downstream from GCD, and 1 mi (1.6 km) upstream from the mouth of the Paria River and the northeastern boundary of Grand Canyon National Park (fig. 1). The Little Colorado River confluence is at RM 61.5, and Diamond Creek enters the Colorado River at RM 225.

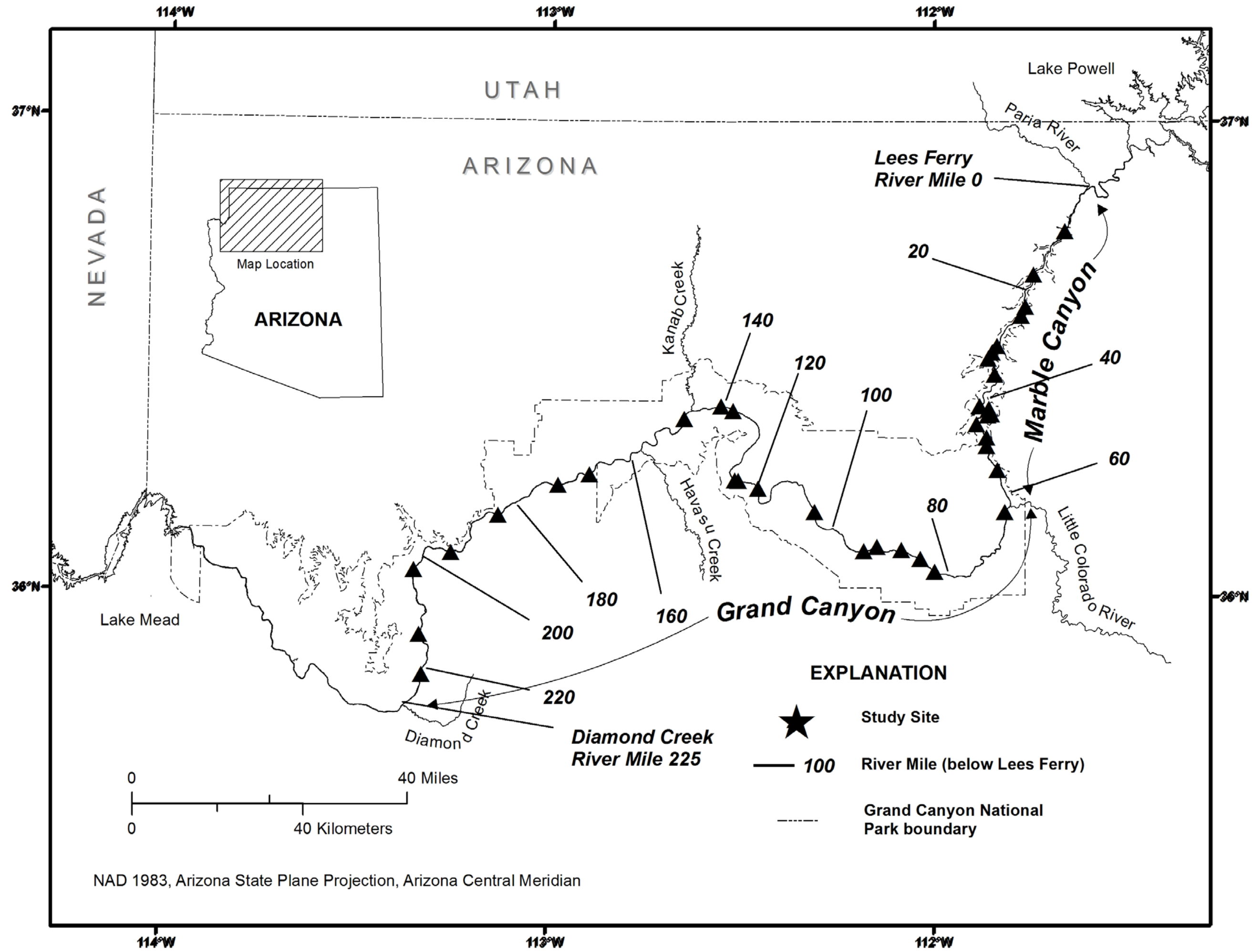

Figure 1. Map showing campsite area study site locations along the Colorado River, Grand Canyon National Park, Arizona.

Study sites are identified by RM and place name after Stevens (1990) and Belknap (2001). The left and right sides of the Colorado River are determined as facing downstream. Different parts of the Colorado River corridor in Marble and Grand Canyons have been classified as critical and non-critical recreational segments, as defined by Kearsley and Warren (1993). Critical segments are stretches of the river in which the number of available campsites is limited because of geomorphic setting, high demand for nearby attraction sites, or other logistical factors. Non-critical segments are stretches in which campsites are plentiful, resulting in little competition for most sites. Each campsite described in this report is located in a critical or a noncritical recreational segment. The International System of Units is used for all measures except for river mile, as noted above, and discharge, which is reported in cubic feet per second (ft^3/s).

Glen Canyon Dam Flows Releases during Study Period

Flows during the study period (fig. 2) followed the Modified Low Fluctuation Flow (MLFF) preferred alternative of the 1996 Record of Decision on the Glen Canyon Dam Environmental Impact statement (U.S. Department of Interior, 1996). The MLFF restricted minimum and maximum flows to 5,000 and 25,000 ft^3/s, respectively, and included low-, medium-, and high-volume months, with low flows during the late spring and late autumn, moderate flows in May and September, and high flows during mid-summer and mid-winter. The daily fluctuation or range in flow was limited to 5,000 ft^3/s during low-volume months, 5,000 ft^3/s during medium-volume months, and 8,000 ft^3/s during high-volume months. In this report, flow releases regulated by the MLFF protocols are referred to as "normal dam operations."

