2008 High-Flow Experiment at Glen Canyon Dam—Morphologic Response of Eddy-Deposited Sandbars and Associated Aquatic Backwater Habitats along the Colorado River in Grand Canyon National Park

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Cover: Photograph of a Grand Canyon sandbar created as the result of the 2008 high-flow experiment at Glen Canyon Dam. To the left of the sandbar is a newly created backwater. (Photograph courtesy of Matthew Kaplinski, Northern Arizona University.)

Grand Canyon Monitoring and Research Center

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By Paul E. Grams, John C. Schmidt, and Matthew E. Andersen

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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)
	Area	
square meter (m^2)	10.76	square foot (ft^2)
	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)

Conversion of discharge from SI to Inch/Pound units for values used frequently in this report.

Use in report	m^3/s	ft^3/s
Peak discharge of 1996 HFE	1,274	45,000
Peak discharge of 2004 and 2008 HFEs	1,203	42,500
Discharge used in analyses	227	8,000
Discharge used in analyses	283	10,000
Discharge used in analyses	340	12,000
Discharge used in analyses	453	16,000
Discharge used in analyses	566	20,000
Bottom of range of fluctuations for Flow Regime (FR) 1	198	7,000
Top of range of fluctuations for FR 1	340	12,000
Bottom of range of fluctuations for FR 2	283	10,000
Top of range of fluctuations for FR 2	453	16,000
Bottom of range of fluctuations for FR 3	311	11,000
Top of range of fluctuations for FR 3	538	19,000
Steady discharge for FR 4	351	12,400

In this report, horizontal and vertical coordinate information is referenced in meters above the GRS80 ellipse defined by the North American Datum of 1983 (NAD 83). Elevation, as used in this report, refers to NAD83/GRS80 ellipsoid heights and not traditionally defined NAVD88 orthometric heights.

2008 High-Flow Experiment at Glen Canyon Dam—Morphologic Response of Eddy-Deposited Sandbars and Associated Aquatic Backwater Habitats along the Colorado River in Grand Canyon National Park

By Paul E. Grams[1], John C. Schmidt[2], and Matthew E. Andersen[1]

Abstract

The March 2008 high-flow experiment (HFE) at Glen Canyon Dam resulted in sandbar deposition and sandbar reshaping such that the area and volume of associated backwater aquatic habitat in Grand Canyon National Park was greater following the HFE. Analysis of backwater habitat area and volume for 116 locations at 86 study sites, comparing one month before and one month after the HFE, shows that total habitat area increased by 30 percent to as much as a factor of 3 and that volume increased by 80 percent to as much as a factor of 15. These changes resulted from an increase in the area and elevation of sandbars, which isolate backwaters from the main channel, and the scour of eddy return-current channels along the bank where the habitat occurs. Because of this greater relief on the sandbars, backwaters were present across a broader range of flows following the HFE than before the experiment.

Reworking of sandbars during diurnal fluctuating flow operations in the first 6 months following the HFE caused sandbar erosion and a reduction of backwater size and abundance to conditions that were 5 to 14 percent greater than existed before the HFE. In the months following the HFE, erosion of sandbars and deposition in eddy return-current channels caused reductions of backwater area and volume. However, sandbar relief was still greater in October 2008 such that backwaters were present across a broader range of discharges than in February 2008.

Topographic analyses of the sandbar and backwater morphologic data collected in this study demonstrate that steady flows are associated with a greater amount of continuously available backwater habitat than fluctuating flows, which result in a greater amount of intermittently available habitat. With the exception of the period immediately following the HFE, backwater habitat in 2008 was greater for steady flows associated with dam operations of relatively lower monthly volume (about 227 m^3/s) than steady flows associated with dam operations of higher monthly volume. Similarly, there was greater habitat availability associated with lower monthly volume fluctuating flows (post-HFE through mid-April) compared to higher monthly volume fluctuating flows (after mid-April 2008).

The sites monitored for this study represent about 20 percent of the 569 estimated number of potential sand-bounded backwaters that occur in eddies below Glen Canyon Dam in Grand Canyon

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National Park. Data from fish sampling in backwaters, by seining, demonstrates that both native and nonnative species were present in the backwaters monitored for this study.

Introduction

In a landscape dominated by bedrock and talus, sandbars along the margins of the Colorado River in Grand Canyon are distinct features of the river corridor. Before completion of Glen Canyon Dam in 1963 (fig. 1), fine sediment, including sand, silt, and clay, accumulated during much of the summer and fall (Topping and others, 2000). This sediment was redistributed by annual spring floods and deposited at high elevations along the channel margin (Schmidt and Graf, 1990; Webb, 1996). The sand deposited by the annual floods provided substrate for riparian vegetation, created beaches for recreational use, and shaped aquatic habitat used by native fish (Kearsley and others, 1994; Stevens and others, 1995). Following completion of Glen Canyon Dam, the supply of sand to the Colorado River downstream from Lees Ferry, Arizona, was reduced by 94 percent (Topping and others, 2000; Wright and others, 2005). In addition, dam-regulated flows, typically constrained to the capacity of the hydropower plant, limit the area that is affected by river flows and thereby reduce the area of potential sandbar deposition during floods. Closure of Glen Canyon Dam resulted in three primary changes: (1) a greatly decreased sediment supply, (2) a greatly reduced flood magnitude, and (3) a greatly increased base flow (Topping and others, 2003). These dam-induced changes have resulted in fewer sandbars (Schmidt and Graf, 1990), decreased areal extent of exposed sand (Schmidt and others, 1999), and lower sandbar elevations (Schmidt and others, 1995).

The largest proportion of the Colorado River’s sediment load in Grand Canyon is sand. Although completion of Glen Canyon Dam caused a large reduction in the supply of sand to Grand Canyon, sandbars remain in many zones of lateral flow separation—eddies—that occur downstream from rapids and in the lee of bank obstructions, such as debris fans, talus cones, and rock outcrops. Eddy sandbars have a characteristic morphology, because flow patterns in eddies are generally similar. Schmidt (1990) and Schmidt and Rubin (1995) proposed a nomenclature for these bars based on topography and relation to typical flow patterns at flood stages when the bars are inundated and active (fig. 2).

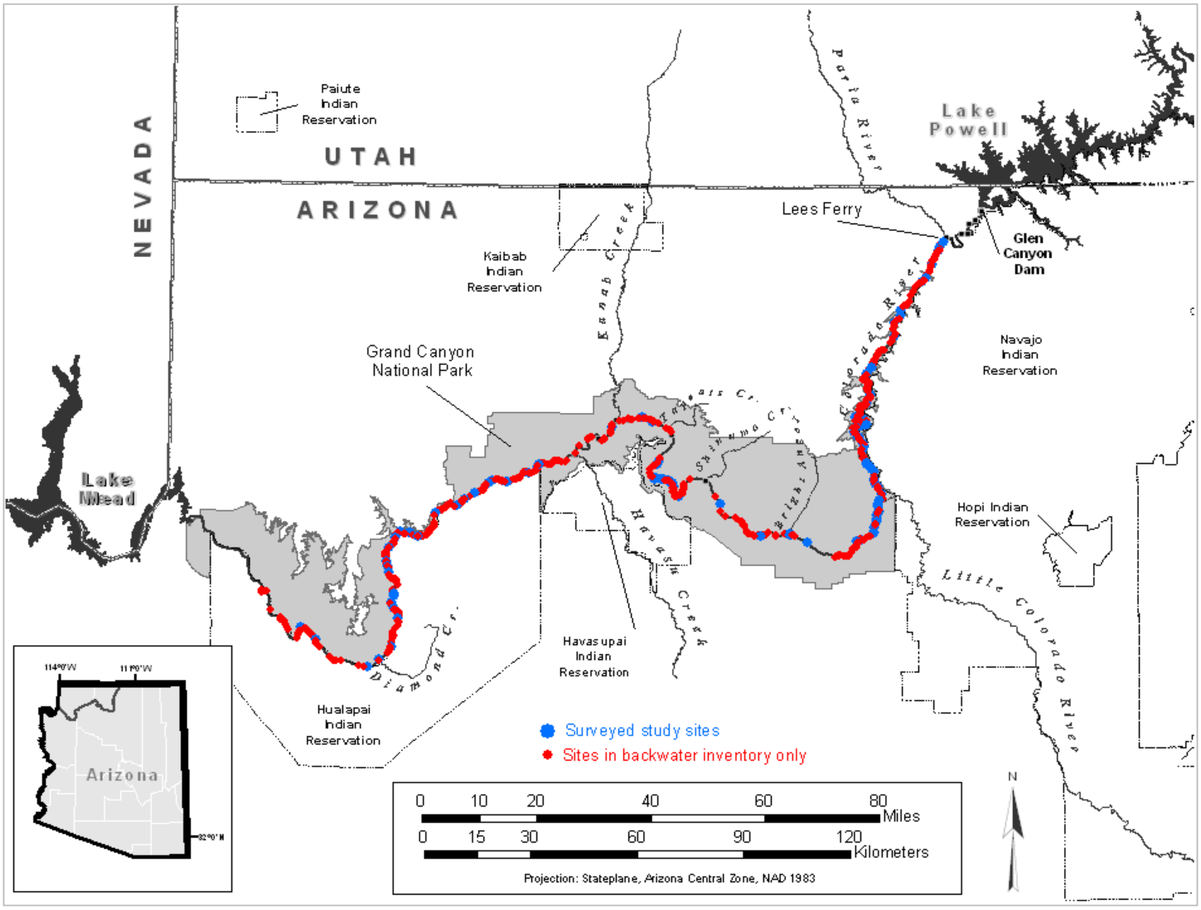


Figure 1. Map of the Colorado River in Grand Canyon, Arizona, showing study sites (blue) and the locations of all backwaters (red and blue) identified in the backwater inventory.

Eddy sandbars may be subdivided into reattachment bars and separation bars, and the primary eddy return-current channel (hereafter referred to as the return channel) occurs between them. Reattachment bars form beneath the central and downstream parts of the eddy, have the form of an upstream-projecting spit (called the bar platform), and are highest at their downstream end where they are attached to the bank (Rubin and others, 1990). Schmidt and Graf (1990), and Rubin and others (1990) showed that large reattachment bars that are emergent at base flow project far upstream. In contrast, if reattachment bars are small, the only part of the bar that is emergent at base flows is at the downstream end. The term “reattachment bar” arises because this downstream part of the bar occurs where the main downstream flow reattaches to the bank at times of bar inundation.

The upstream parts of the reattachment bar are typically bounded by a deep channel that occurs between the bar and bank (fig. 2). This channel is maintained by upstream flow, or return current, that is concentrated along the bank of each eddy. Sand in return channels has been transported across the top of the bar platform and is efficiently swept upstream by the relatively higher velocity flows of this upstream current. This channel is referred to as the primary eddy return-current channel.

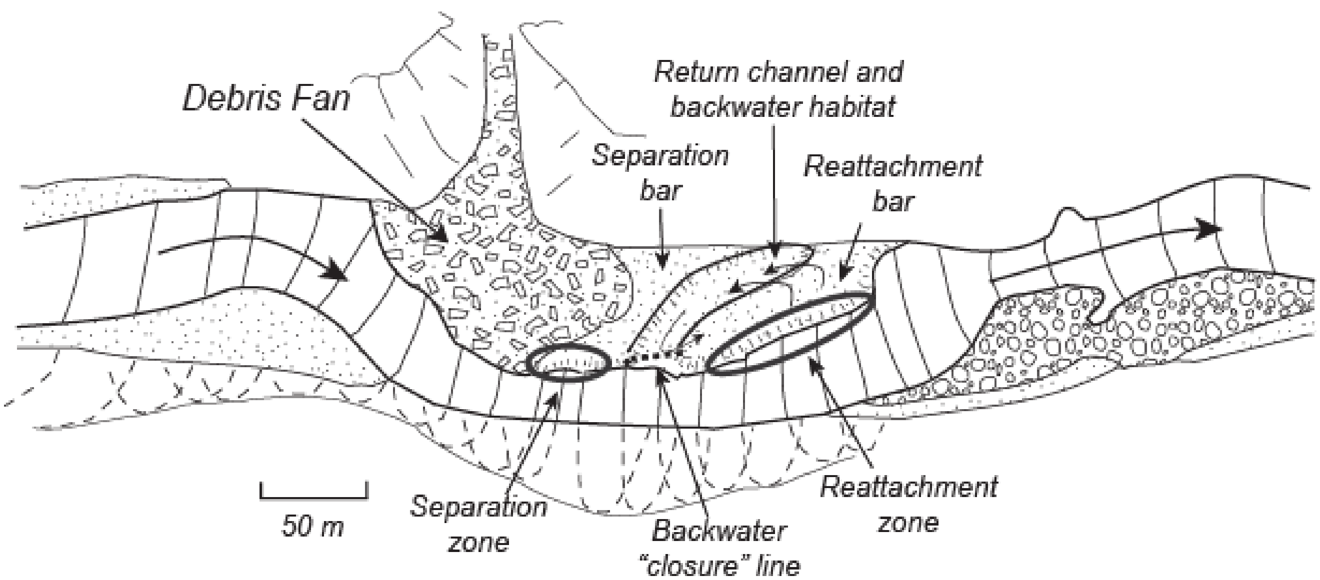


Figure 2. Diagrammatic illustration of typical reattachment bar, return channel, and backwater habitat. Main channel flow is from left to right. The separation zone is the area where downstream flow separates from the bank, and the reattachment zone is the area where downstream flow reattaches to the bank. The small arrows indicate the region of recirculating flow within the eddy at flows during which the sandbar would be submerged. The dotted line is an example backwater closure line that separates the backwater from the main channel. Figure is modified from Schmidt and Graf (1990).

During low flow, reattachment bars that are sufficiently large block eddy circulation into return channels. If the return channel is sufficiently deep, the inundated return channel becomes an embayment of stagnant water that is only connected to the main flow at the upstream end (fig. 2). Fisheries biologists refer to this stagnant flow feature as "backwater" aquatic habitat. The existence of this type of backwater habitat is therefore dependent on two key geomorphic attributes. First, the reattachment bar must be sufficiently large such that flow circulation at some discharges is blocked. Second, the return channel must be sufficiently large and deep that it is inundated at the same discharges when flow is blocked across the bar platform.

Although return channels create the greatest proportion of backwater habitat, other geomorphic features create zones of low velocity or stagnant flow elsewhere. Occasionally, backwaters form adjacent to reattachment bars but downstream from the reattachment zone and beyond the return channel. Backwaters are also found on separation bars, which occur upstream from the return channel and typically mantle the debris fan that creates lateral separation eddies. Areas of low velocity occasionally form near separation bars at low discharges, but these areas typically have a larger water-exchange rate with the main channel flow than do inundated return channels. Other areas of stagnant water or low velocity flow occur near emergent gravel bars and other channel obstructions.

The use of backwater habitats by endangered native humpback chub (*Gila cypha*) has been documented by monitoring efforts since the early 1990s (Valdez and others, 2001). Because of the federally listed endangered status of humpback chub, backwaters are a major focus of ecological investigation to better understand the use and role of these habitats in the life history of various native and nonnative fish species. Scientists and managers have hypothesized that backwater habitats of the mainstem Colorado River may be especially important for humpback chub and other native fish species because they offer potentially warmer water temperatures under conditions of low velocity, which likely promote growth of juvenile life stages. Schmidt and Brim-Box (2004) described backwaters in the Green River (a tributary of the Colorado River located in the upper Colorado River Basin) and showed that their abundance is dependent on channel geomorphology and discharge. On the Green River, backwaters occur both in canyons with debris fans and near emergent bank-attached bars in alluvial segments of the river system, such as the Uinta Basin. The latter type of backwaters are critical habitat for nursery-age Colorado pikeminnow (*Ptychocheilus lucius*). Backwaters associated with debris fans and eddy bars occur in Desolation and Grey Canyons of the Green River, but their importance to upper Colorado River Basin humpback chub populations is less, because the temperature of the mainstem flow is much warmer than below Glen Canyon Dam in Grand Canyon (Valdez and Clemmer, 1982; Valdez and others, 1990). In Grand Canyon, backwaters may provide seasonally warmer habitats (summer and fall) in contrast to the mainstem temperatures, which are cool throughout the year. In some situations in Grand Canyon, however, competition or predation with nonnative species may be such that backwater habitats are disadvantageous where, for example, native fish congregate in backwaters and subsequently are consumed by predaceous nonnative fishes. In winter, backwater temperatures may be colder than water in the main channel and therefore may be less suitable habitat for juvenile native fish.

One of the current goals of native fish management in Grand Canyon National Park is to maintain or increase the availability of backwaters because of their potential role in providing habitat for juvenile native fish. Previous studies on the relation between backwater habitats and flow regime in Grand Canyon have shown that flows larger than the capacity of the Glen Canyon Dam powerplant, such as the 1996 controlled flood (see Webb and others, 1999), cause redistribution of eddy sandbars (Schmidt and others, 1999) and short-term increases in the area of backwater habitat (Brouder and others, 1999; Goeking and others, 2003). Goeking and others (2003) analyzed historical aerial photographs taken as early as the mid-1930s and found that backwater area in specific eddies was highly variable among the different years of available photographs. They found that there may be significant changes in the number and size of backwaters over short (~ 1 yr) time periods, but they also found that significant changes in backwater area were not evident over multiyear or decadal time scales. The implication of these findings is that reattachment bar platforms are sufficiently large in many eddies, and return-current channels are sufficiently large, that backwaters persist as habitat over multiyear or decadal time scales, although the locations of specific backwaters change from year to year. Goeking and others (2003) also found that backwaters do not necessarily exist if reattachment bars are very large and fill the return-current channel, as was seen in many eddies in the mid-1930s aerial photographs.

Since 1990, three experimental controlled floods exceeding the capacity of the Glen Canyon Dam powerplant have been released. Administratively, these releases are termed high-flow experiments (HFE), defined as planned releases from the dam that exceed the peak capacity of the hydroelectric powerplant (~940 m^3/s) by at least 30 percent (U.S. Department of the Interior, 1995). The primary purpose of these experiments has been to determine whether HFEs have the potential to effectively increase and maintain sandbars and related habitats that are located in eddies and along the channel margins. During the first HFE, conducted in March and April 1996, approximately 1,274 m^3/s were released for a period of 7 days. Although this test did result in sandbar deposition, measurements made of sand-storage change in eddies (Hazel and others, 1999; Schmidt and others, 1999) and a calculation of sand mass balance (Topping and others, 1999; Schmidt, 1999) both indicated net erosion of sand from low-elevation (below the stage associated with a discharge of approximately 227 m^3/s) parts of eddies and the channel. In a study based on examination of aerial videography following this flood, Brouder and others (1999) reported that the number of backwaters increased between Lees Ferry and Diamond Creek (fig. 1) because bar platforms were elevated and return channels were excavated. They also stated that the number of backwaters decreased during the months following the controlled flood, when normal hydropower plant operations resumed (referred to as Modified Low Fluctuating Flows, as described in the 1996 Record of Decision on Glen Canyon Dam operations, see U.S. Department of the Interior, 1996), but they did not quantify the magnitude of this decrease. Reduction in backwater area was caused by infilling of return channels and erosion of bar platforms.