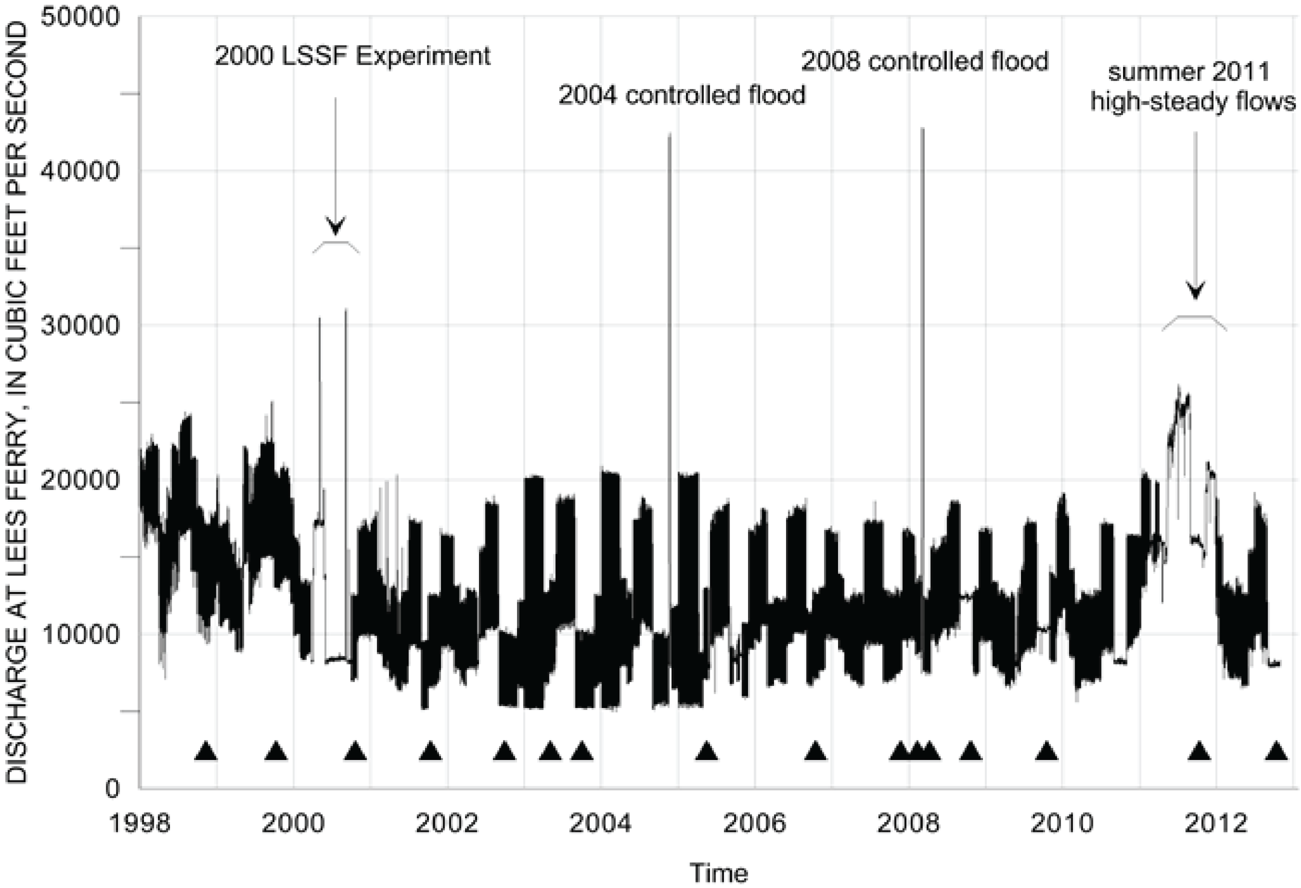

Figure 2. Hydrograph showing the Colorado River at Lees Ferry (09380000), Arizona, 1998–2013. Survey trip dates are shown as triangles. Note the daily and seasonal fluctuations in discharge volume, the May and September 30,000 ft^3/s powerplant capacity flows during the 2000 Low Steady Summer Flow (LSSF) experiment, the November 2004 High Flow experiment, March 2008 High Flow experiment, and sustained high volume flows during the summer of 2011.

During the study period, several flows were released that deviated from the MLFF operating guidelines. These flows were either experiments (such as controlled floods), or the result of equalization flows between Lake Powell and Lake Mead. Five high-flow releases occurred during the study period and are of particular interest, as they resulted in elevated main stem discharge that inundated sandbars and affected campsite areas. We refer to these flow events as "controlled floods." The first two controlled floods occurred in May and September 2000 as part of a flow experiment termed the Low Summer Steady Flow Experiment (LSSF). The LSSF consisted of a 4-day power-plant capacity controlled flood of 30,000 ft^3/s that was released in May 2000, followed by 3 months of constant 8,000 ft^3/s discharge, and then another 4-day power plant capacity controlled flood in September 2000. Two controlled floods greater than powerplant capacity were released in November 2004 and March 2008. Both of these controlled floods consisted of a 60-hour release of 42,000 ft^3/s. In 2003, 2004, and 2005, high-fluctuating flow experiments were conducted from January through March of each year. Flows during these months consisted of diurnal fluctuations from 5,000 to 20,000 ft^3/s. A non-experimental flow that affected campsite area occurred from June 1 to August 31, 2011. We refer to these flow releases as the "summer 2011 high-steady flows," during which equalization flows governed by the interim operating criteria averaged approximately 25,000 ft^3/s, with no daily fluctuation (U.S. Department of Interior, 2007).

Methods

Study Design and Site Selection

The objective of this study was to monitor changes in campsite areas associated with changing sandbar condition and to relate these changes to operations of Glen Canyon Dam. The study was designed as a companion component of a sandbar monitoring project in which the area and volume of sandbars at selected monitoring sites is measured at least annually by topographic survey (Beus and others, 1992; Kaplinski and others, 1995; Hazel and others, 1999; Hazel and others, 2010). Sandbars monitored for change in campsite area are a subset of the sites measured for topographic change, because not all sandbars are used as campsites. The original criteria for selection of the sandbar monitoring sites were (1) distribution throughout the river corridor, (2) distribution of geomorphic settings, (3) availability of historical data, (4) variation in recreation use intensity, and (5) variation in vegetation cover (Beus and others, 1992). Some of the current sandbar and campsite area monitoring sites were established by other researchers in the 1970s or 1980s (Howard and Dolan, 1981; Beus and others, 1985; Schmidt and Graf, 1990). A total of 37 study sites are monitored for changes in campsite area and provide the basis for this report (table 1). Thirty two sites were initially selected in 1998, and an additional five sites were added in 2002. These campsites comprise approximately 10 percent of all the sandbars identified as campsites by Grand Canyon National Park (*http://www.nps.gov/grca/parkmgmt/upload/2011CampsiteList.pdf).*

The locations, informal camp names, and reach designation of the 37 sites are shown in table 1. Sixteen of the study sites are in Marble Canyon, and 21 are in Grand Canyon (fig. 1). Sixteen sites are located in critical reaches, and 21 are in non-critical reaches. No campsites upstream of Lees Ferry in Glen Canyon (RM -15 to 0) or downstream of Diamond Creek (RM 225) were evaluated.

Table 1. Campsite monitoring study sites, along the Colorado River, Grand Canyon National Park, Arizona.

Mile[1]	Side	Name	Reach[2]
8.1	L	Jackass	NC
16.6	L	Hot Na Na	C
22.1	R	22 Mile	C
23.5	L	Lone Cedar	C
29.5	L	Silver Grotto	C
30.7	R	Sand Pile	C
31.9	R	South Canyon	C
35.0	L	Nautiloid	C
41.2	R	Buck Farm	NC
43.4	L	Anasazi Bridge	NC
44.5	L	Eminence	NC
45.0	L	Willy Taylor	NC
47.6	R	Lower Saddle	NC
50.1	R	Dino	NC
51.5	L	51 Mile	NC
55.9	R	Kwagunt Marsh	NC
62.9	R	Crash	NC
81.7	L	Grapevine	C
84.6	R	Clear Creek	C
87.7	L	Cremation	C
91.7	R	91 mile - above Trinity	C
93.8	L	Granite	C
104.4	R	104 Mile	C
119.4	R	119 Mile	NC
122.8	R	122 Mile	NC
123.2	L	Forster	NC
137.7	L	Football Field	C
139.6	R	Fishtail	C
145.9	L	145 Mile	C
167.1	L	Lower National	NC
172.2	L	172 Mile	NC
183.3	R	183Left	NC
183.3	L	183 Right	NC
194.6	L	194 Mile	NC
202.3	R	202 Mile	NC
213.3	L	Pumpkin Springs	NC
220.1	R	Middle 220 Mile	NC

[1]Based on the river mile centerline (U.S. Geological Survey, 2013) downstream from Lees Ferry (river mile 0)

[2]C=Critical Reach, NC = Non-Critical Reach, as defined by Kearsley and Warren (1993).

Data Collection and Processing

There are no administrative definitions of what constitutes a campsite, and the National Park Service (NPS) has few regulations that dictate campsite use. Aside from a few areas that are closed to camping, river runners camp anywhere they choose. Visitors are, however, discouraged from camping in previously undisturbed areas and clearing vegetation to establish new camping areas is not allowed. Most river runners camp at sites that are repeatedly used throughout the river running season; some sites are used nearly every night during the summer.

Because the purpose of this project is to track changes in the areas available for camping at regularly used sites, we adopted a definition of "campsite area" similar to that used by the NPS in previous studies (Kearsley and Warren, 1993). Campsite area is defined as any area of smooth substrate (most commonly sand) with no more than an 8 degree slope and little or no vegetation. We used this definition, but relaxed the slope criteria to include steeper areas near boat mooring locations where campers typically establish their kitchens. Following this definition, a single campsite consists of any number of smaller areas that meet the above criteria.

Campsite area was surveyed on 16 trips between 1998 and 2012 (fig. 2, table 2). Campsite surveys were conducted using standard total-station survey techniques. Hazel and others (2008) reported that individual points collected with total stations have horizontal accuracies that range from ±0.05 to 0.25 m and vertical accuracies that range from ±0.05 to 0.09 m, depending on the number of rod extensions used. Approximately 90 percent of the points were collected at the standard rod height with no extensions, where the accuracy is closer to the minimum level of 0.05 m, both horizontally and vertically. Each campsite survey was completed by measuring topographic points that outlined the perimeter of areas that meet the campsite area criteria, as well as collecting points to exclude areas containing features within campsite areas such as trees, bushes, and rocks. The perimeter points were then used to define polygons of campsite area (fig. 3). Slope was visually estimated in the field.

We did not include all campsite areas at every study site. Some campsites are large, and areas outside a fixed outer perimeter were not monitored. The areas excluded from monitoring were located far from mooring and kitchen locations and were typically at high elevations (greater than 45,000 ft^3/s) where current NPS regulations discourage camping (National Park Service, 2006). At other sites, some of the campsite area was obstructed from view by the survey equipment and was not included. At every site, the area for repeat monitoring was consistently defined. Survey crews used orthophotographs of each site with previously surveyed areas plotted to ensure that previously excluded campsite areas were not included in the mapping.

Because delineation of campsite area involves some unavoidable subjectivity, the question arises as to whether or not campsite area mapping, using the methods described above, can be accurately repeated. The repeatability of campsite area mapping was investigated by conducting surveys of the same campsite (Nautiloid camp; RM 35.0; appendix A) on the same day by two separate crews during the 1998 survey trip (fig. 3). Each crew established their own point locations to define the campsite area. The total amount of campsite area measured by the two surveys was 751 and 723 m^2, a 3.7 percent difference in campsite area. Topographic and campsite area complexity varies between the study sites; therefore, we conservatively estimate that the methods described here can detect changes in campsite area greater than 10 percent for all sites. Additional repeat surveys will be conducted in the future to better define the range of uncertainty associated with the mapping.

Table 2. Campsite survey trip data collected along the Colorado River, Grand Canyon National Park, Arizona, 1998–2012.

Trip date	Start date	End date	Discharge during surveys[1]
October 1998	10/10/1998	10/22/1998	10,000–18,000 ft^3/s
October 1999	10/3/1999	10/14/1999	13,000–20,000 ft^3/s
October 2000	10/15/2000	10/27/2000	7,000–12,500 ft^3/s
October 2001	10/5/2001	10/18/2001	7,000–12,500 ft^3/s
October 2002	9/20/2002	10/6/2002	5,500–10,000 ft^3/s
May 2003	4/25/2003	5/12/2003	7,000–13,000 ft^3/s
October 2003	9/20/2003	10/6/2003	5,500–10,000 ft^3/s
May 2005	5/7/2005	5/22/2005	7,000–13,000 ft^3/s
October 2006	10/7/2006	10/22/2006	7,000–13,000 ft^3/s
October 2007	10/13/2007	10/29/2007	7,000–13,000 ft^3/s
February 2008	2/2/2008	2/17/2008	8,500–13,500 ft^3/s
April 2008	3/28/2008	4/12/2008	7,500–13,000 ft^3/s
October 2008	10/11/2008	10/26/2008	12,100–12,600 ft^3/s
October 2009	10/10/2009	10/25/2009	10,000–10,700 ft^3/s
October 2011	10/5/2011	10/20/2011	15,000–16,300 ft^3/s
October 2012	10/3/2012	10/18/2012	7,800–8,300 ft^3/s

[1]Flow levels from USGS gage (09380000) Colorado River at Lees Ferry, AZ.