The second HFE, with a shorter peak duration of 2.5 days and a slightly lower peak magnitude, was conducted in November 2004, following tributary sand inputs from the Paria River (located 25 km below the dam) to determine if it was possible to build sandbars without causing net erosion from the eddies and the channel. This second high-flow experiment was specifically released following tributary sand enrichment and was designed with a shorter peak duration on the basis of results from the 1996 HFE, as summarized by Rubin and others (2002). Measurements of sand-storage change and sand flux past mainstem stream gages at various locations below the Paria River show that net deposition did occur in some upstream segments where pre-HFE sand enrichment was greatest (Topping and others, 2006). In downstream segments where sand enrichment was less, net erosion occurred. Tributary sand production (mostly from the Paria River, fig. 1) in 2006 and 2007 resulted in sand accumulation in all river segments between Lees Ferry and Diamond Creek (fig. 1).

The March 2008 HFE was conducted to determine whether a third high flow conducted under these conditions of relatively high sand enrichment would result in net sandbar deposition over a greater portion of the river corridor between Lees Ferry and Diamond Creek. The average discharge of 1,203 m^3/s during the March 2008 HFE was about 6 percent lower than the peak of the 1996 test but identical to the November 2004 dam release. The 2008 HFE was much shorter than the 1996 experiment but was the same duration as the 2004 HFE (fig. 3). Hazel and others (2010) report on sandbar response measured during all three HFEs.

The purpose of this report is to describe changes in sandbar morphology caused by the 2008 HFE and subsequent operations, to describe how those changes affected backwater habitats, and to provide some general information about the presence or absence of native and nonnative fish found in backwaters following the 2008 experiment.

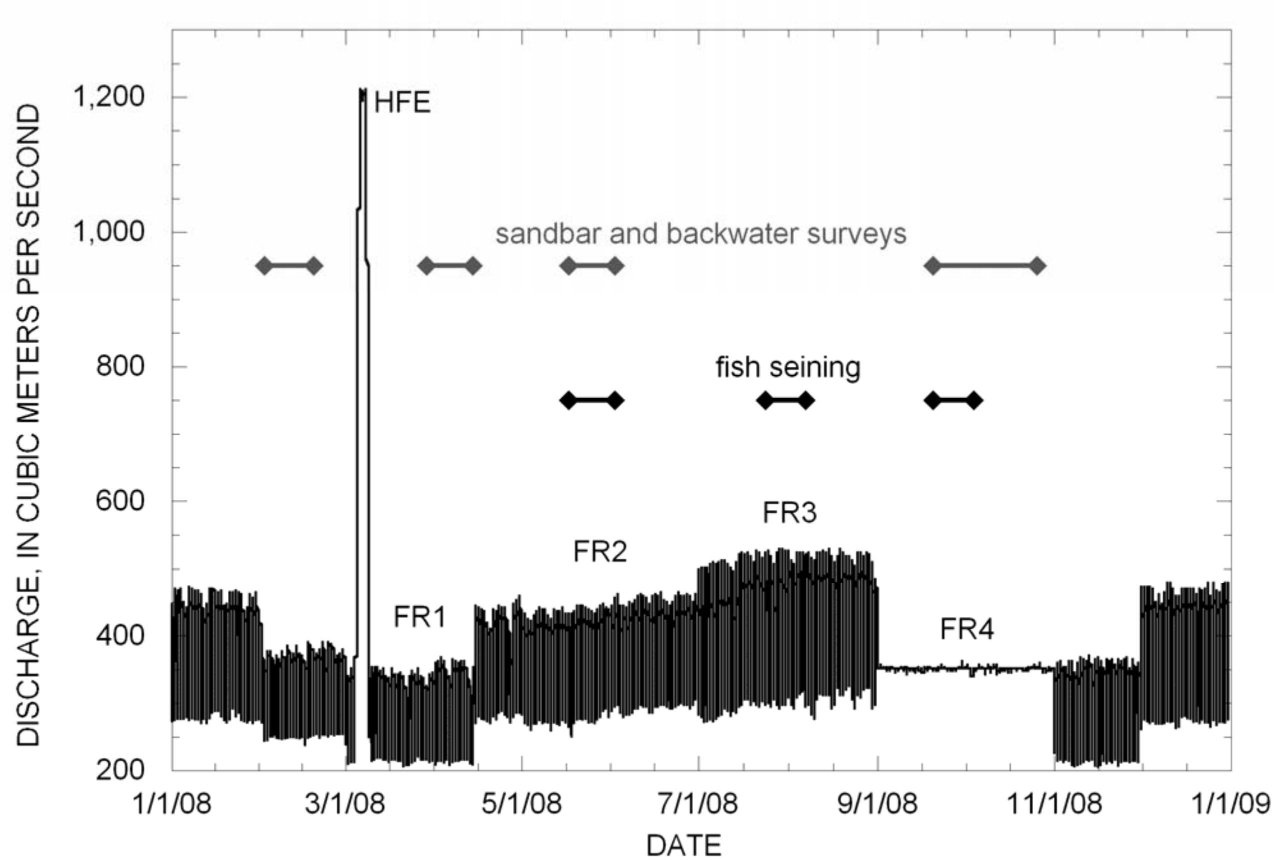


Figure 3. Discharge for the Colorado River at Lees Ferry, Arizona (USGS Station 09380000), for calendar year 2008. The March 4–8, 2008 HFE is shown in addition to the times of the four survey trips and the three fish-seining trips. Also shown are the time durations of four distinct flow regimes (FR1, FR2, FR3, and FR4) that occurred in the period following the HFE through October 2008.

Methods

Description of Approach

As described above, backwater habitats are dynamic features whose size depends on topographic characteristics of the reattachment bar (or other bars that block circulation into an embayment) and river stage, which determines the proportion of the embayment where stagnant flow occurs. Thus, a multimonth, or multiyear, backwater monitoring program requires resurvey of the topographic characteristics of the bar platform and return channel and must account for differences in river stage at the time of surveys. Additionally, the influence of steady or varying river stage on backwater distribution requires determination of backwater size and frequency at a range of discharges. Evaluation of how the habitat varies across a range of flows for a given eddy and associated sandbar morphology requires describing the eddy-bar topography and determining the local stage-discharge relation so that site-specific topographic models that account for the size of backwaters can be constructed and analyzed. This approach allows the development of discharge-dependent relations for backwater size and abundance similar to the method proposed by Goeking and others (2003). The large site-to-site variability in eddy, sandbar, and backwater characteristics led us to collect data for a relatively large sample of the population of sites where backwaters are expected to occur in Grand Canyon National Park.

Selection of Study Sites

Our first step in determining the number and distribution of sample sites was to assess the size and characteristics of the population of all backwaters in Marble and Grand Canyons (fig. 1). Although sandbars in Grand Canyon National Park have been the subject of ongoing research and monitoring (Wright and others, 2005; Hazel and others, 2006b) and the potential importance of backwater habitats has been recognized (Valdez and others, 2001), before this study there did not exist a comprehensive and field-verified catalog of locations where backwaters have historically occurred.

Three datasets were considered with which to evaluate the population of all backwaters and with which to devise a sampling strategy. This effort was necessary because previous studies of sandbar response (Hazel and others, 1999; Schmidt and others, 1999) and backwater dynamics (Goeking and others, 2003) demonstrated large site-to-site variability and because preliminary data indicated the likely existence of hundreds of potential backwater locations. First, detailed topographic information was collected at 46 sites by Hazel and others (2010) for the purpose of measuring sandbar response to the 2008 HFE. Because backwaters have the potential to form at each of these sites, they were analyzed in our study as well. These sites are referred to herein as the sandbar monitoring sites (SBM). The second set of data describing backwaters were fish-seining efforts between 2003 and 2007. During this period, one river trip was conducted each year in late summer for the purpose of seining backwaters to determine the presence or absence of fish. On these trips, each backwater present at the time of visitation was seined. The location, number of fish caught, and species of fish caught were recorded. The records from these five trips provide an estimate of the number and locations of backwaters present for this period. These data did not distinguish the geomorphic conditions that gave rise to each backwater. In addition, only backwaters present at those specific river stages at the time of visitation were sampled, and no discharge-dependent descriptions of backwaters are available for that sample group. The third set of data that identifies potential backwater locations represented an attempt to estimate the population of all backwaters. This characterization was provided by automated inspection of the shoreline visible on digital aerial photographs collected in May 2002 and May 2005, at an approximately steady flow of 227 m^3/s (T.M. Gushue, U.S. Geological Survey, and M.J. Breedlove, Utah State University, unpub. data, 2009). The data resulting from the image analysis provide, for two points in time and two river stages, an additional estimate of potential backwater locations. Thus, discharge-dependent relationships could not be estimated from these data.

To develop a sampling strategy made on the basis of backwater population characteristics, the latter two datasets were merged and coregistered in a geographic information system (GIS) such that for each potential backwater location the presence or absence of a backwater was recorded on each of the 2003-2007 seining trips and for each of the two image sets analyzed. This resulted in a list of 687 potential backwater locations. These data were visually inspected in a GIS with orthorectified images from 2004 and 2005 as background, and classified according to backwater type. Our classification (table 1) is the first that we are aware of that explicitly distinguishes the geomorphic context of backwater habitats. The primary criteria used to classify the backwaters were the characteristics of the geomorphic feature separating the embayed backwater from the main channel. Sand-bounded backwaters were defined as those where the backwater is separated from the main channel by the reattachment bar platform, parts of emergent separation bars, or by any other sand deposit. As described in the introduction, the majority of sand-bounded backwaters occur near reattachment bars (table 1). There are also backwaters that are not bounded from the main channel by sand, but are formed by irregularities in bedrock or talus along the bank and, in some cases, gravel bars. This inventory includes backwaters in all reaches of the river from Lees Ferry downstream to river mile[3] (RM) 258, the approximate upper extent of Lake Mead (fig. 1).

Table 1. Geomorphic classifications of backwaters in the inventory and among study sites between Lees Ferry and river mile 258. Locations along the Colorado River in Grand Canyon are referenced by the convention of river mile, which is distance downstream from Lees Ferry, Arizona along the channel centerline.

Sand-bounded backwaters associated with eddies	Code	Number in inventory	Number of study sites
Reattachment Bar: Located downstream from debris fan, bar spit projects upstream into eddy. Backwater occurs in return channel.	rb	333	87
Bedrock-formed Reattachment Bar: Same form as reattachment bar but located in eddy formed by bedrock bank irregularity rather than debris fan.	rb-br	36	2
Reattachment Bar Extension: Zone downstream from reattachment point where backwater may occur in location other than return channel.	rb-ext	34	1
Gravel Bar Reattachment Bar: Same form as reattachment bar but located in eddy caused by a gravel bar rather than a debris fan.	rb-gb	15	2
Separation Bar: Located immediately downstream from debris fan, backwaters may form in irregularities along sand bank or as a result of sand spit projecting into eddy.	sb	70	3
Upper Pool: Zone of recirculating or low velocity flow in ponded flow upstream from debris fans; backwaters may occur when sand spit projects into eddy.	up	81	10
Subtotal of all sand-bounded backwaters in eddies		569	105
Other backwaters			
Channel Margin Sand: Sand deposits generally outside of eddies; backwater may form along shoreline bounded from main channel by river parallel bar form.	cm	173	0
Bank Irregularity: Zone of recirculating flow or low velocity flow caused by bank irregularities such as bedrock or talus; small embayments may be separated from the main channel by bedrock, talus, or gravel, but may also include small sand spits.	bank	68	0
Gravel Bar: Low-velocity or stagnant flow bounded from the main channel by a gravel bar.	gb	36	0
Small tributary mouth: Bank irregularity may result in formation of backwater.	st	34	0
Subtotal of other backwaters		311	0
Total		880	105

[3] Locations along the Colorado River in Grand Canyon are referenced by the convention of river mile, which is distance downstream from Lees Ferry, Arizona along the channel centerline.

The inventory of backwater habitats was verified in the field to confirm and expand the catalog of potential backwater locations. The locations of all backwaters in the original remotely sensed catalog were plotted on a set of maps, and these sites were inspected in the field on each survey trip, described below. An inventory was also conducted in July 2008. New backwater sites identified in the field were added to the database and revisited on subsequent trips. Because the presence of a backwater habitat is a function of water-surface elevation, or discharge, as well as topography, it is not possible to have a constant reference frame for determining backwater presence in an environment where flows fluctuate hourly within a trip and the flow regimes vary between trips. The inventory was designed to minimize the dependence of the observation on the discharge at the immediate time of observation by using four different categories for fluctuating flow conditions. These categories are (0) no backwater present for any discharge within the range of current flow fluctuations; (1) backwater present only for the lower 50 percent of the range of current flow fluctuations; (2) backwater present only for the upper 50 percent of the range of current flow fluctuations; and (3) backwater present across the full range of current flow fluctuations. For the inventory conducted during steady dam releases in September 2008, these categories were prefixed with an indication of whether a backwater was present (P) or absent (A) at the time of observation. The numerical classification used in the inventory conducted during steady flow in September indicates whether a backwater would be present (1) at flows lower than the steady discharge, (2) at flows greater than the steady discharge, or (3) at flows both lower and greater than the steady discharge.

On the basis of our assessment of the population of all backwaters in Grand Canyon estimated from the datasets described above, 62 additional study sites were selected from among the catalog of identified potential backwater locations (appendix A). These sites are referred to herein as backwater monitoring (BWM) sites. Because most sand-bounded backwaters occur near reattachment bars and because reattachment bars that project into eddies are the bar form most likely to be affected by HFE deposition and erosion, this geomorphic setting was the focus of our study. A limited sample of other bar forms were included among the study sites, however. We made an effort to locate study sites throughout Grand Canyon National Park in approximate proportion to the frequency of backwaters identified in our inventory. However, in river segments where humpback chub are known to occur in greatest abundance (table 2), more sample sites were selected than strictly in proportion to the frequency of backwaters identified in the inventory. Study sites were established throughout the river ecosystem downstream from Lees Ferry, including three sites downstream from Diamond Creek. However, because the segment downstream from Diamond Creek was not monitored on the May through October 2008 trips, the analyses of the data presented in this report are restricted to the river corridor between Lees Ferry and Diamond Creek (approximately 15 and 240 miles below Glen Canyon Dam, fig. 1).

Table 2. Humpback chub aggregation areas (Valdez and Ryel, 1995)

Aggregation Site	from RM	to RM
1. 30-mile	29.8	31.3
2. LCR inflow	57.0	65.4
3. Lava to Hance	65.7	76.3
4. Bright Angel Creek inflow	83.8	92.2
5. Shinumo Creek inflow	108.1	108.6
6. Stephen Aisle	114.9	120.1
7. Middle Granite Gorge	126.1	129.0
8. Havasu Creek inflow	155.8	156.7
9. Pumpkin Spring	212.5	213.2

Sandbar Surveys

Field Data Collection and Processing

The purpose of the field surveys for both the SBM and BWM sample sites was to collect topographic data that would enable construction of a three-dimensional computer topographic surface model of each sandbar and predict the existence and size of backwaters, when present, for a range of discharges associated with dam operations. Thus, we sought to define continuous functions wherein backwater area is a function of river discharge. Development of these discharge-dependent functions required collection of precise and repeatable measurements of location and elevation on each sandbar, along the shoreline upstream and downstream from the sandbar, and in the adjacent eddy, including the return channel. The upper and lower elevation of the surveyed area was constrained by our focus on backwater changes between the elevations associated with stages of 227 m^3/s and 566 m^3/s, because these discharges are the typical range of Glen Canyon Dam hydropower plant operations. The upstream and downstream bounds of the survey were determined by the extent of each eddy, with the purpose that each survey covered the length of the zone of recirculating flow from upstream of the separation zone to downstream of the reattachment zone (fig. 2). These criteria were followed for all the new BWM sites established in 2008. The data collection boundary for the SBM sites (Hazel and others, 2010) encompassed these criteria and typically covered a larger area.

All sites were surveyed following protocols described in Hazel and others (2008). Each study site was surveyed using an electronic total station referenced to two geodetically referenced control points (for the BWM sites, geodetic referencing was done following the 2008 field data collection). Field technicians occupied desired topographic or other positions, and location information was stored on digital data collectors. Distinct breaks in slope were captured, and water surface elevations and high water marks were surveyed. High-water marks that were surveyed included the peak river stage reached in the preceding 24 hours, the peak flow level reached in the preceding month, and the peak flow level reached by the March 2008 HFE. Most sites were surveyed a total of four times during river trips that were conducted February 2 to 19, March 28 to April 14, May 17 to June 3, and September 20 to October 26 (appendix B). Hereafter, we refer to each data collection period as the February, April, May, and October 2008 measurements. The September to October period included two separate river trips; each site was surveyed once during this period.

Morphologic Analyses

The sandbar survey data were analyzed to compute erosion and deposition between measurements, compute the area and volume of associated backwaters at different river stages, and determine spatial patterns of erosion and deposition. These analyses required the following sequence of processing steps for each measurement site: (1) processing of the raw survey data to create surface models, (2) translation and rotation of raw survey data and surface models from local coordinates to Arizona State plane coordinates (this step was not necessary for the SBM sites, where data were collected in State plane coordinates), (3) construction of relations between water stage and discharge, (4) delineation of backwaters and computation of backwater area and volume for a suite of discharges for each survey, (5) computation of sandbar erosion and deposition between surveys, and (6) creation of maps showing spatial patterns of erosion and deposition.

Following each data-collection trip, the raw survey data were imported into survey software (Sokkia Mapping Software for the SBM sites and Eagle Point for the BWM sites). The data were inspected for errors and edited. The points and break lines were then used to construct a triangular irregular network (TIN) surface model. For the SBM sites, which were collected in State plane coordinates, the surface model was then exported as a grid of points with 1.0-m spacing. These grids were imported into GIS software (ArcMap 9.2), where digital elevation models (DEMs) with 1.0-m grid spacing and TIN surfaces were created. The BWM sites required translation and rotation, which were accomplished by exporting the surface models and raw data from Eagle Point as AutoCad drawing files, which were then imported into Trimble Geomatics Office, where the coordinate transformation was performed. Terramodel was then used to export from the AutoCad data files 1.0-m resolution grids, which were imported into the GIS software as described above.

For each sandbar survey, backwater area was determined for five discrete discharges chosen to encompass the range of most common dam operations. This required that a relation between discharge and water stage be developed for each site. For the SBM sites, which have been surveyed multiple times over the past several years, stage and discharge relations were already available (Hazel and others, 2006a). For the BWM sites, stage-discharge relations were constructed using the data collected during this study. For each site surveyed, water surface elevations and high-water marks were plotted as functions of discharge. The discharge for the time of survey and the surveyed high-water indicators was determined by routing flow downstream from the nearest upstream stream-gaging station using an unsteady one-dimensional streamflow model (Wiele and Griffin, 1997). A second-order polynomial fit was applied to the data for each site using least-squares regression (appendix C).

The sandbar topography and the stage-discharge relations were used to determine whether backwater habitat existed across a range of discharges and to compute the backwater area and volume when backwaters were present. The topographic contour lines corresponding to discharges of 227, 283, 340, 453, and 566 m^3/s were determined from the triangular integrated network (TIN) surface. If a backwater was present within the survey area boundary, then the area of the backwater was outlined as a polygon feature defined by the corresponding contour line and an additional backwater “closure” line (fig. 2). The intent of the backwater closure line is to separate the region of stagnant flow in the backwater from the higher velocity current in the adjacent eddy. Although it was not possible to observe flow conditions across the range of discharges for each survey, observations were made at each site at the time of survey. These observations included a field description of the sandbar, the backwater (if present), and the closure line that would separate the backwater from the eddy on the basis of flow-velocity criteria. These observations were used during analysis to guide the delineation of backwater area. This polygon provides the measurement of backwater area. The volumetric difference between the polygon of backwater area and the underlying sandbar surface provides the measurement of backwater volume. The volume thus measured is the volume of water required to fill the backwater for the specified discharge. Backwaters with an area less than 2 m^2 were excluded from the analysis. Several study sites were observed to have backwaters at multiple locations. Where this occurred, each backwater location was delineated and tracked separately through the data analysis. Thus, the number of backwater locations exceeds the number of study sites.

To evaluate changes in backwater area and volume in the context of changes in sandbar volume and morphology, maps showing erosion and deposition between successive surveys were constructed and volumes of sandbar change were computed. The erosion and deposition, or “difference” maps were constructed by calculating the difference between successive surveys in a raster environment. Areas and volumes of erosion and deposition were calculated only for the region of overlap common to all four surveys.

Remote Cameras

Remotely deployed cameras were used to document daily changes in sandbar and backwater morphology that occurred between field surveys. Twelve of the sites were monitored with digital cameras that were programmed to take five photographs daily at approximately 8 a.m., 10 a.m., 12 p.m., 2 p.m., and 4 p.m. These cameras captured photographs daily from the date of installation through the study period (appendix B). An additional 19 sites were monitored by analog film cameras that took photographs once daily for variable periods of time determined by the number of exposures available per roll of film and the time interval between site visits when exposed films could be recovered and changed (appendix B).

Fish Sampling of Backwater Habitats

Sampling backwaters for fish was accomplished by two approaches, full sampling and supplemental sampling. Full sampling was conducted with a full staff of experienced fisheries biologists that accompanied physical scientists and surveyors on monitoring trips. These trips were launched in May and September 2008, coinciding with the survey trips. The supplemental trips were conducted in April and July and were led by science professionals assisted by youth volunteers participating in the Grand Canyon Youth program. These supplemental trips visited fewer sites, but provided valuable additional information. The April trip sampled only sites downstream from Diamond Creek and occurred shortly before the full trip conducted in May 2008.

Seining was conducted with seine nets that were either 9 m or 4.5 m long by 1.2 m high with a 3-mm mesh. All backwaters that were present at the observed discharge and were larger than about 2 m^2 were sampled.

Summary statistics of the fish captures (intended only to portray presence or absence of fish at a specific time) were assembled to provide an overview of the fish community present during the months that followed the 2008 HFE, the first growing season available to fish following the experiment. Sampling was delayed until after the spring equinox so that backwaters were exposed to some solar radiation, allowing them to warm and thereby providing one of the hypothesized primary benefits to fish. The summary statistics presented in this report characterize the numbers and species captured; a more synthetic analysis has been initiated that incorporates backwater capture data from previous years as well as additional physical habitat information.

Results

Sandbar Surveys

Processes of Sandbar Morphologic Change that Affect Backwater Habitat

Changes in bar morphology that affect the size and location of the return channel and backwater habitats depend on the specific pattern of sand deposition and erosion within the eddy. The morphology of the potential backwater habitats are most directly dependent on whether there is deposition or erosion on the reattachment bar platform and whether there is scour or fill in the return channel. The frequency of each of these processes during the 2008 HFE and the period between the March 2008 HFE and October 2008, is shown in table 3, along with information about whether the habitat changes were associated with an increase, decrease, or no measurable change in backwater area and volume. The most common responses during the 2008 HFE were reattachment bar deposition and return channel scour that resulted in increases in backwater area and volume.

Additional changes in sandbar topography occurred between April and October 2008. During this period, deposition on reattachment bars continued to cause increases in backwater area, although this deposition occurred at lower elevations than deposition during the 2008 HFE. Return channel scour during summer 2008 was much less common than during the March HFE. In addition, the processes that caused increases in backwater area and volume in that period were accompanied by processes of reattachment bar erosion and return channel fill that resulted in a net decrease in backwater volume.

Table 3. Processes of observed sandbar morphologic response associated with changes in return channel volume

Process	Number of sites Feb.-Apr.	Number of sites Apr.-Oct.
Responses associated with an increase in return channel volume		
Deposition on reattachment bar[1]	44	37
Erosion in return channel	36	19
Responses associated with a decrease in return channel volume		
Erosion of reattachment bar[2]	21	37
Deposition in return channel	9	25
Responses associated with little or no change in return channel volume		
Deposition on reattachment bar[1]	18	10
Erosion in return channel	11	
Total number of sites evaluated[3]	**78**	**78**

[1] Deposition was above the elevation associated with the 340 m^3/s stage between February and April and below that stage thereafter.

[2] Erosion was below the elevation associated with the 340 m^3/s stage between February and April and above that stage thereafter.

[3] Responses are not mutually exclusive and, therefore, do not sum to equal the number of sites evaluated.

At many of the study sites, the combination of deposition on the reattachment bar and scour in the return channel during the HFE resulted in the formation of large sandbars and distinct return channels. This type of response is illustrated at RM 45 on the left, looking downstream (figs. 1, 5). In this case deposition that occurred during the 2008 HFE (S.A. Wright, U.S. Geological Survey, written commun., 2009) resulted in a large reattachment bar that extended into the eddy (fig. 4). The return channel was also scoured during the HFE and, following flow recession, a large backwater was present (fig. 4). These changes are illustrated by relations between calculated backwater size (area and volume) and discharge for each of the survey trips (fig. 6). In February, before the HFE, there was no backwater present at any discharge, which is indicated by zero values for both backwater area and volume. In April, following the HFE, a backwater was present at all discharges modeled, and both backwater area and volume were largest at flows of about 450 m^3/s. The erosion of the sandbar caused both backwater area and volume to decrease in such a pattern that the area and volume of habitat was similar across the range of discharges modeled. This is an example of a backwater for which the size of the habitat was moderately sensitive to changes in flow immediately following the HFE and insensitive to changes in flow by May. In each of the post-HFE surveys through October 2008, backwater habitat was continuously present across the range of flows considered.

A March 4, 2008, 7:56 a.m.

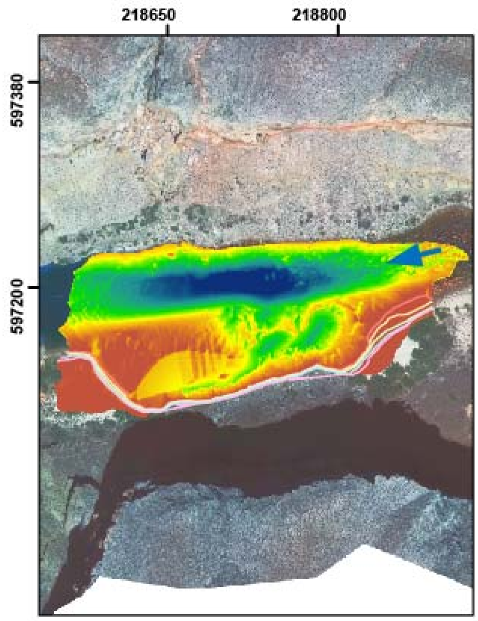
B March 11, 2008, 3:56 p.m.

C April 11, 2008, 3:56 p.m.

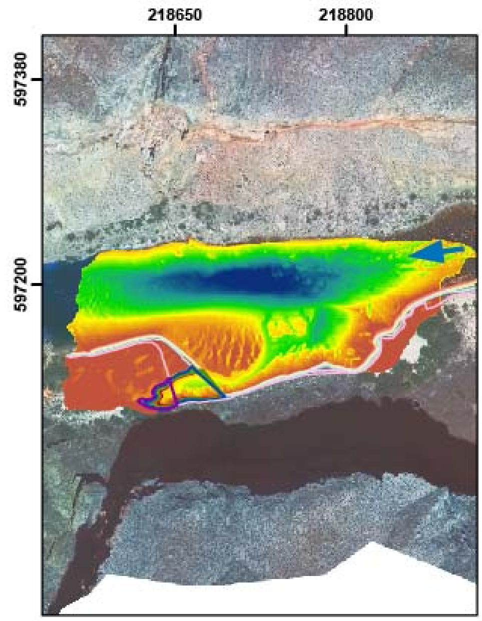
D May 11, 2008, 3:56 p.m.

Figure 4. Matching oblique views photographed by remote camera looking from the right shore across to the sandbar and backwater at RM 45 left. Flow is from left to right. *A*, The eddy before the March 2008 HFE on March 4, 2008, 7:56 a.m. *B*, The sandbar and newly created backwater on March 11, 2008, 3:56 p.m. *C*, The eddy on April 11, 2008, 3:56 p.m., showing sandbar erosion and decreasing backwater size. *D*, The eddy on May 11, 2008, 3:56 p.m. following additional sandbar erosion.

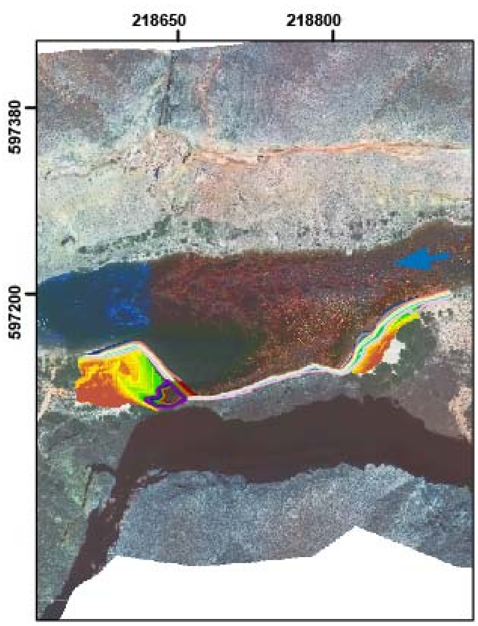
Reattachment bar deposition and return channel scour did not result in bar morphology that created backwaters at every site where those processes occurred (table 3). At 21 of the study sites, reattachment bars eroded, resulting in loss of return channel morphology and decrease in backwater area and volume. The sandbars that eroded were typically low-elevation deposits emergent at elevations associated with discharges of 340 m^3/s or lower. This type of response was evident at the RM 3 left study site, where erosion of a low-elevation reattachment bar during the HFE resulted in the elimination of most of the bar platform and the loss of the return channel morphology and backwater habitat (fig. 7). This is an example of a site where backwater habitat size was extremely sensitive to changes in discharge. Both backwater area and volume were highest at relatively low discharges and nonexistent at relatively high discharges before the HFE (fig. 8). Between discharges of about 350 m^3/s and 450 m^3/s, the reattachment bar would be inundated and backwater habitat would no longer be present. At this upstream study site, a low-discharge backwater habitat returned in October 2008, when a new low-elevation reattachment bar was present (fig. 8).



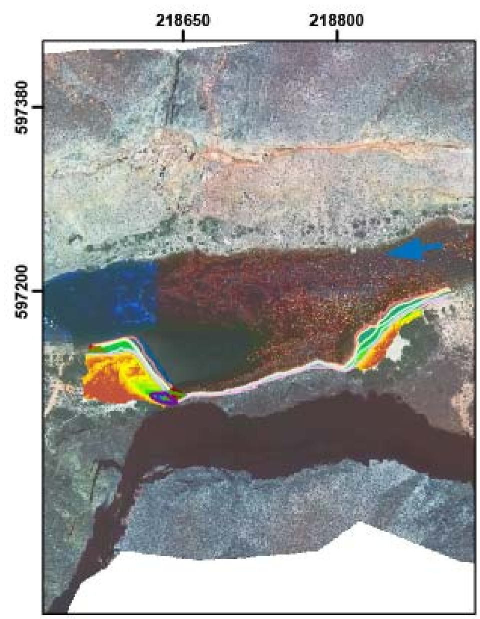
A DEM of surface elevation, Feb. 2008.



B DEM of surface elevation, Apr. 2008.



C DEM of surface elevation, May 2008.



D DEM of surface elevation, Oct. 2008.

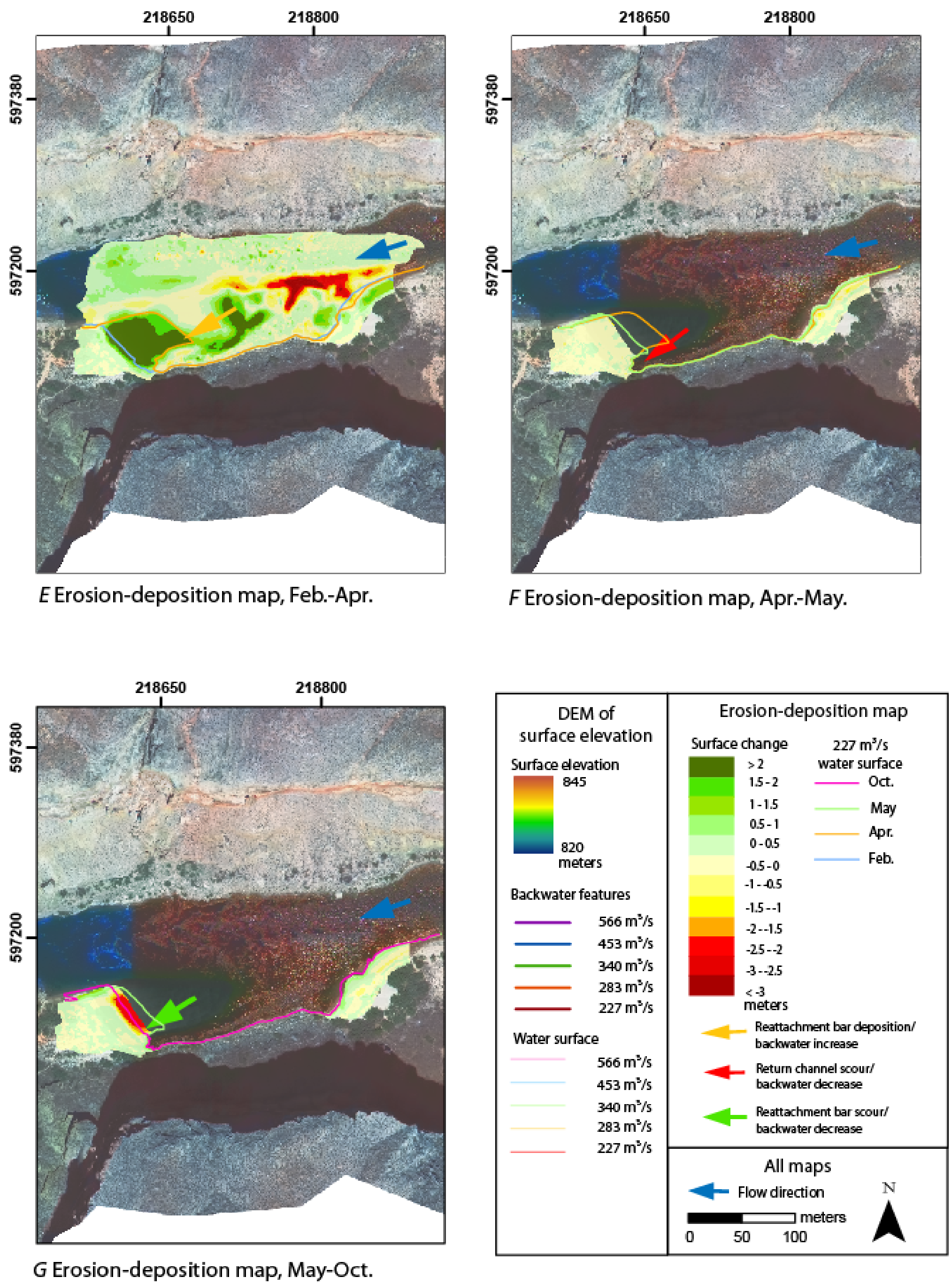
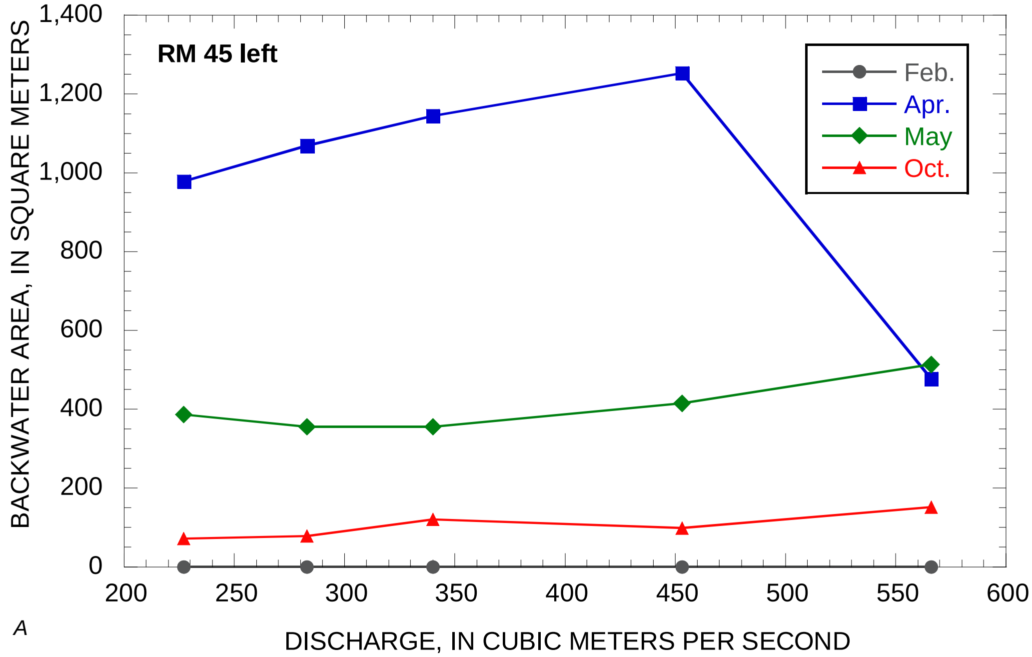


Figure 5. Maps of study site RM 45 left showing 1-m resolution DEMs derived from topographic and bathymetric mapping occurring from February to October 2008. Arrows indicate locations where erosional or depositional processes resulted in changes to the backwater. *A*, DEM of surface elevations in February 2008. *B*, DEM of surface elevations in April 2008. *C*, DEM of surface elevations in May 2008. *D*, DEM of surface elevations in October 2008. Dates of survey and discharge at time of measurement are listed in appendix B. *E*, Erosion-deposition map, calculated as the difference between DEMs comparing the February and April surveys. *F*, Erosion-deposition map comparing the April and May surveys. *G*, Erosion-deposition map comparing the May and October surveys.