The elevation of campsite areas relative to the river elevation is also important when river runners decide where to camp because it is undesirable to carry equipment long distances or far upslope. A campsite is also undesirable if it can be temporarily flooded. To account for fluctuating flows on campsite areas, the campsite surveys were integrated with the topographic surveys so that changes to the campsite area could be analyzed within specific ranges of discharge. Surveys were integrated by constructing Digital Elevation Models (DEM) within the campsite area polygons. DEMs of the site topography were constructed from the survey points using triangular irregular networks (TINs) by Delaunay triangulation (McCullagh, 1998), and campsite area polygons were used to clip the DEM boundary to produce a DEM within the campsite area polygons. The campsite area DEMs were used to tabulate campsite area within six discrete discharge ranges, or zones. These zones were: (1) 10,000–15,000 ft^3/s, (2) 15,000–20,000 ft^3/s, (3) 20,000–25,000 ft^3/s, (4) 25,000–30,000 ft^3/s, (5) 30,000–45,000 ft^3/s, and (6) greater than 45,000 ft^3/s. For each site, these discharge ranges were converted into elevation ranges based on local stage-to-discharge relations computed by Hazel and others (2006). The lowermost stage range (10,000–15,000 ft^3/s) could not always be surveyed for all sites because discharges often were greater than 10,000 ft^3/s during the survey trips (table 2). Data for this zone is included only in the tabulation of individual site data (appendix A).

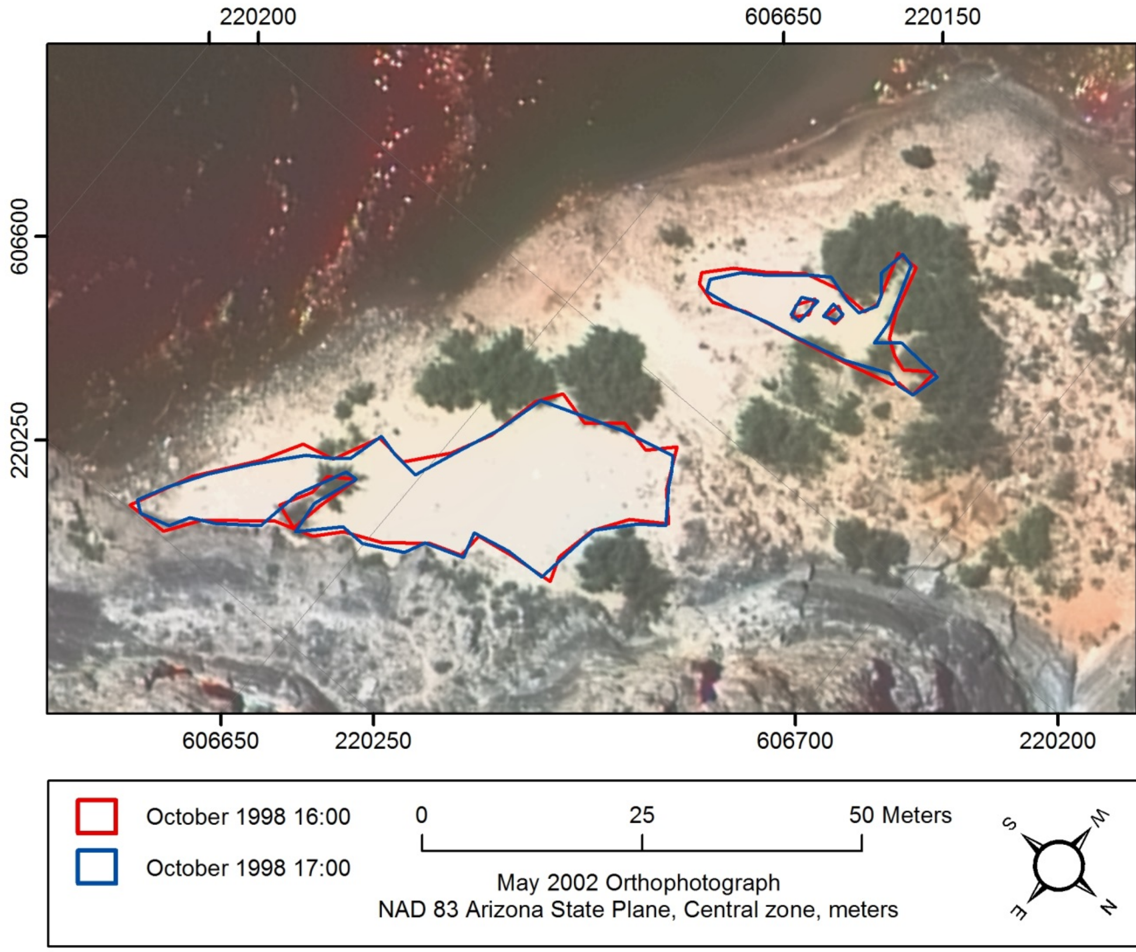

Figure 3. Map showing repeat surveys of Nautiloid camp (RM 35.0) conducted on October 12, 1998 at 16:00 and 17:00 by independent survey crews. The total campsite area measured was 751 m^2 (16:00) and 723 m^2 (17:00), which equates to a 3.7 percent difference in campsite area between surveys. Flow in main channel was from right to left. Grand Canyon Monitoring and Research Center aerial photographs taken in May 2002 when discharge was approximately 8,000 ft^3/s.

Campsite area measurements were summarized by grouping the data into two zones that are of greatest management interest. Normal dam operations generally consist of discharges with peaks rarely exceeding 25,000 ft^3/s (fig. 2). Discharges greater than this occur only during experimental floods conducted to build sandbars (Schmidt and Grams, 2011). We reported “low stage-elevation” campsite area as the sum of all campsite area in the zones between 15,000 and 25,000 ft^3/s. These areas are most affected by normal dam operations, are subjected to depositional and erosional processes, and are where riparian vegetation has established only to a minor degree. The “high stage-elevation” campsite area consists of all zones at elevations higher than 25,000 ft^3/s. The high stage-elevation zone is situated above the range of normal dam operations and is partially inundated only during controlled floods with magnitudes typically between 40,000 and 45,000 ft^3/s (fig. 2). Normal MLFF dam operations typically involve release volumes that are higher in June, July, and August. During summer months, most available campsite area is in the high stage-elevation zone. We also reported “total” campsite area as the sum of the low and high stage-elevation zones. This sum includes all the campsite area consistently measured at all of the study sites.