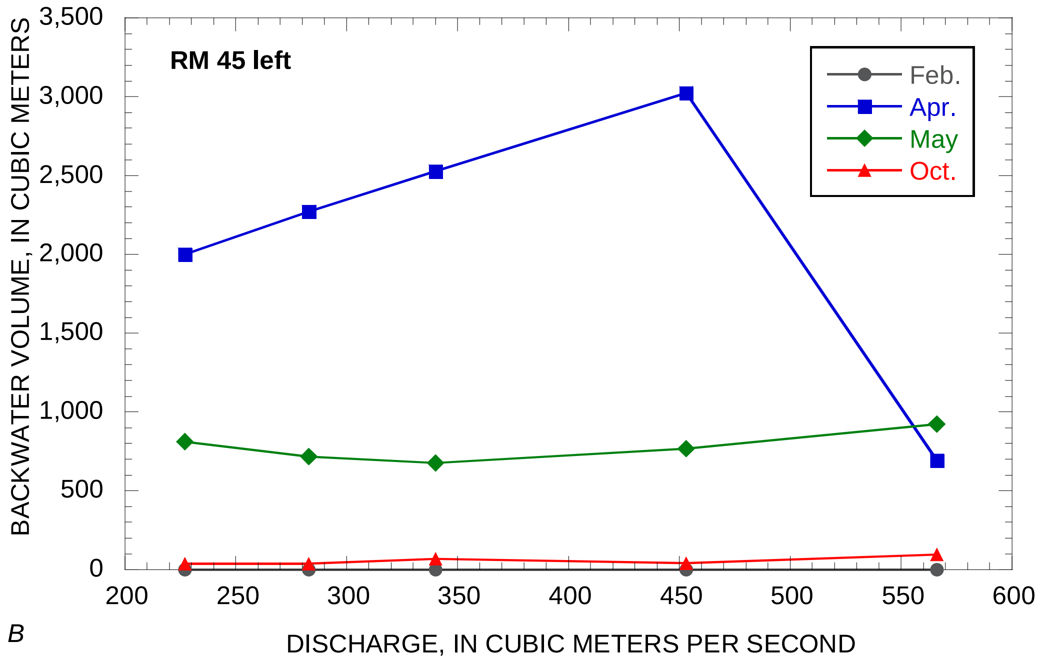


Figure 6. Relations between backwater size and discharge for RM 45 left during 2008. *A*, Measured backwater area plotted as a function of discharge. *B*, Measured backwater volume plotted as a function of discharge.

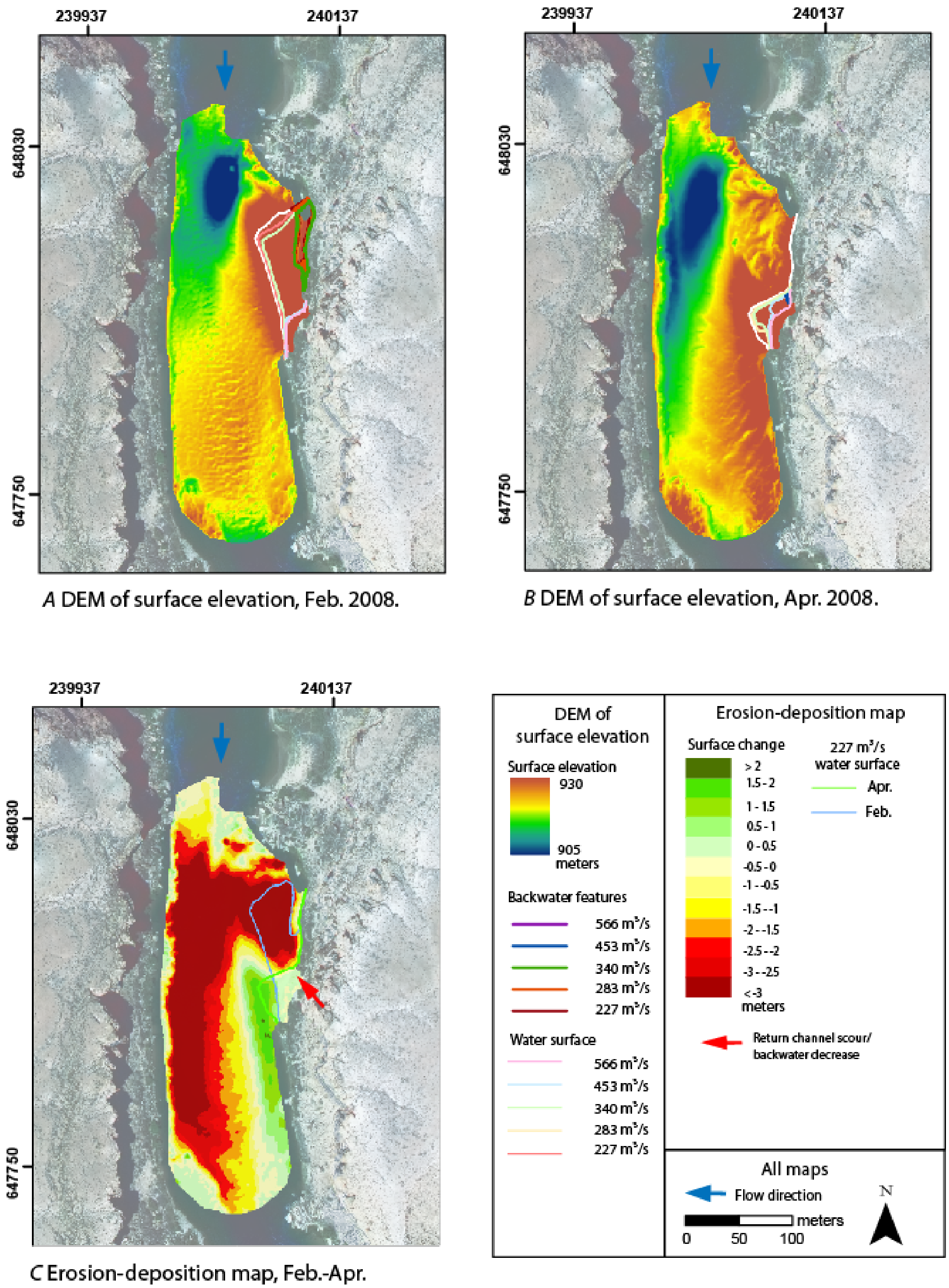
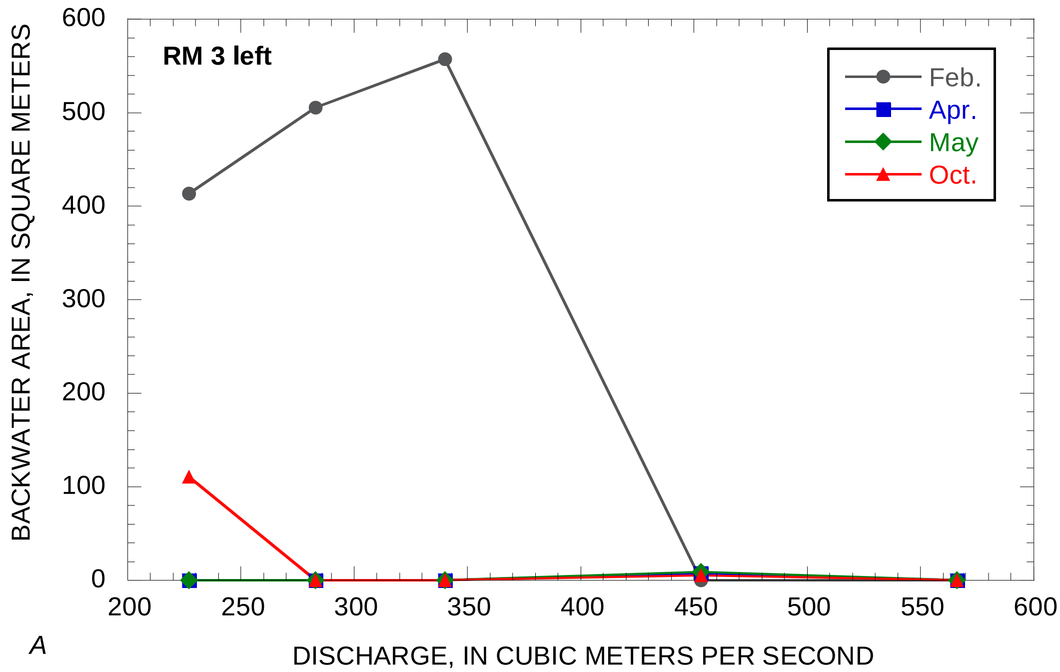


Figure 7. Maps of study site RM 3 left showing 1-m resolution DEMs derived from topographic and bathymetric mapping between February and April, 2008. Arrows indicate locations where erosional processes resulted in changes to the backwater. *A*, DEM of surface elevations in February 2008. *B*, DEM of surface elevations in April 2008. Dates of survey and discharge at time of measurement are listed in appendix B. *C*, Erosion-deposition map, calculated as the difference between DEMs comparing the two surveys.



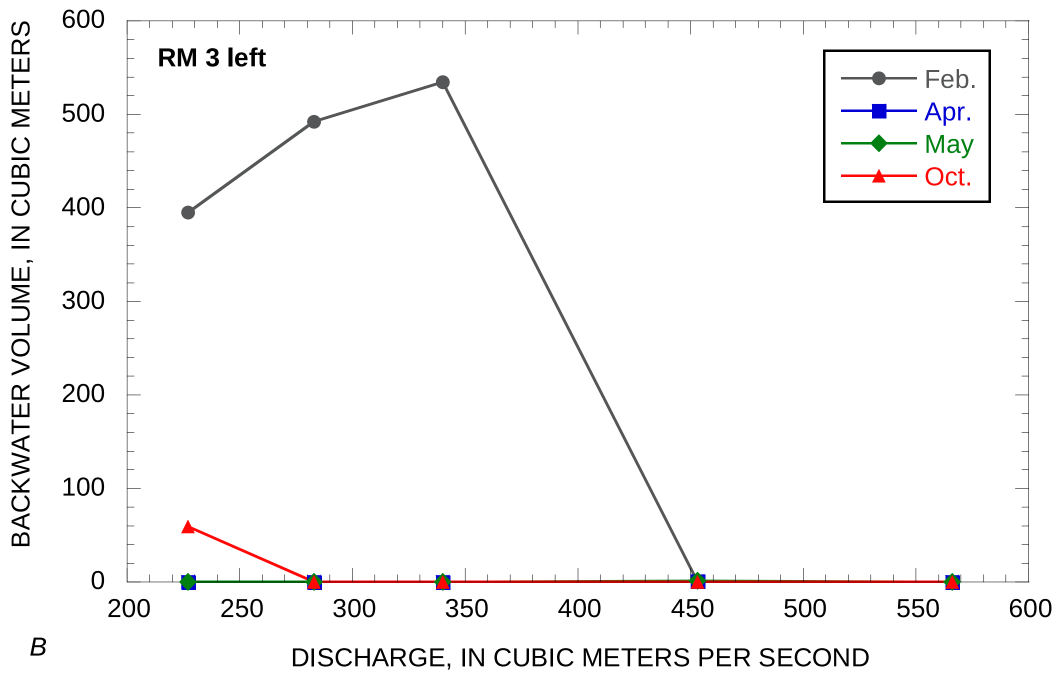
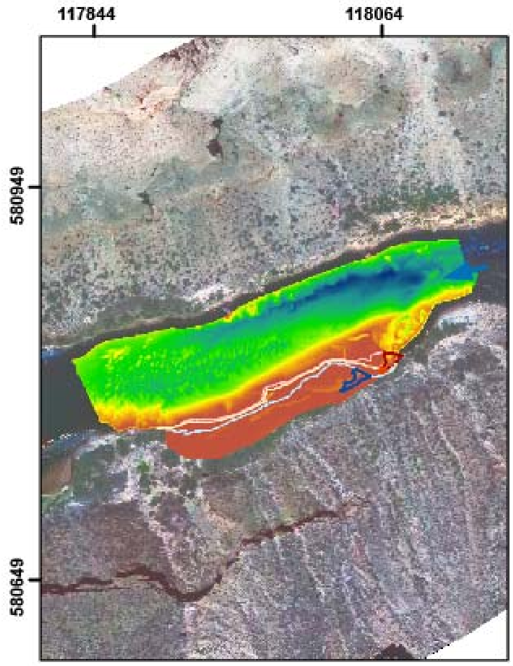


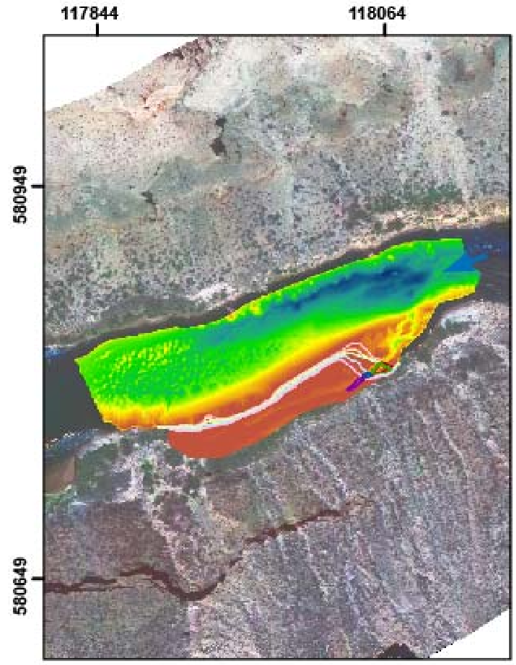
Figure 8. Relations between backwater size and discharge for RM 3 left during 2008. *A*, Measured backwater area plotted as a function of discharge. *B*, Measured backwater volume plotted as a function of discharge.

Substantial fluvial reworking of the 2008 HFE sandbars occurred in the 2 to 3 months following the return to diurnal fluctuating flow operations at the Glen Canyon Dam hydropower plant, particularly in response to higher dam releases in mid April (fig. 3) associated with a shift to wetter hydrology in the upper Colorado River Basin and requirements to equalize water storage between Lakes Powell and Mead (fig. 1); these sandbar responses are described by Hazel and others (2010). At many sites, newly rebuilt sandbars eroded, resulting in smaller return channels and reduced area and volume of backwater habitat. This response is illustrated at RM 45 left, where erosion following the HFE occurred between March and May and continued thereafter to October (fig. 5). By October 2008, the remaining backwater was small, yet still larger than the size present in February 2008, before the HFE. At other sites, backwater area decreased owing to sandbar reworking and filling of the return channel. This process occurred at RM 172 left, where reattachment bar deposition and return channel scour resulted in increases in backwater area and volume (fig. 9). Following the March HFE, between the April and October measurements, deposition in the return channel resulted in decreases in backwater area and volume (fig. 10). This also occurred at RM 65 left, where deposition near the mouth of the return channel can be seen in repeat, time-lapse photographs (fig. 11).

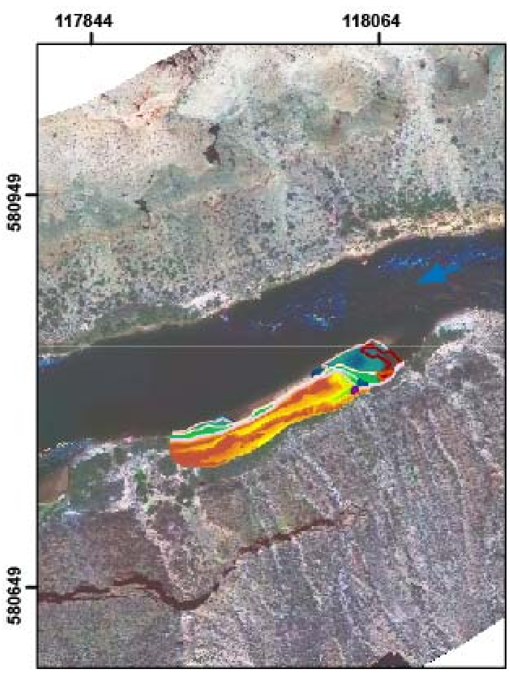
The relations between backwater area and volume for RM 172 left provide an illustration of how backwater habitat can change in response to changes in morphology that occur over time, and to changes in discharge for any given morphology. In February, there was a backwater present at low discharge and high discharge, but not at intermediate discharges (fig. 10). This often occurs when there are distinct low-elevation and high-elevation parts of the sandbar. Low-elevation habitat is first lost as discharge increases and stage rises, then new high-elevation habitat is gained as yet higher stages inundate the return channel associated with the higher part of the sandbar. Deposition during the HFE resulted in a sandbar morphology that provided backwater habitat across the full range of discharges, with greatest area and volume at low to intermediate discharges (fig. 10).



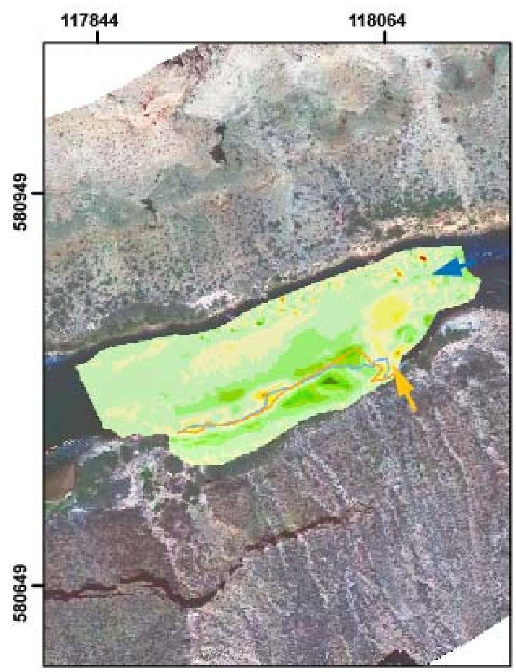
A DEM of surface elevation, Feb. 2008.



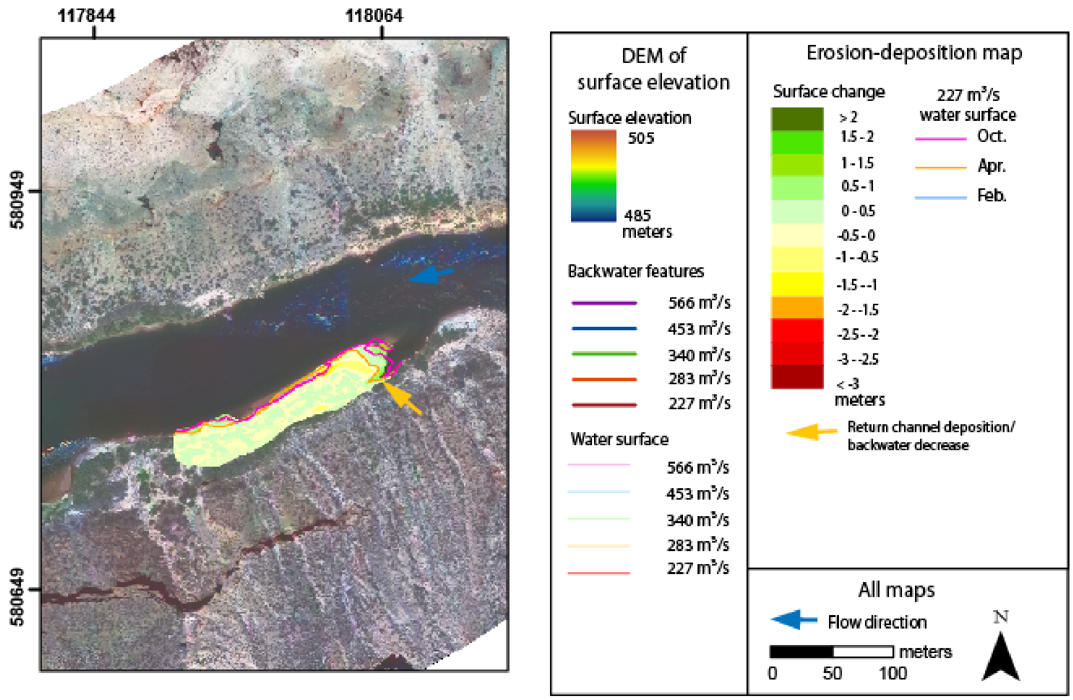
B. DEM of surface elevation, Apr. 2008.



C DEM of surface elevation, Oct. 2008.

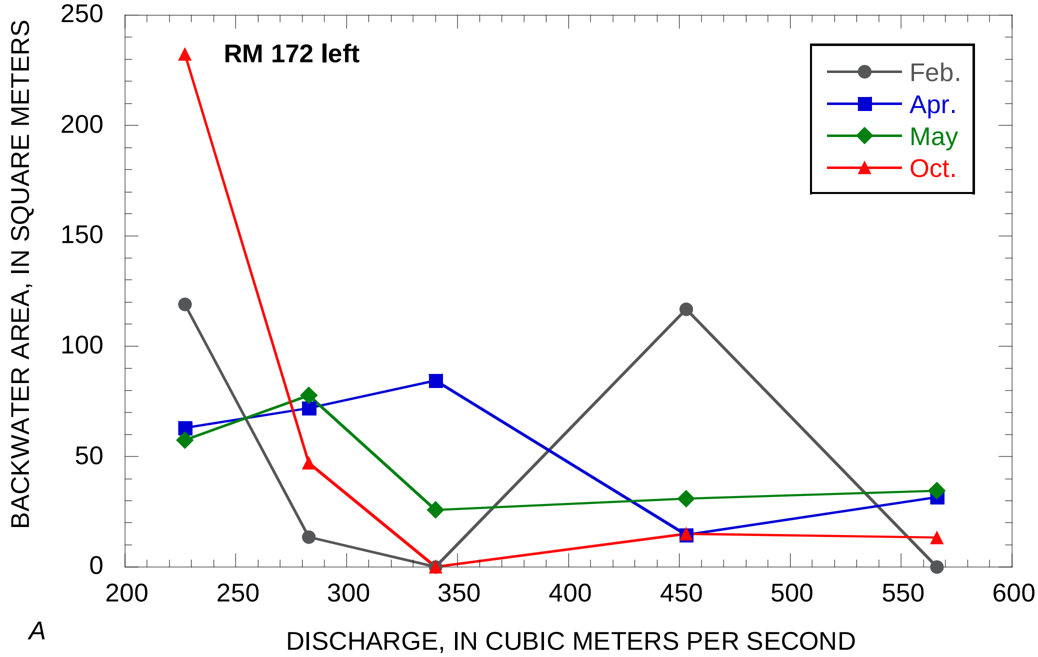


D Erosion-deposition map, Feb.-Apr.



E Erosion-deposition map, Apr.-Oct.

Figure 9. Maps of study site RM 172 left showing 1-m resolution DEMs derived from topographic and bathymetric mapping between February and April, 2008. Arrows indicate locations where depositional processes resulted in changes to the backwater. *A*, DEM of surface elevations in February 2008. *B*, DEM of surface elevations in April 2008. *C*, DEM of surface elevations in October 2008. Dates of survey and discharge at time of measurement are listed in appendix B. *D*, Erosion-deposition map, calculated as the difference between DEMs comparing the February and April surveys. *E*, Erosion-deposition map comparing the April and October surveys.



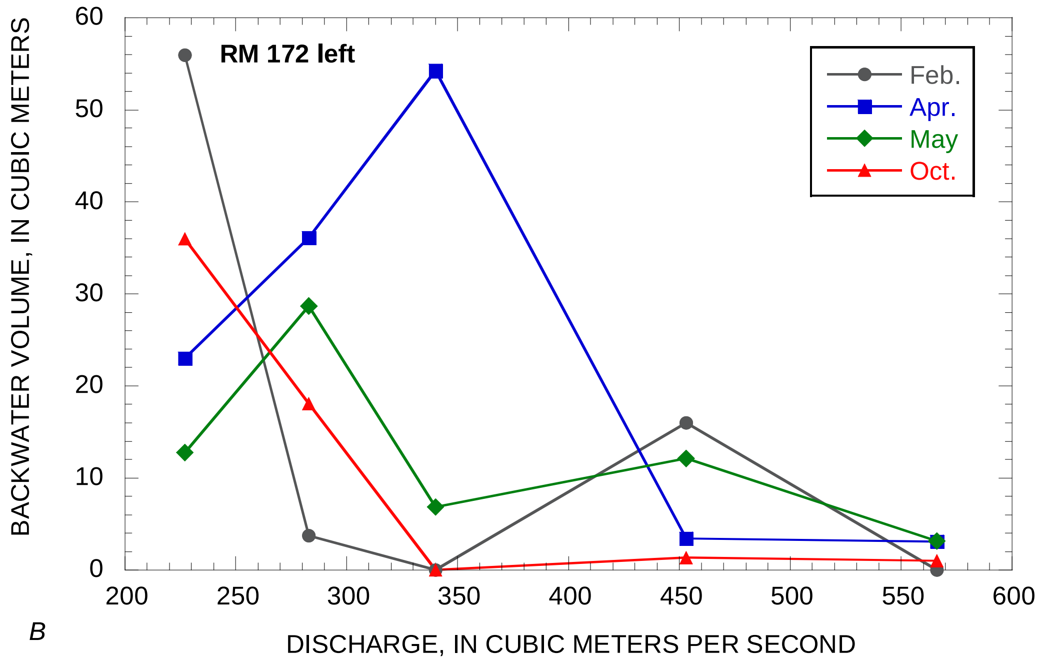


Figure 10. Relations between backwater size and discharge for RM 172 left during 2008. *A*, Measured backwater area plotted as a function of discharge. *B*, Measured backwater volume plotted as a function of discharge.

A April 13, 2008, 11:56 a.m.

B October 25, 2008, 1:44 p.m.

Figure 11. Two matching oblique views photographed by remote camera looking across the Colorado River to the RM 65 left study site. Flow is from left to right. *A*, Image taken on April 13, 2008, at 11:56 a.m. *B*, Image taken on October 25, 2008, at 1:44 p.m.

In some cases, sandbar reworking resulted in increases in backwater area and volume between April and October 2008. This typically occurred by deposition forming a new reattachment bar emergent at discharges below the range of fluctuating hydroelectric powerplant discharges, which peaked at 527 m^3/s in July 2008, during FR 3 (fig. 3). At the RM 55 right study site, the March 2008 HFE did not produce a sandbar that supported a large return channel and backwater. However, reworking and deposition between April and October did result in a new low-elevation bar and backwater (fig. 12) that was largest at flows of 227 m^3/s (fig. 13). This also occurred at the RM 65 left study site, where repeat, time-lapse photographs taken by the remote camera showed the formation of a low-elevation bar and associated backwater during the higher fluctuating flow operations during the month of August (fig. 11).

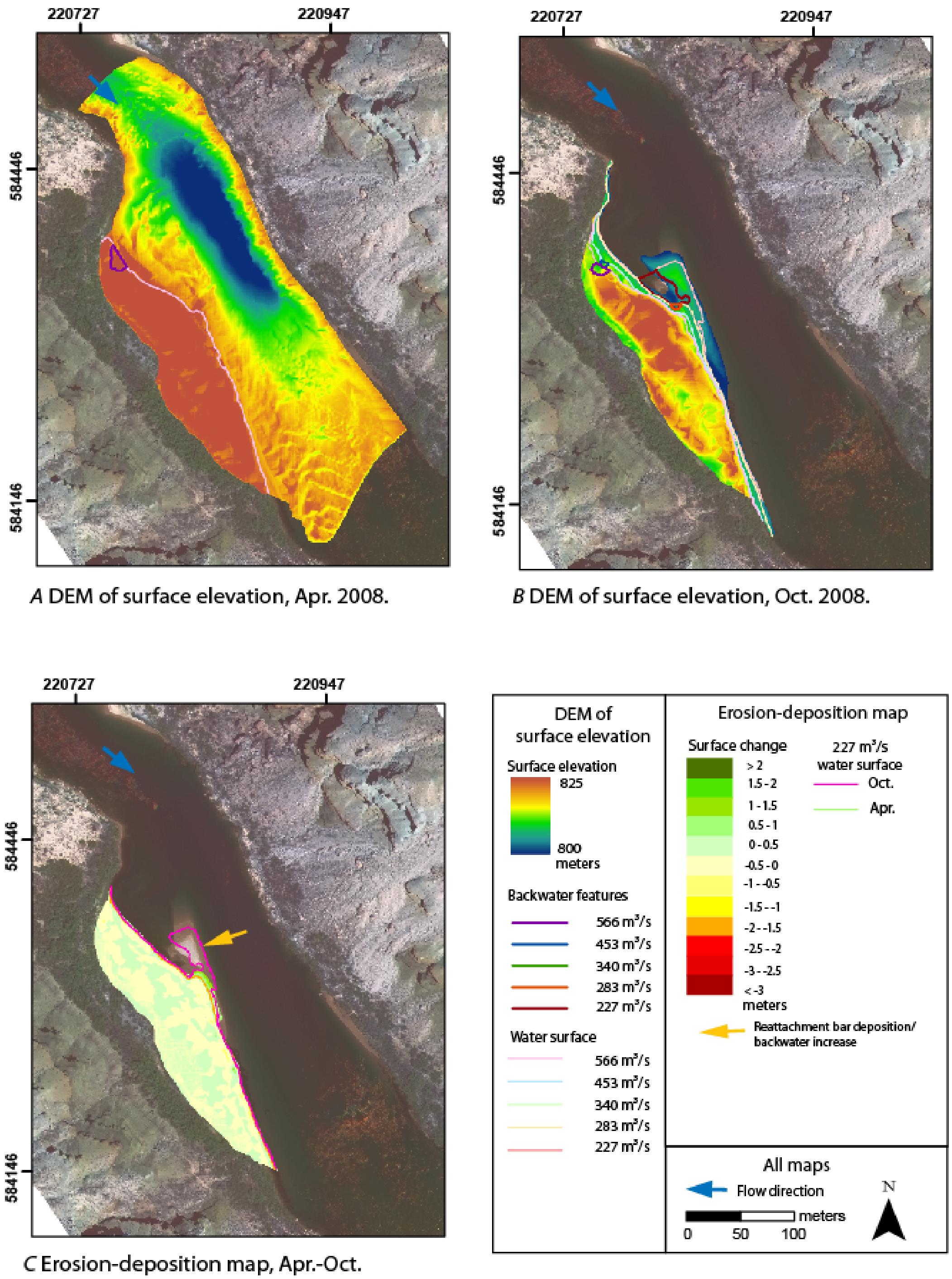
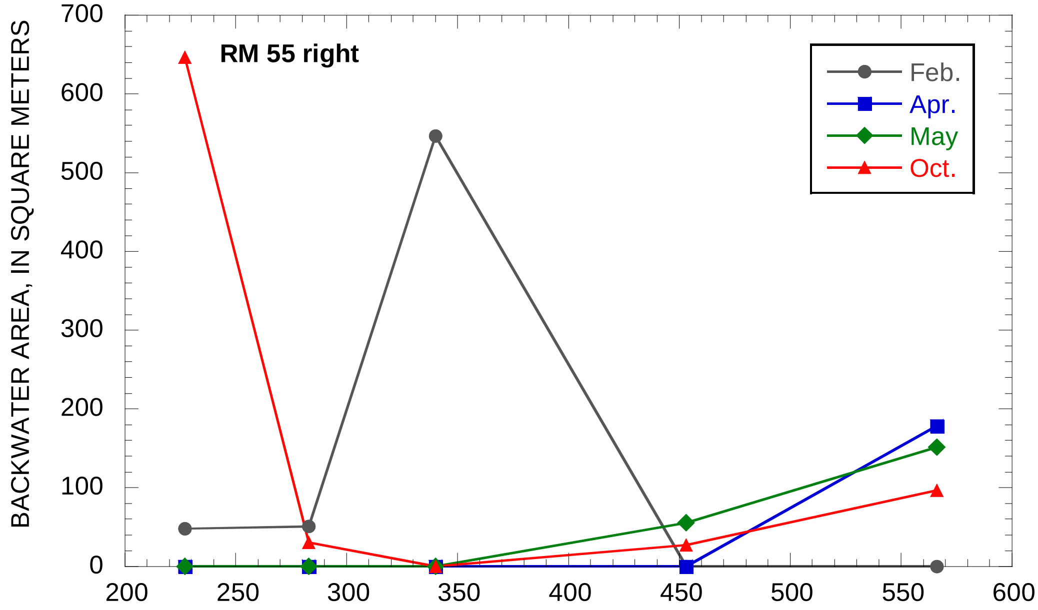
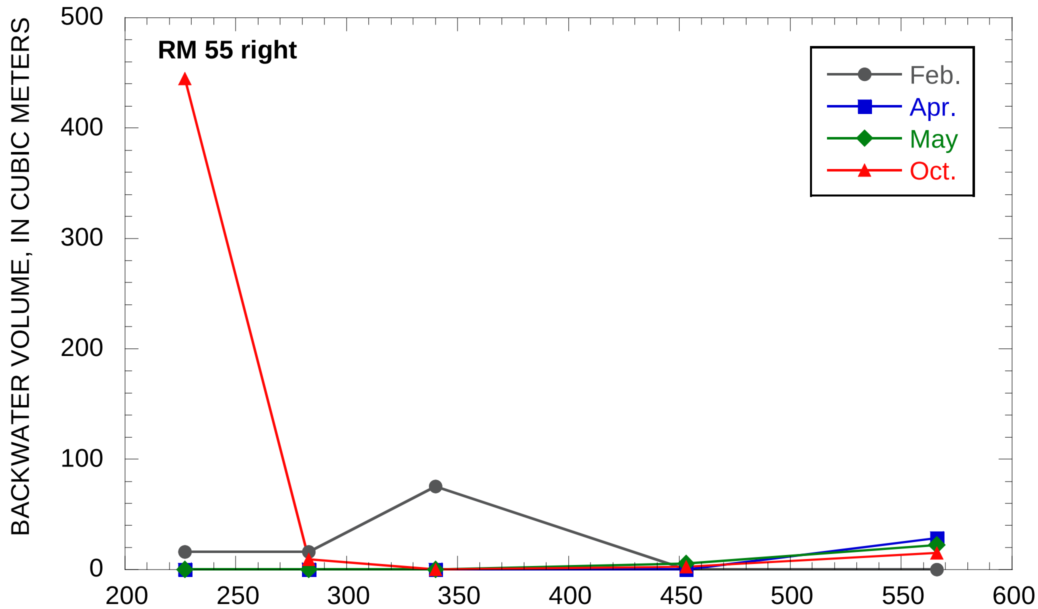


Figure 12. Maps of study site RM 55 right showing 1-m resolution DEMs derived from topographic and bathymetric mapping between February and April, 2008. Arrows indicate locations where depositional processes resulted in changes to the backwater. *A*, DEM of surface elevations in April 2008. *B*, DEM of surface elevations in October 2008. Dates of survey and discharge at time of measurement are listed in appendix B. *C*, Erosion-deposition map, calculated as the difference between DEMs comparing the two surveys.



A



B

Figure 13. Relations between backwater size and discharge for RM 55 right during 2008. *A*, Measured backwater area plotted as a function of discharge. *B*, Measured backwater volume plotted as a function of discharge.

Systemwide Changes in the Abundance and Size of Backwater Habitat

The above descriptions of responses at specific study sites illustrate the dependence of backwater habitat on sandbar morphology and flow regime. These examples also demonstrate how processes of sandbar erosion and deposition that are associated with sandbar building and subsequent dam operations result in changes to backwater habitat over relatively short time periods. Relations between habitat and flow regime were developed for a total of 135 backwater locations at 97 study sites where detailed topographic surveys were made in 2008. The wide range of backwater sizes and the large number of zero values (sites where no backwater was present at a given discharge) creates difficulty with quantification of average response. For these reasons, we begin with an analysis of the number of backwaters present among the study sites, which is not size dependent. Next, we present all of the data for backwater area and volume, which illustrate the range of backwater sizes, followed by a summary by total habitat area and volume. Finally, we present an analysis that quantifies the habitat abundance for particular diurnally fluctuating and steady flow operations associated with Glen Canyon Dam.