Complete data sets for each study site are given in appendix A. The appendix contains, for each site, a site location map, a table of the campsite area data, time series plots for each stage elevation zone, maps of each survey, and photographs of the study site at the beginning and end of the study period, where available.

Time-series plots of the campsite area surveys show the changes to campsite area over time. A summary of the campsite area data in all three stage elevation zones (total, high, and low) is presented for all sites (fig. 4, table 3), sites in Marble and Grand Canyons (fig. 5, tables 4 and 5) to show longitudinal changes with distance away from GCD, and within critical and non-critical recreational segments (fig. 6, tables 6 and 7). Data were summarized by computing the mean and standard error of the mean for the campsite area measured within each stage elevation zone for each survey. The significance of the time series trends were evaluated by linear regression modeling (table 8).

Table 3. Mean campsite area for all sites in low, high, and total stage elevation zones along the Colorado River, Grand Canyon National Park, Arizona, 1998–2012.

	Low[1]		High[2]		Total[3]		
Survey date	**Mean**	**s.e[4]**	**Mean**	**s.e.[4]**	**Mean**	**s.e.[4]**	**n[5]**
October 1998	185	45	487	70	623	75	30
October 1999	105	31	458	61	537	65	31
October 2000	327	69	414	54	741	90	30
October 2001	222	69	353	54	574	86	30
October 2002	162	35	272	38	434	48	37
May 2003	254	47	229	31	483	57	37
October 2003	248	47	231	33	479	54	37
May 2005	301	63	302	40	593	79	37
October 2006	120	28	218	30	337	44	37
October 2007	119	23	164	25	282	33	37
February 2008	121	26	180	27	301	42	37
April 2008	212	61	398	52	610	100	37
October 2008	123	30	265	35	388	45	37
October 2009	82	20	225	29	307	36	37
October 2011	215	44	168	24	383	50	37
October 2012	211	42	160	23	371	49	37

[1]Low = campsite area measured between the 15,000 to 25,000 ft^3/s stage elevation zone.

[2]High = campsite area measured above the 25,000 ft^3/s stage elevation zone.

[3]Total = all campsite area measured above 15,000 ft^3/s stage elevation zone.

[4]s.e. = standard error of the mean.

[5]n = number of sites.

Table 4. Mean campsite area for sites in low, high, and total stage elevation zones in Marble Canyon along the Colorado River, Arizona, 1998–2012.

	Low[1]		High[2]		Total[3]		
Survey date	**Mean**	**s.e.[4]**	**Mean**	**s.e.[4]**	**Mean**	**s.e.[4]**	**n[5]**
October 1998	221	83	549	105	637	114	11
October 1999	96	45	621	81	651	81	12
October 2000	365	143	502	78	867	165	10
October 2001	335	160	390	66	725	161	11
October 2002	144	48	304	55	448	56	16
May 2003	230	60	258	48	488	78	16
October 2003	203	61	284	59	487	71	16
May 2005	305	61	363	55	646	80	16
October 2006	118	40	263	37	381	58	16
October 2007	119	36	215	42	335	54	16
February 2008	133	47	236	45	369	75	16
April 2008	357	126	472	91	830	198	16
October 2008	171	52	315	52	485	64	16
October 2009	100	31	241	39	341	44	16
October 2011	214	75	203	39	418	71	16
October 2012	248	60	196	43	444	73	16

[1]Low = campsite area measured between the 15,000 to 25,000 ft^3/s stage elevation zone.

[2]High = campsite area measured above the 25,000 ft^3/s stage elevation zone.

[3]Total = all campsite area measured above 15,000 ft^3/s stage elevation zone.

[4]s.e. = standard error of the mean.

[5]n = number of sites.

Table 5. Mean campsite area for sites in low, high, and total stage elevation zones in Grand Canyon along the Colorado River, Grand Canyon National Park, Arizona, 1998–2012.

	Low[1]		High[2]		Total[3]		
Survey date	**Mean**	**s.e.[4]**	**Mean**	**s.e.[4]**	**Mean**	**s.e.[4]**	**n[5]**
October 1998	164	53	451	94	615	100	19
October 1999	111	43	354	78	466	91	19
October 2000	308	77	370	70	677	107	20
October 2001	156	55	331	77	487	96	19
October 2002	176	50	247	53	424	75	21
May 2003	272	70	207	41	479	82	21
October 2003	283	69	190	36	473	80	21
May 2005	298	102	255	56	553	126	21
October 2006	121	41	183	43	304	65	21
October 2007	118	31	125	28	243	41	21
February 2008	112	30	138	31	250	46	21
April 2008	101	36	342	59	443	77	21
October 2008	87	34	227	47	314	58	21
October 2009	69	26	212	43	281	53	21
October 2011	216	55	141	30	357	70	21
October 2012	182	59	133	25	315	66	21

[1]Low = campsite area measured between the 15,000 to 25,000 ft^3/s stage elevation zone.

[2]High = campsite area measured above the 25,000 ft^3/s stage elevation zone.

[3]Total = all campsite area measured above 15,000 ft^3/s stage elevation zone.

[4]s.e. = standard error of the mean.

[5]n = number of sites.

Table 6. Mean campsite area for sites in critical reaches in low, high, and total stage elevation zones along the Colorado River, Grand Canyon National Park, Arizona, 1998–2012.

	Low[1]		High[2]		Total[3]		
Survey date	**Mean**	**s.e.[4]**	**Mean**	**s.e.[4]**	**Mean**	**s.e.[4]**	**n[5]**
October 1998	185	77	388	83	573	89	13
October 1999	127	50	360	82	487	80	13
October 2000	234	60	364	75	598	96	14
October 2001	128	41	304	79	432	76	13
October 2002	173	49	228	56	401	63	16
May 2003	244	77	197	44	442	86	16
October 2003	222	78	193	42	415	79	16
May 2005	292	112	283	60	574	129	16
October 2006	100	45	232	53	332	70	16
October 2007	93	29	179	39	272	41	16
February 2008	107	29	171	36	278	45	16
April 2008	187	61	353	68	541	91	16
October 2008	164	61	265	50	429	68	16
October 2009	102	38	223	42	325	52	16
October 2011	225	83	176	41	401	84	16
October 2012	242	82	169	34	411	84	16

[1]Low = campsite area measured between the 15,000 to 25,000 ft^3/s stage elevation zone.