There were approximately 60 to 70 backwaters present, among the 135 backwater locations that were monitored, at discharges in the range of 227 m^3/s to 283 m^3/s at all surveys (fig. 14). At flows of 340 m^3/s and greater, there were more backwaters in April following the HFE than there were at other times. Thus, the reattachment bar deposition and return channel scour associated with the March HFE caused an increase in the number of backwaters present at higher flows (typically associated with summer fluctuating flow dam operations) while maintaining the number of backwaters present at lower flows (more typically associated with monthly release volumes from Glen Canyon Dam typical of spring and fall seasons in years with below-average upper Colorado River Basin hydrology). Water year 2008 was below average in terms of annual release volume from Lake Powell, but it was slightly higher than a minimum release year of 8.23 million acre feet, owing to requirements that year to equalize storage between Lakes Powell and Mead after April 1. Between April and May, there was a decrease in the number of backwaters at those same flows of 340 m^3/s and greater. By October, the pattern of the relationship between backwater abundance and discharge was very similar to the pattern that existed in February before the HFE, but with 5 to 14 percent more backwaters present in October than in February.

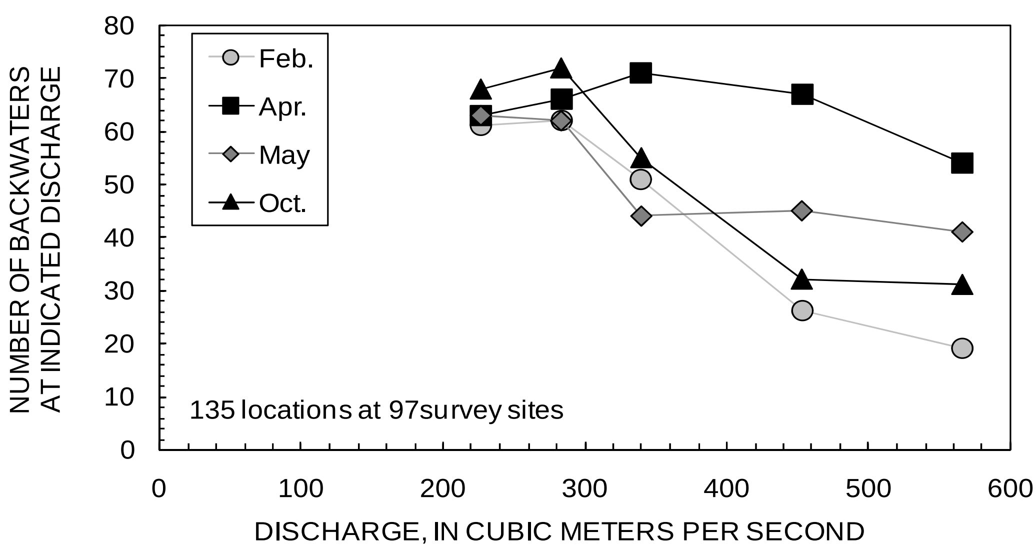
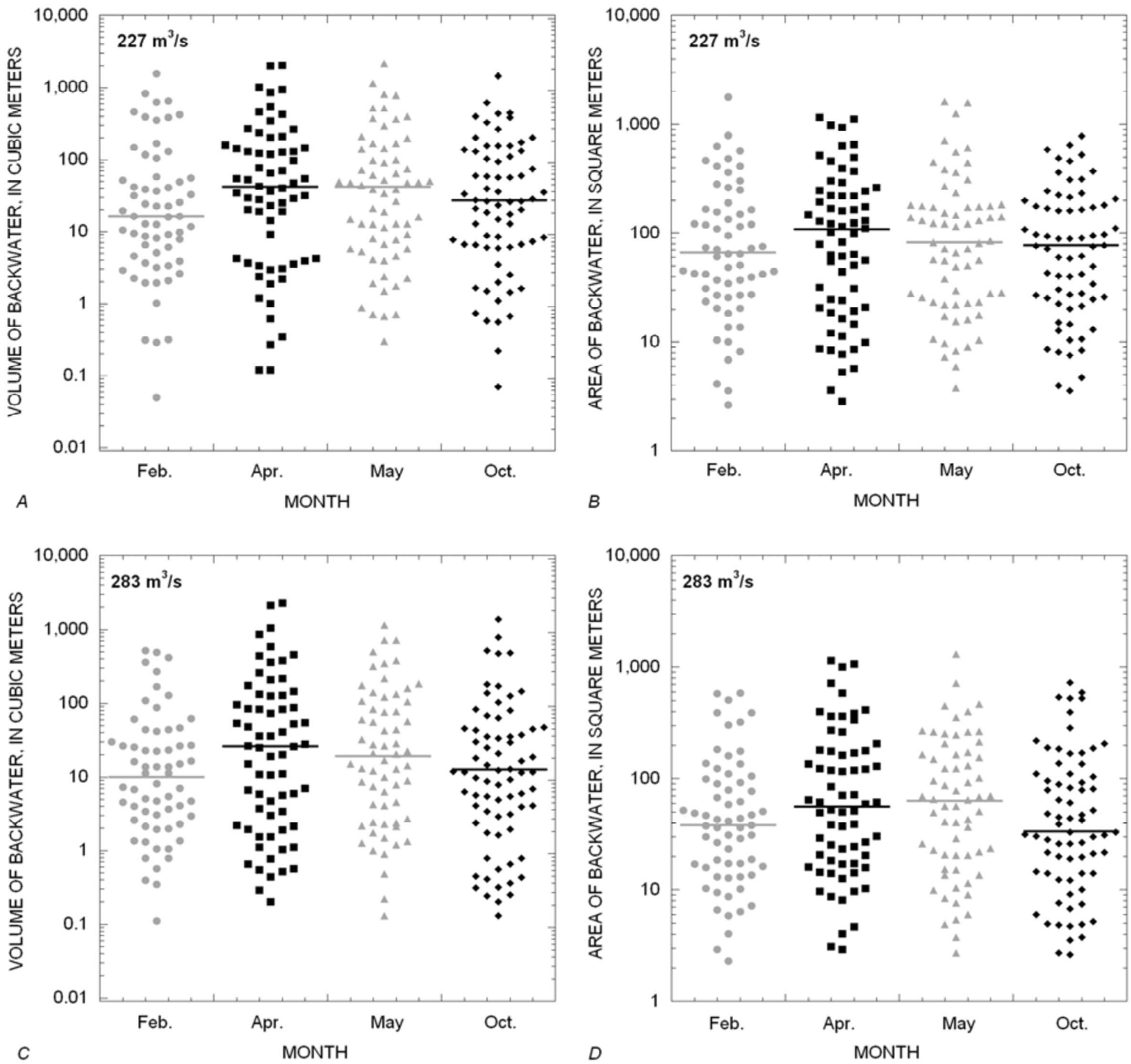
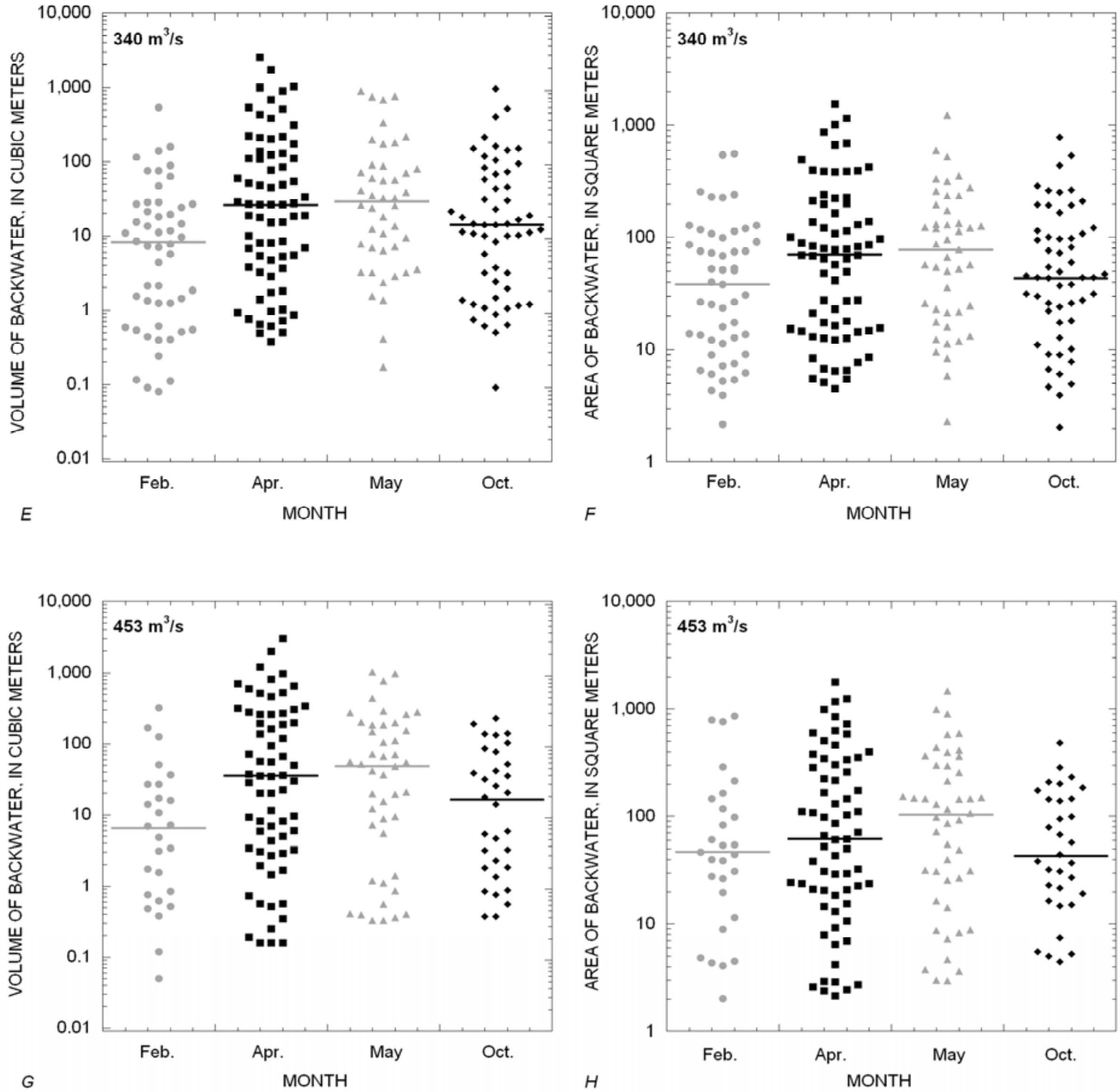


Figure 14. The number of backwaters present among the study sites for each survey period in 2008 as a function of discharge.

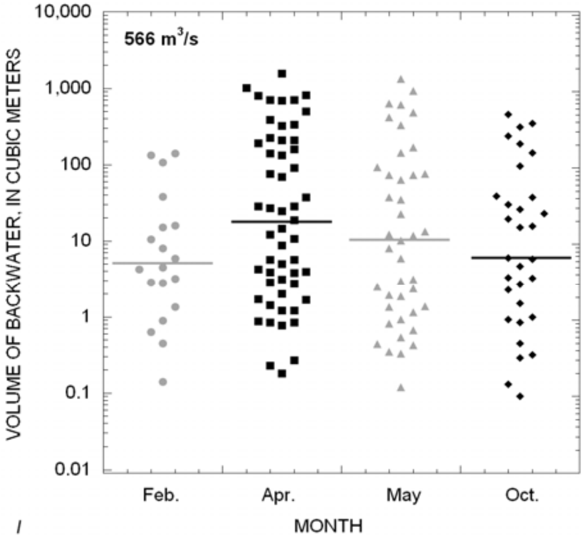
The changes in backwater area and volume from February through October are consistent with the changes in backwater abundance, but they show the extremely wide range in size of backwater habitats (fig. 15). There were backwaters as small as 2 m^2 in area (the minimum mapping size) and 0.1 m^3 in volume. The largest backwaters mapped were more than 2,000 m^2 in area and 3,000 m^3 in volume (fig. 15). Despite this wide range in size, there was a clear shift up in both area and volume between February and April, followed by downward shifts between April and May and again between May and October.

The changes in habitat size are summarized by relations between discharge and total backwater area and volume (fig. 16). These plots show the same pattern of response shown by the changes in backwater abundance (fig. 14). There were measurable increases in habitat area and volume between February and April, especially at the higher discharges, followed by decreases in habitat size in the subsequent time intervals. By October 2008, total backwater habitat area and volume were very similar to the condition prior to the 2008 HFE.





340 m³/s
VOLUME OF BACKWATER, IN CUBIC METERS
10,000
1,000
100
10
1
0.1
0.01
Feb.
Apr.
May
Oct.
E
MONTH
340 m³/s
AREA OF BACKWATER, IN SQUARE METERS
10,000
1,000
100
10
1
Feb.
Apr.
May
Oct.
F
MONTH
453 m³/s
VOLUME OF BACKWATER, IN CUBIC METERS
G
MONTH
453 m³/s
AREA OF BACKWATER, IN SQUARE METERS
H
MONTH



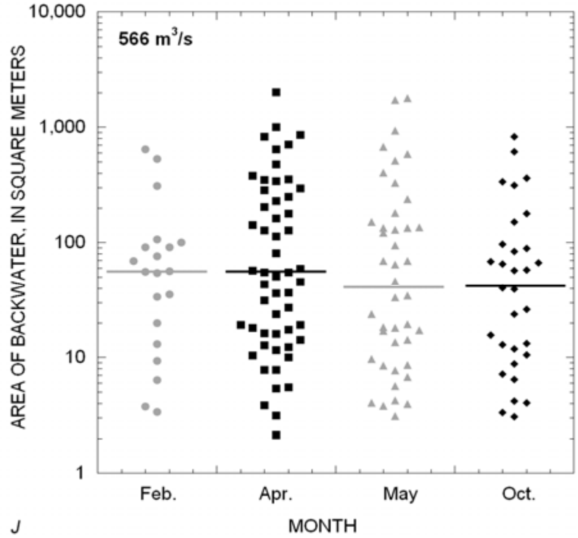


Figure 15. Plots showing calculated backwater volume and area for each of the five discharges analyzed in 2008. Horizontal lines are the median of non-zero values. *A*, Backwater volume for 227 m^3/s. *B*, Backwater area for 227 m^3/s. *C*, Backwater volume for 283 m^3/s. *D*, Backwater area for 283 m^3/s. *E*, Backwater volume for 340 m^3/s. *F*, Backwater area for 340 m^3/s. *G*, Backwater volume for 453 m^3/s. *H*, Backwater area for 453 m^3/s. *I*, Backwater volume for 566 m^3/s. *J*, Backwater area for 566 m^3/s.

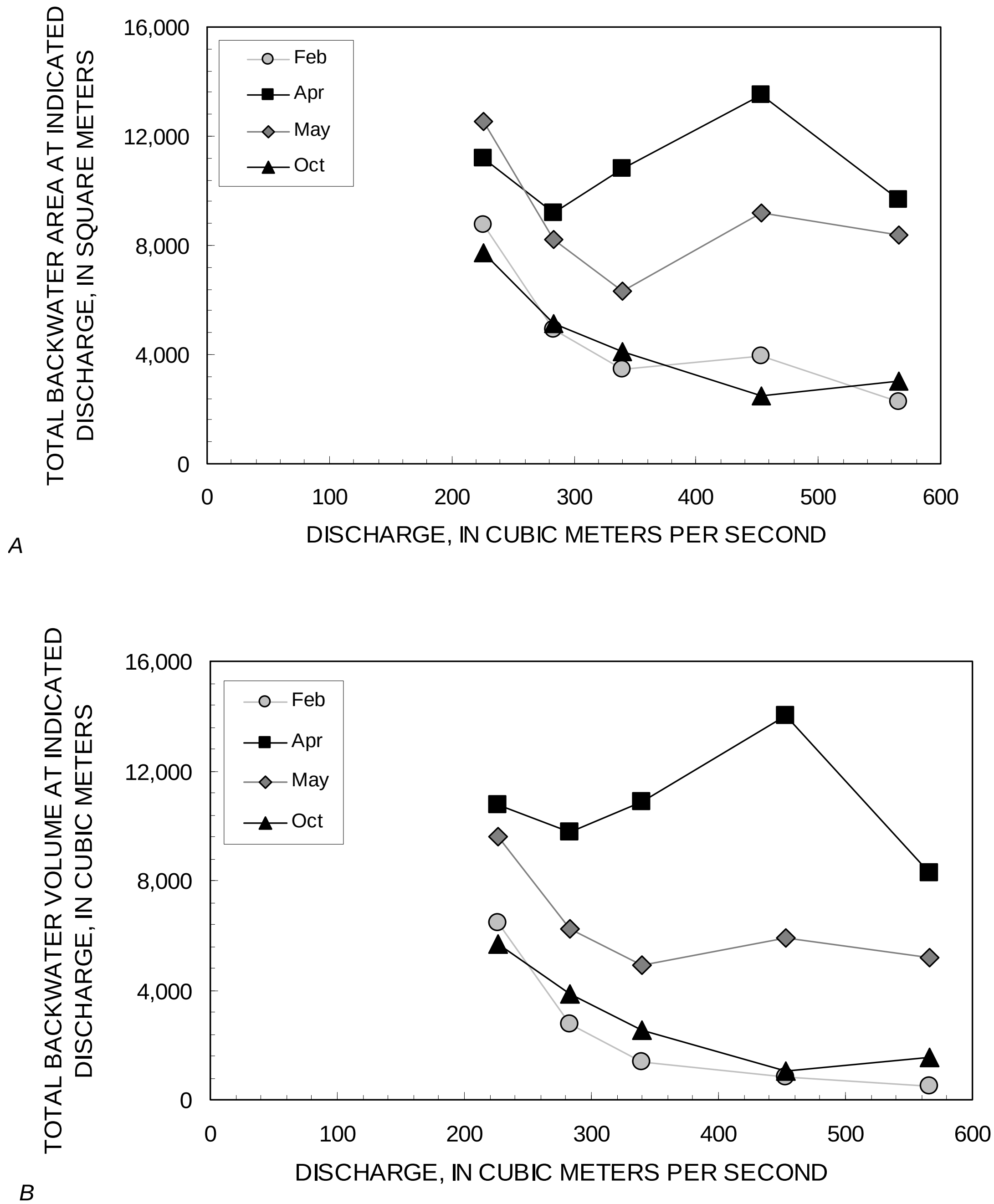


Figure 16. Plots showing total habitat area and volume for all study sites as functions of discharge in 2008. *A*, The sum of backwater area as a function of discharge for all study sites that were surveyed four times in 2008 during the study. *B*, The sum of backwater volume as a function of discharge for the same sites.

Although the data presented above summarize the gross changes in backwater habitat abundance and size, further analysis is required to evaluate the presence of habitat associated with a particular dam operating flow regime. The simple summary relationship for total habitat availability (fig. 16) hides the complexity that arises from the many different relations between backwater size and discharge (for example, figs. 6, 8, 10, and 13), which result from differences in sandbar morphology. These complexities are evaluated in the context of post-HFE flow regime by a calculation of the fraction of time each site has a backwater present for any particular diurnally fluctuating or steady dam operating flow regime. These results are presented as cumulative probability distributions (fig. 17), which show, for each of the four different flow regimes that occurred following the 2008 HFE, comparisons of backwater habitat availability for each of the four measurement periods (fig. 3).

For each of the topographic measurement periods (February, April, May, and October), the fall steady flow regime (FR 4) was associated with the highest percentage of emergent sandbars with backwaters present continuously. For the October topography, the experimental steady dam releases of approximately 351 m^3/s (FR 4) resulted in about 40 percent of the sites having backwaters present 100 percent of the time, while FR3 for the same topography would have resulted in only about 10 percent of the sites having backwaters present 100 percent of the time. However, because during a steady flow regime backwaters are either continuously present or continuously absent (that is, there are no backwaters that are intermittently present as flow rises and falls), the 2008 experimental steady flow regime was also associated with the highest percentage of sites with no backwaters present (fig. 17). For the October topography, about 60 percent of the sites had no backwater present during the steady flows, whereas for FR3 only about 35 percent of the sites had no backwater present. Thus, the fluctuating flow dam operation associated with the FR3 period would have resulted in 55 percent of the sites having intermittently present backwaters if those flows occurred in October 2008.

For the 351-m^3/s steady flow operating regime that occurred in September and October, the fraction of sites with continuously present backwaters was greatest for sandbar topography that existed in April (before the onset of higher monthly volume fluctuating operations) and least for the topography that existed in May (following the abrupt shift to higher monthly volume fluctuating operations associated with reservoir storage equalization), with February and October approximately equal. Among the fluctuating flow regimes, FR1 (fluctuations between 198 and 340 m^3/s) was associated with a greater percentage of sites having backwaters present for a greater fraction of time. This occurred in the period of springtime lower fluctuations following the HFE, but before higher diurnal fluctuating dam operations that were released starting in mid April for purposes of equalizing water storage between Lakes Powell and Mead. These data show that if the habitat requirements for juvenile native fish in the mainstem Colorado River require continuous backwater availability for enhanced growth and survival, then the steady flow regime provides more habitat availability and provides it most consistently. If, however, intermittently present backwater habitat is deemed to be adequate for promoting juvenile native fish growth and survival (meaning, enough added benefit to reduce overwinter mortality), then the fluctuating flow operation may result in approximately equal amounts of backwater habitat, depending on the accompanying upper Colorado River Basin hydrology, the annual flow regime, and sandbar morphology.

A further comparison was made to illustrate the effect of higher monthly volume fluctuating flows than occurred in 2008. Results from an analysis of habitat availability using the same 2008 sandbar-morphology data used in fig. 17, but evaluated for the relatively higher monthly volume, experimental fluctuating flows (a daily peak of 566 m^3/s, with a fluctuating range of 424 m^3/s versus the currently allowed range of 226 m^3/s) that occurred between January 3 and April 9, 2005, following the November 2004 HFE (fig 18). The relative position of each of the curves, with April providing the most abundant backwater habitat and February providing the least, is the same as shown in fig. 17*B* and *C*. All of the curves are, however, shifted upward and to the left for backwaters present about 50 percent of the time or more; and the curves are similar or shifted downward and to the right for backwaters present about 50 percent of the time or less. The above analysis indicates that higher monthly release volumes, when also associated with a wider daily allowable fluctuating flow regime (that also results in high daily peak discharges)—such as the operation tested in the winters of 2003 through 2005—tend to result in fewer backwaters that are available 50 percent of the time or more and a similar or greater number of backwaters that are present intermittently. It is important to point out that this analysis only considers the effect of the different flow regimes on given sandbar morphology (those that were measured during 2008); it does not include consideration of how the different dam operating regimes might result in different rates of sandbar erosion and therefore changing sandbar morphology.

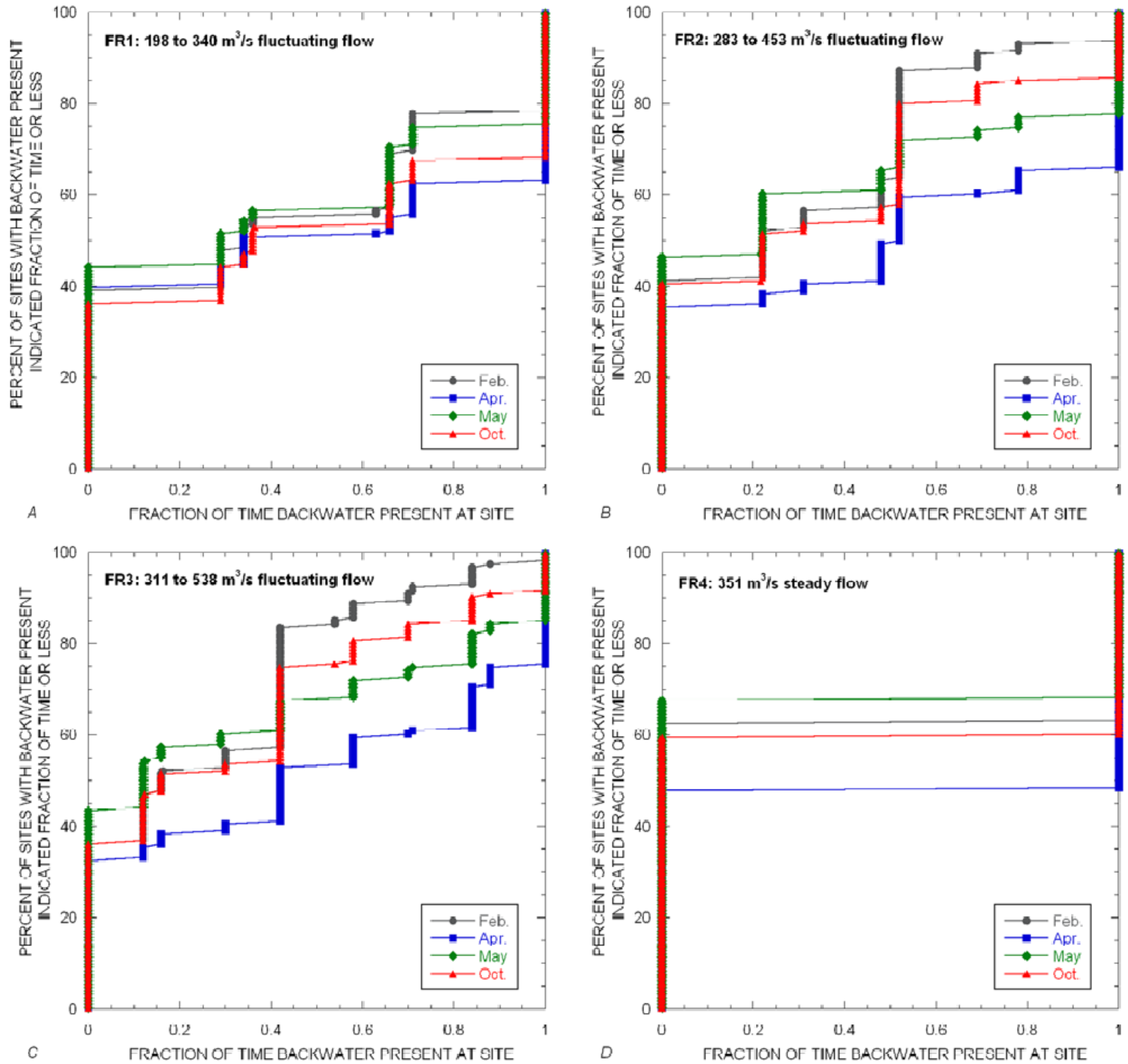


Figure 17. Cumulative frequency distributions showing the fraction of study sites as a function of the fraction of time a backwater is present for each of the four flow regimes associated with dam operations that followed the 2008 HFE (see fig. 3). *A*, Frequency distribution for each survey based on FR 1. *B*, Frequency distribution for each survey based on FR 2. *C*, Frequency distribution for each survey based on FR 3. *D*, Frequency distribution for each survey based on FR 4.

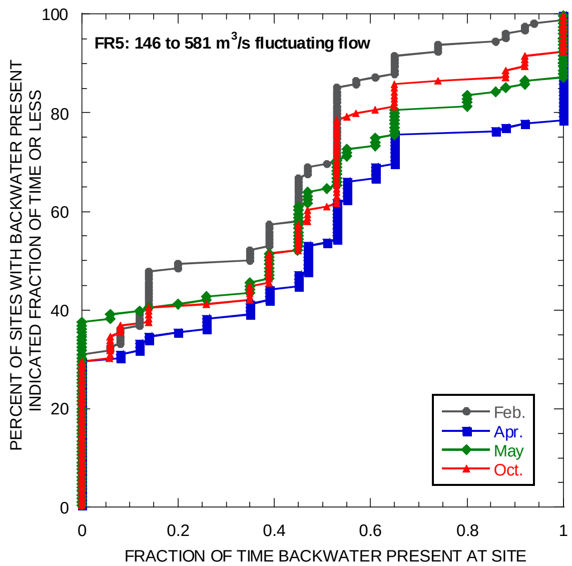


Figure 18. Cumulative frequency distributions showing the fraction of study sites as a function of the fraction of time a backwater is present for the experimental fluctuating flows that occurred from January 3 to April 9, 2005, following the November 2004 HFE.

Backwater Inventory

The inventory of sandbar-created backwaters (appendix A) indicated that backwaters were more abundant in October 2008 than in February 2008 (table 4), which is consistent with the findings made on the basis of analyses of the study sites (fig. 15). However, the inventory also indicated far fewer backwaters were present in April and May, which is not consistent with the findings made on the basis of field surveys. This results from the fact that the inventory is simply a record of all backwaters observed in the field and is, therefore, subject to the biases imposed by the flow regime during the particular trip.

Thus, discrepancies between the inventory and the results from the analysis of the survey data may result from poor water clarity during the inventory conducted in April and from the higher volume flows that occurred during the May inventory. Both of these factors limit the ability to observe the presence of backwaters at the low range of flows (< 283 m^3/s). A comparison between results from the backwater inventory and the surveyed backwaters for all of the study sites (table 5) shows that there was agreement in responses at between about 57 and 74 percent of the study sites. Where there were differences in responses between the inventory and the survey, it was usually the result of identification of a backwater in the survey data where one had not been identified in the field during the inventory. Again, the consistent underprediction of the number of backwaters by the inventory most likely results from the limitations imposed when making field observations at one particular discharge in this river ecosystem, particularly when studies are conducted during unsteady flows associated with the fluctuating flow operations at Glen Canyon Dam.

Table 4. Summary of backwater inventory results.

Observation	Feb.	Apr.	May	July	Sept.[1]
Flow regime	244–382 m^3/s	198–340 m^3/s	283–453 m^3/s	311–538 m^3/s	351 m^3/s
Water visibility	good	poor	good	good	good
			Number of study sites		
No backwater present	524	679	653	701	464
Backwater present only at low range of operations	168	26	130	144	76, 252
Backwater present only at upper range of operations	81	49	33	24	3, 38
Backwater present across range of operations	107	126	64	11	22
Subtotal of backwater present at any discharge within range of operations	356	201	227	179	391
Total number of sites visited	880	880	880	880	855

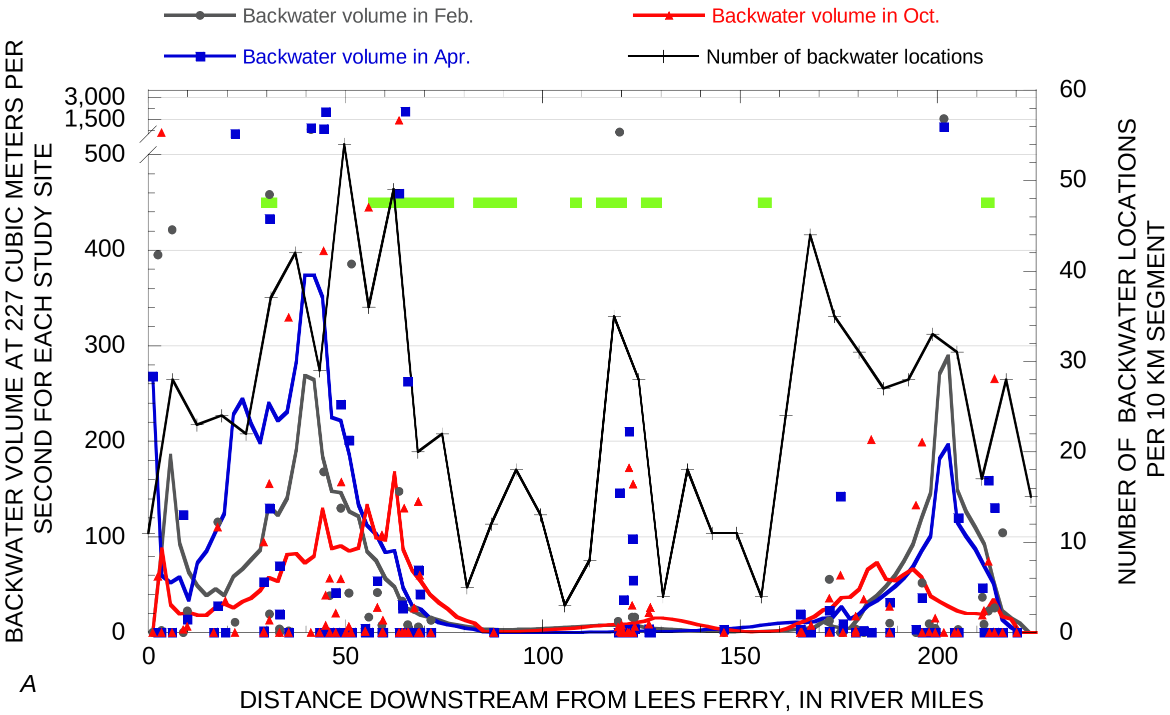
[1]Where two values are listed the first value is the number of backwaters present at the time of observations and the second value indicates the number of backwaters expected to occur at higher or lower flow.

Table 5. Comparison between backwater inventory and surveys.

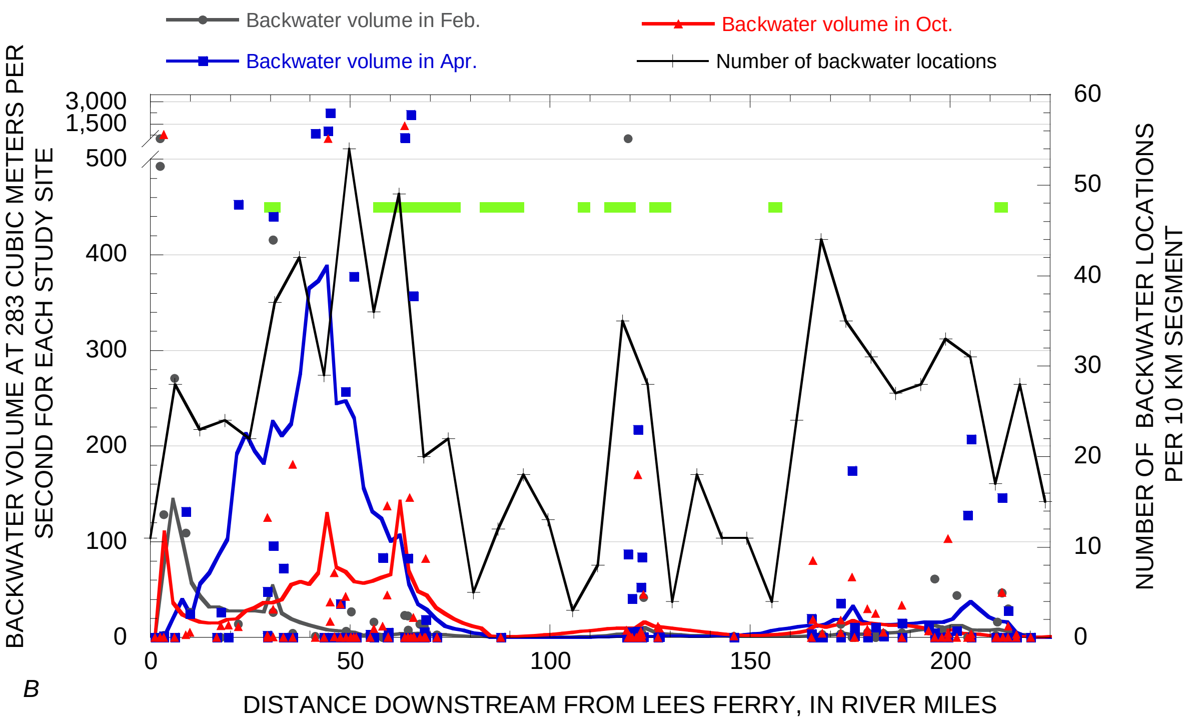
Observation	Feb.	Apr.	May	Oct.
		Number of sites		
Backwater absent in survey and inventory	16	18	12	8
Backwater present in survey and absent in inventory	21	22	27	28
Backwater absent in survey and present in inventory	3	3	4	5
Backwater present in survey and inventory	53	49	42	35
Total number of backwaters identified in survey	74	71	69	63
Total number of backwaters identified in inventory	56	52	46	40
Total number of sites compared	93	92	85	76
		Percent of sites		
Percent of sites with agreement	74	73	64	57