[2]High = campsite area measured above the 25,000 ft^3/s stage elevation zone.

[3]Total = all campsite area measured above 15,000 ft^3/s stage elevation zone.

[4]s.e. = standard error of the mean.

[5]n = number of sites.

Table 7. Mean campsite area for sites in non-critical reaches in low, high, and total stage elevation zones along the Colorado River, Grand Canyon National Park, Arizona, 1998–2012.

	Low[1]		High[2]		Total[3]		
Survey date	**Mean**	**s.e.[4]**	**Mean**	**s.e.[4]**	**Mean**	**s.e.[4]**	**n[5]**
October 1998	185	55	563	105	661	115	17
October 1999	90	40	528	85	573	97	18
October 2000	408	117	457	77	865	142	16
October 2001	293	115	390	75	683	136	17
October 2002	154	50	305	52	459	71	21
May 2003	262	60	253	43	515	77	21
October 2003	268	60	260	48	528	74	21
May 2005	308	74	317	56	608	102	21
October 2006	135	37	206	34	341	59	21
October 2007	138	35	152	33	290	51	21
February 2008	132	41	187	40	319	67	21
April 2008	231	98	432	76	663	163	21
October 2008	92	24	265	50	357	60	21
October 2009	67	19	226	41	293	49	21
October 2011	208	47	162	30	369	61	21
October 2012	187	42	153	33	340	60	21

[1]Low = campsite area measured between the 15,000 to 25,000 ft^3/s stage elevation zone.

[2]High = campsite area measured above the 25,000 ft^3/s stage elevation zone.

[3]Total = all campsite area measured above 15,000 ft^3/s stage elevation zone.

[4]s.e. = standard error of the mean.

[5]n = number of sites.

Table 8. Results of linear regression of mean campsite-area time series presented in tables 2 through 6, Grand Canyon National Park, Arizona, 1998–2012.

Sites	Stage zone	F[1]	P[2]	(R^2)[3]
all sites	low	0.93	0.351	0.06
all sites	high	19.16	0.001	0.58
all sites	total	11.86	0.004	0.46
Marble Canyon	low	0.33	0.574	0.02
Marble Canyon	high	17.50	0.001	0.56
Marble Canyon	total	5.78	0.031	0.29
Grand Canyon	low	1.40	0.256	0.09
Grand Canyon	high	19.11	0.001	0.58
Grand Canyon	total	19.00	0.001	0.58
critical	low	0.01	0.920	0.00
critical	high	10.92	0.005	0.44
critical	total	5.15	0.040	0.27
noncritical	low	1.82	0.198	0.12
noncritical	high	24.06	0.000	0.63
noncritical	total	14.99	0.002	0.52

[1]F-ratio from single factor ANOVA with degrees of freedom = 1,14.

[2]P is the significance of the F-ratio. Significance at the 95 percent level = 0.05.

[3]R^2 represents the percentage of variation explained by the fitted line, or "goodness of fit" of the line.

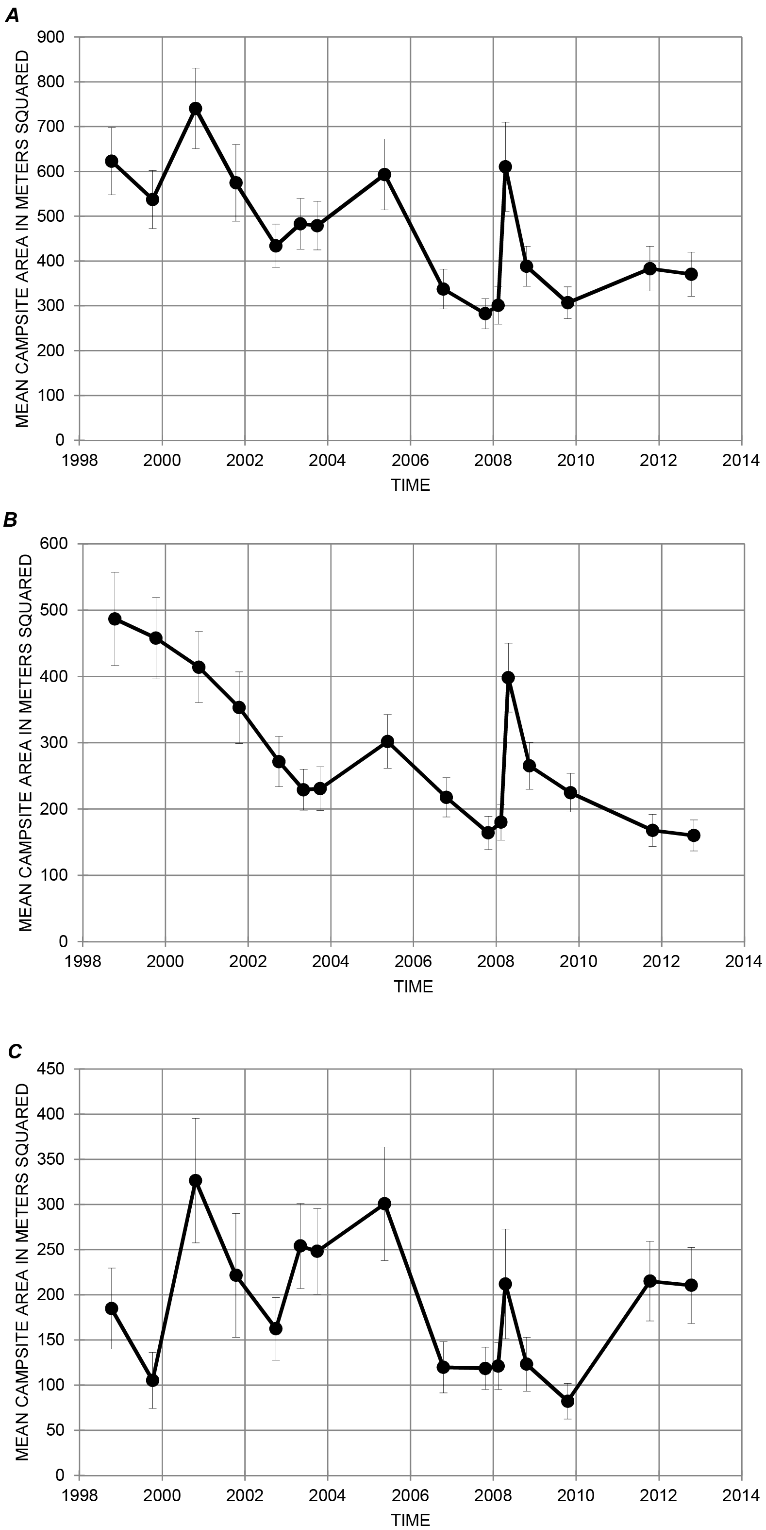

Figure 4. Time series plots showing mean campsite area for all sites along the Colorado River, Grand Canyon National Park, Arizona. Standard error of the mean shown by error bars (*A*) Mean campsite area in total (greater than 15,000 ft^3/s) stage-elevation zone; (*B*) mean campsite area in high (greater than 25,000 ft^3/s) stage-elevation zone; (*C*) mean campsite area of low (15,000–25,000 ft^3/s) stage-elevation zone. Refer to table 2 for data.

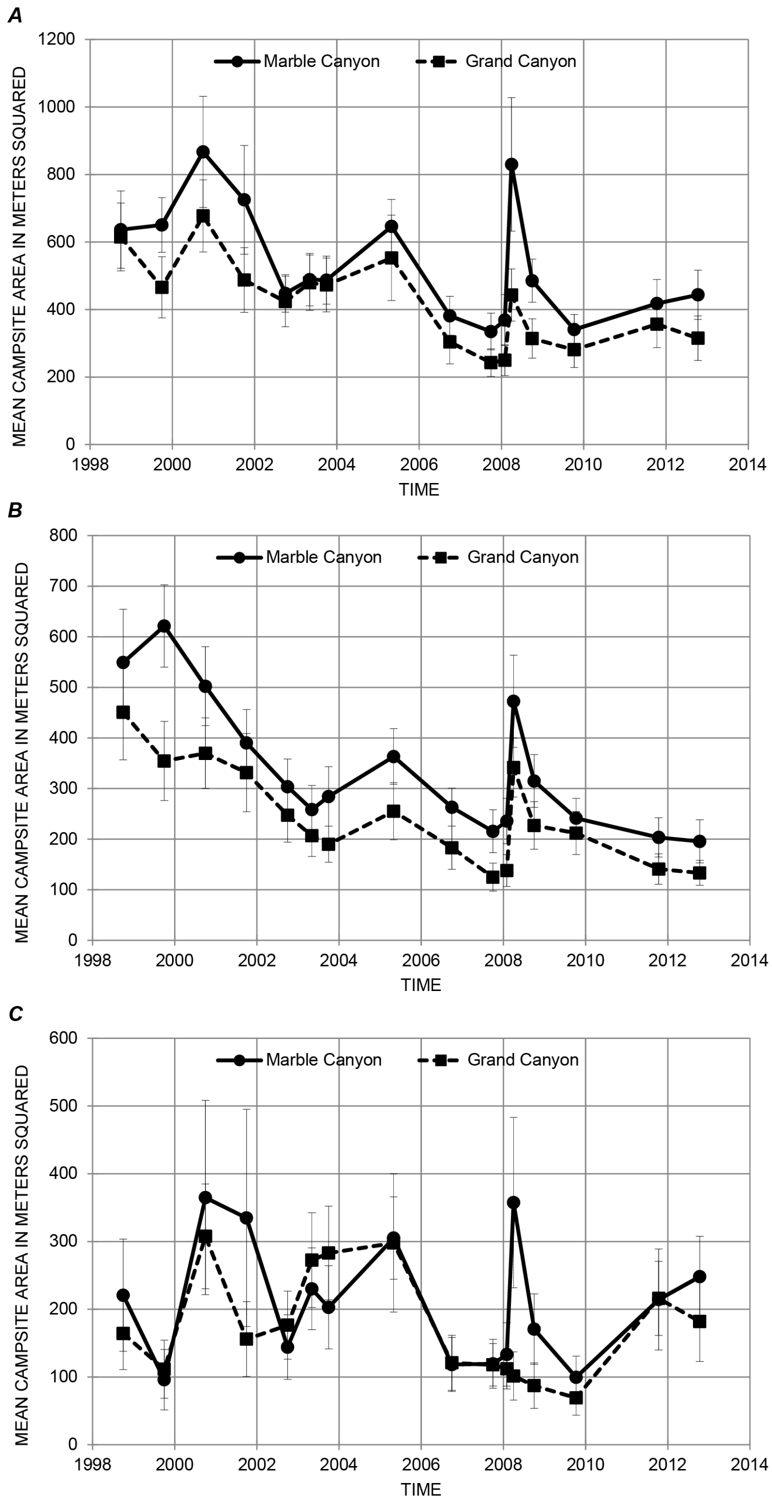

Figure 5. Time series plots showing mean campsite area for sites in Marble and Grand Canyons along the Colorado River, Grand Canyon National Park, Arizona. Standard error of the mean shown by error bars. (*A*) Mean campsite area in total (greater than 15,000 ft^3/s) stage-elevation zone; (*B*) mean campsite area in high (greater than 25,000 ft^3/s) stage-elevation zone; (*C*) mean campsite area of low (15,000–25,000 ft^3/s) stage-elevation zone. Refer to tables 3 and 4 for data.

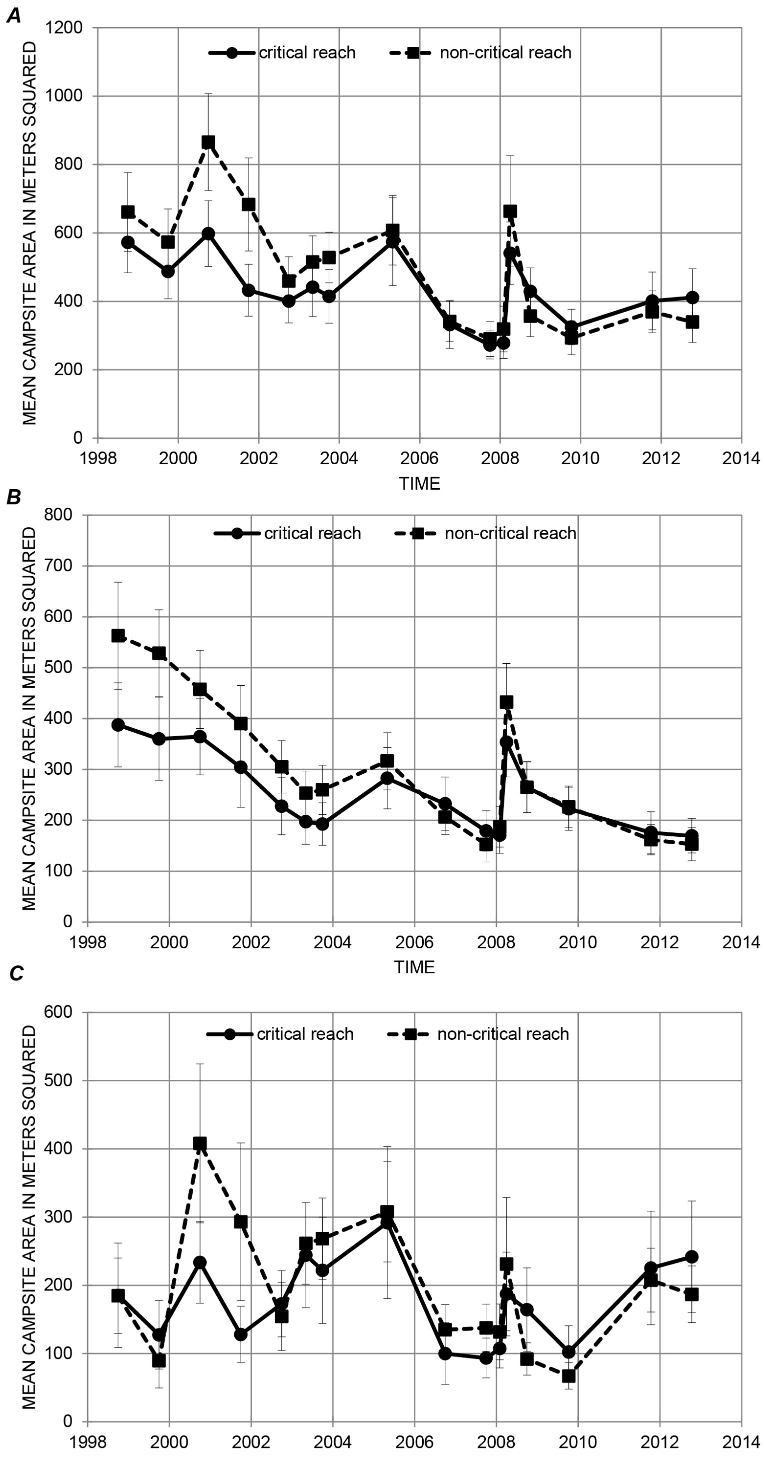

Figure 6. Time series plots showing mean campsite area for sites in critical and non-critical recreational segments along the Colorado River, Grand Canyon National Park, Arizona. Standard error of the mean shown by error bars. (*A*) Mean campsite area in total (greater than 15,000 ft^3/s) stage-elevation zone; (*B*) mean campsite area in high (greater than 25,000 ft^3/s) stage-elevation zone; (*C*) mean campsite area of low (15,000–25,000 ft^3/s) stage-elevation zone. Refer to tables 5 and 6 for data.

Results and Conclusions

Campsite area decreased over the course of the study period, but varied strongly by elevation zone and between surveys (figs. 4, 5, and 6). From 1998 to 2012, the mean total campsite area decreased by an average of 36 percent and decreased at 29 of the 37 study sites. Regression modeling shows that the decreasing trend in the total amount of campsite area (figs. 4A, 5A, and 6A) is significant ($p<0.05$; table 8). Campsite area within the high stage-elevation zone shows a significant decreasing trend ($p<0.05$; table 8) for all categories of sites (figs. 4*B*, 5*B*, and 6*B*), whereas there was no significant long-term trend in low stage-elevation campsite area (figs. 4*C*, 5*C*, and 6*C*). Campsite area decreased at all 37 study sites in the high stage-elevation zone by an average of 61 percent. In the low stage-elevation zone, 21 sites increased in campsite area, 12 sites decreased in area, and 4 sites showed no change.

The effects of dam operations on campsite area are highlighted by examining changes between surveys. In the high stage-elevation zone, campsite area increased for all categories (all sites, Marble Canyon, Grand Canyon, critical and non-critical) after the controlled floods in November 2004 and March 2008 (fig. 2). Increases in high stage-elevation campsite area result from sandbar deposition during controlled floods (Grams and others, 2010; Hazel and others, 2010), where deposition builds larger bars, fills gullies, and buries or removes vegetation. In contrast, high stage-elevation campsite area decreased in the intervals between high flows when normal Record of Decision (ROD) flows did not inundate the high-elevation zone. The two powerplant capacity (about 31,000 ft^3/s) controlled floods released during the 2000 LSSF experiment only partially inundated the high stage-elevation zone but did not increase campsite area in this zone. The loss of campsite area during these intervals is likely due to a combination of changes in sandbar slope and vegetation growth.

In the low stage-elevation zone, campsite area increases occurred after higher volume flows within powerplant capacity as well as the two controlled floods greater than powerplant capacity. Low stage-elevation campsite area increased after the two powerplant capacity controlled floods during the 2000 LSSF experiment, the high-fluctuating flows from January to March 2003, the 2004 and 2008 controlled floods, and the summer 2011 high-steady flows. Campsite area increased during these intervals because flows partially or completely inundated the low stage-elevation zone, deposited sediment (if sediment concentrations were high enough), and inhibited vegetation growth.

The campsite area surveys show a long term loss in campsite area. We conclude that dam operations have not met the management objectives of the Glen Canyon Adaptive Management program to increase the size of camping beaches in critical and non-critical reaches of the Colorado River between Glen Canyon Dam and Lake Mead. However, a more thorough investigation is needed to better quantify the mechanisms that cause campsite area change. We are currently conducting an analysis that aims to correlate changes in campsite area with changes in topography and vegetation to provide a more complete analysis of changes to campsite area along the Colorado River in Grand Canyon.

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Appendix A. Campsite Area Data for Each Study Site

The appendix contains, for each site, a site location map, a table of the campsite area data, time series plots for each stage elevation zone, maps of each survey, and photographs of the study site at the beginning and end of the study period, where available.Appendix A in .PDF format can be downloaded from *http://pubs.usgs.gov/ofr/2014/1161*.

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