Longitudinal Distribution of Backwater Habitats

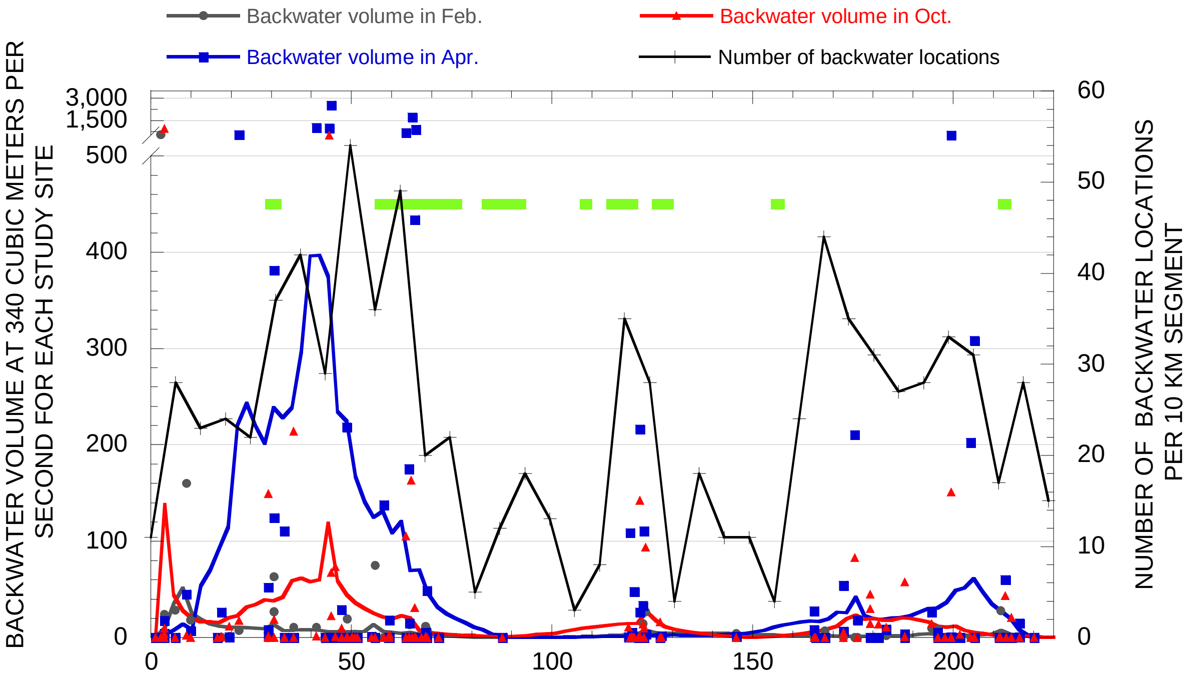
The changes in backwater habitat were not distributed uniformly in the downstream direction, but were generally greatest in reaches where known backwater habitat locations are most abundant. In some cases, increases in backwater volume coincided with reaches of known humpback chub aggregations. We evaluated the backwater volumes for each of the five discharges analyzed based on the February, April, and October survey data after these data were plotted by distance downstream from Lees Ferry (fig. 19). As described above, the sandbar topography in April resulted in the greatest amount of backwater habitat at all discharges. At a discharge of 227 m^3/s, the February topography resulted in greater backwater habitat volume than October in all reaches. However, for most reaches, and at all discharges greater than 227 m^3/s, the October sandbar topography resulted in greater backwater habitat volume than February. The increases in backwater habitat volume were concentrated in three segments of the river: RM 25 to RM 70, RM 120 to RM 125, and RM 175 to RM 215. Within these reaches are some, but not all, of the known humpback chub aggregation areas (table 2).


Backwater volume in Feb.
Backwater volume in Oct.
Backwater volume in Apr.
Number of backwater locations
BACKWATER VOLUME AT 227 CUBIC METERS PER SECOND FOR EACH STUDY SITE
NUMBER OF BACKWATER LOCATIONS PER 10 KM SEGMENT
3,000
1,500
500
400
300
200
100
0
60
50
40
30
20
10
0
0
50
100
150
200
DISTANCE DOWNSTREAM FROM LEES FERRY, IN RIVER MILES

A

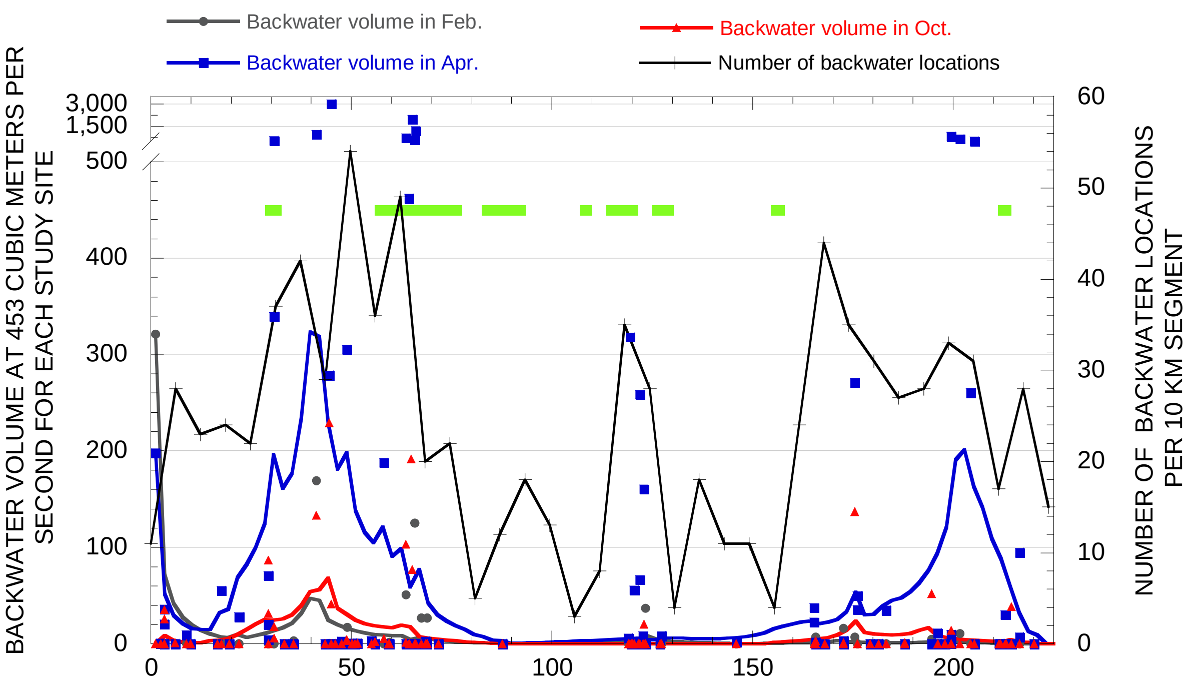

Backwater volume in Feb.
Backwater volume in Oct.
Backwater volume in Apr.
Number of backwater locations
BACKWATER VOLUME AT 283 CUBIC METERS PER SECOND FOR EACH STUDY SITE
NUMBER OF BACKWATER LOCATIONS PER 10 KM SEGMENT
3,000
1,500
500
400
300
200
100
0
60
50
40
30
20
10
0
0
50
100
150
200
DISTANCE DOWNSTREAM FROM LEES FERRY, IN RIVER MILES

B



Backwater volume in Feb.
Backwater volume in Oct.
Backwater volume in Apr.
Number of backwater locations
BACKWATER VOLUME AT 340 CUBIC METERS PER SECOND FOR EACH STUDY SITE
NUMBER OF BACKWATER LOCATIONS PER 10 KM SEGMENT
DISTANCE DOWNSTREAM FROM LEES FERRY, IN RIVER MILES

C



Backwater volume in Feb.
Backwater volume in Oct.
Backwater volume in Apr.
Number of backwater locations
BACKWATER VOLUME AT 453 CUBIC METERS PER SECOND FOR EACH STUDY SITE
NUMBER OF BACKWATER LOCATIONS PER 10 KM SEGMENT
DISTANCE DOWNSTREAM FROM LEES FERRY, IN RIVER MILES

D

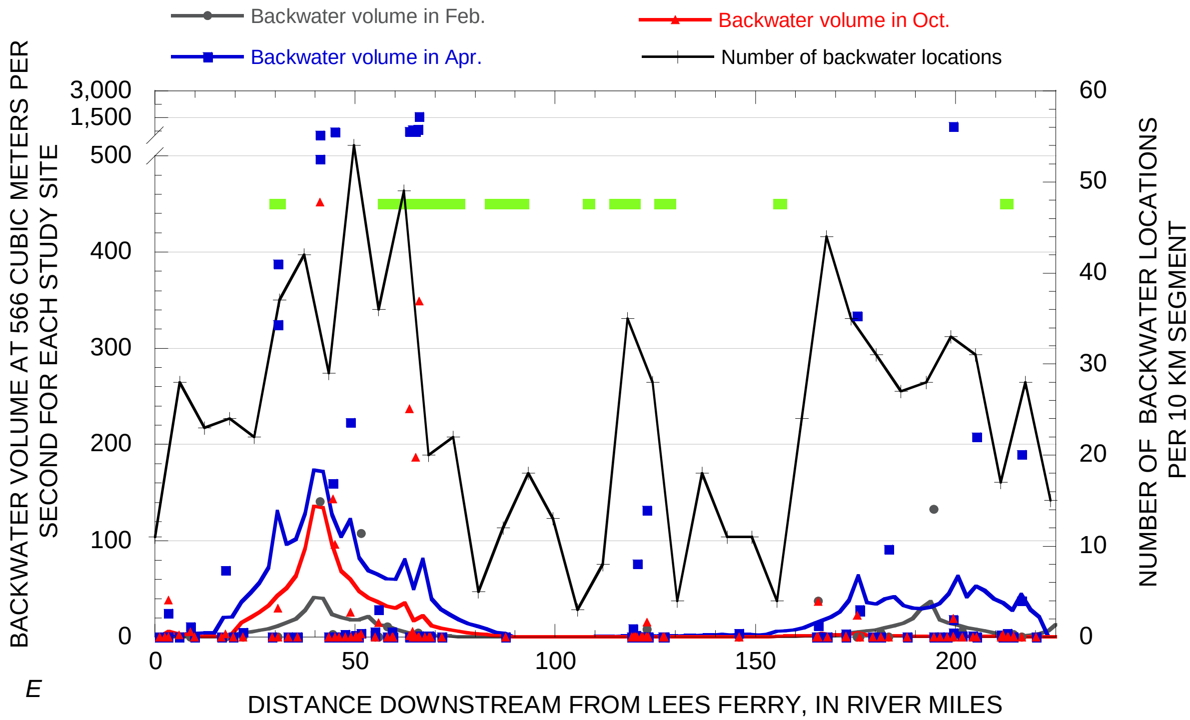


Figure 19. Downstream distributions of backwater habitat at differing discharges during 2008. Each plot shows backwater habitat volume for each site at the indicated discharge. Each plot also shows the number of backwater habitat locations per 10 km river segment based on the complete backwater inventory (appendix A). The locations of known humpback chub aggregations (table 2) are shown by the thick green lines. Note the break in scale on the left axis to improve readability. *A*, Backwater volume by distance downstream for a discharge of 227 m^3/s. *B*, Backwater volume by distance downstream for a discharge of 283 m^3/s. *C*, Backwater volume by distance downstream for a discharge of 340 m^3/s. *D*, Backwater volume by distance downstream for a discharge of 453 m^3/s. *E*, Backwater volume by distance downstream for a discharge of 566 m^3/s.

Observations of Fish in Backwater Habitats

A total of 16,070 fish were captured during the four fish-sampling trips. The supplemental trip in April 2008 only sampled sites downstream of Diamond Creek (RM 225), accounting for 180 of the total number of fish captured. Over the course of the four trips, 185 different backwaters were seined, including backwaters occurring at 60 of the SBM and BWM study sites. Fish were captured at 44 out of the study sites that were seined. Native fish, especially speckled dace (*Rhinichthys osculus*), were captured more frequently than nonnative fish. Captures of bluehead sucker (*Catostomus discobolus*) and flannelmouth sucker (*Catostomus latipinnis*) were high, but humpback chub captures were rare. Among nonnative fish, the most numerous were fathead minnow (*Pimephales promelas*). Most fish were found in backwaters in September, when 7,402 fish and 11 different fish species were captured. The species were: common carp (*Cyprinus carpio*), fathead minnow, red shiner (*Cyprinella lutrensis*), speckled dace, humpback chub, bluehead sucker, flannelmouth sucker, rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), plains killifish (*Fundulus zebrinus*), and black bullhead (*Ameiurus melas*). Of these, speckled dace, humpback chub, bluehead sucker, and flannelmouth sucker are the only species native to Grand Canyon (fig. 20). The capture data from the supplemental sampling trips accounted for smaller numbers of fish but were generally consistent for the number of species captured (data not shown).

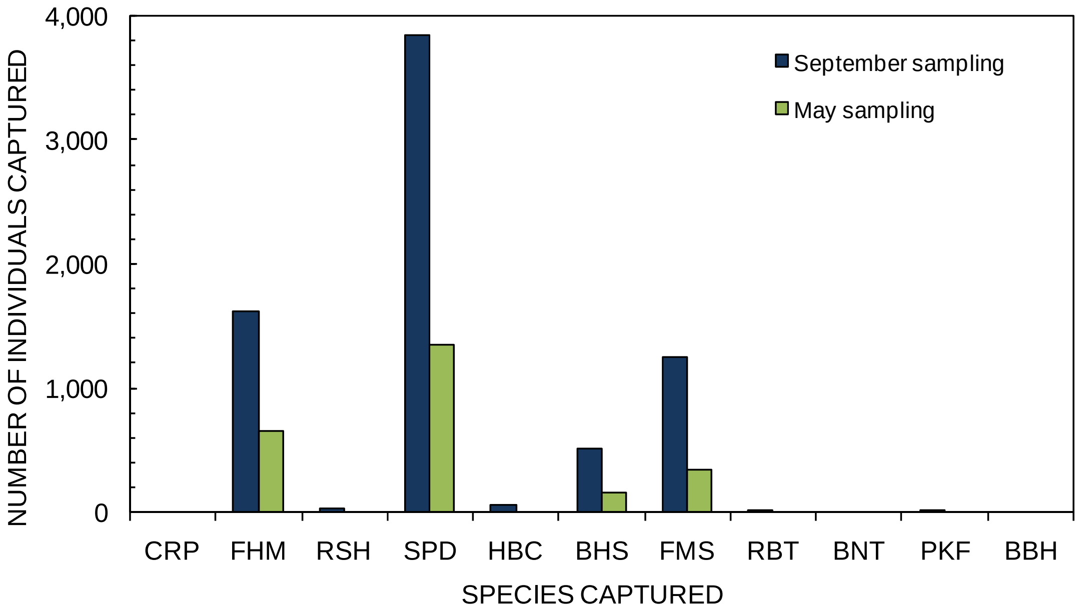


Figure 20. Captures of fish species for the May (under fluctuating flows) and September (under experimental steady flows of 354 m³/s) backwater sampling periods in 2008. Speckled dace and flannelmouth sucker were the most common native fish captured in the backwaters. Fathead minnow were the most common nonnative fish species captured in the backwaters. Key to species abbreviations: CRP, common carp (*Cyprinus carpio*); FHM, fathead minnow (*Pimephales promelas*); RSH, red shiner (*Cyprinella lutrensis*); SPD, speckled dace (*Rhinichthys osculus*); HBC, humpback chub (*Gila cypha*); BHS, bluehead sucker (*Catostomus discobolus*); FMS, flannelmouth sucker (*Catostomus latipinnis*); RBT, rainbow trout (*Oncorhynchus mykiss*); BNT, brown trout (*Salmo trutta*); PKF, plains killifish (*Fundulus zebrinus*); and BBH, black bullhead (*Ameiurus melas*).

Conclusions and Management Implications

Topographic and bathymetric surveys conducted at 97 study sites before and after the March 2008 HFE show that the experimental release from Glen Canyon Dam resulted in sand deposition on reattachment sandbars and scour in return channels that more than doubled the total backwater area and volume at the study sites. The 97 study sites represent about 20 percent of the total number of these habitats in Grand Canyon National Park between Lees Ferry and Diamond Creek. The HFE also resulted in the loss of some backwaters where low-elevation reattachment bars scoured or return channels filled with HFE-deposited sand.

In the 6-month period between the March HFE and the October measurements, reattachment bars were eroded and there was deposition in return channels. These processes resulted in loss of backwater habitat created by the 2008 HFE. However, during this period there was also formation of new low-elevation reattachment bars and creation of new backwater habitats. The net result from the sandbar reworking that occurred in response to the fluctuating flow operation at the dam was a return to a number of backwaters and total area and volume of backwater habitat for selected flows that was similar to the condition measured before the March 2008 HFE. However, some lasting effect of the HFE was evident in the availability of backwater habitats across the range of flows associated with the dam's normal fluctuating flow regime (termed the Modified Low Fluctuating Flow; see U.S. Department of the Interior, 1995, 1996). For each of the flow regimes that were released in 2008, following the HFE, the October topography associated with the experimental steady flow of 351 m^3/s was consistently associated with a greater number of sites with backwaters present 50 percent of the time or greater compared to the February topography. Thus, while the most dramatic effects of the HFE on backwater habitat persisted only for a month or two, a small (up to 14 percent) increase in habitat availability persisted through October 2008.

The availability of continuously present backwater habitats was maximized by steady flows compared to fluctuating flows, regardless of sandbar morphology. The precise steady flow that would maximize habitat, depends, of course, on the sandbar morphology and varied throughout the year. In April, habitat would have been maximized by a steady flow of about 453 m^3/s. However, the amount of habitat that would have been available at lower steady flows was also relatively high. In October, the greatest area and volume of habitat would have been achieved with a lower steady flow of 227 m^3/s. Thus, based on the limited data collected over the 6-month period for this study, low steady flows appear to provide as much or more habitat when compared to higher flows, except immediately following a HFE.

Among the four fluctuating flow regimes analyzed, the relatively lower monthly volume fluctuating flows (FR1) were consistently associated with higher backwater availability than the higher monthly volume fluctuating flows, such as those that occurred mid-April through August (FR 2 and FR 3), or the higher monthly volume, experimental fluctuating flows that occurred during January through March 2003 through 2005. Compared to steady flows of 351 m^3/s, the relatively lower monthly volume fluctuating flows associated with March to mid April 2008, had a greater number of intermittently available backwaters across the range of daily dam operations, but fewer backwaters that were continuously available. Annual release volumes at Glen Canyon Dam are associated with variability in upper Colorado River Basin hydrology and are determined by a variety of laws and the Colorado River Compact, whereas variability of seasonal to monthly release volumes is associated with development of the annual operating plan for the Colorado River. In addition to affecting the characteristics of backwater habitat available to native fish, the relative proportion of continuously available versus intermittently available backwaters may have implications for other aspects of the ecosystem, such as the degree of warming and primary production.

The results from the backwater inventory indicate that there are as many as 880 potential backwater locations between Lees Ferry and Diamond Creek, of which 569 are sand-bounded backwaters of the type included among the study sites where topographic data were collected. These estimates of the total population of backwaters may be used in conjunction with the results from the detailed surveys to estimate total habitat abundance by reach. However, because the results of the inventory are biased by factors such as the discharge at time of observation and water clarity, the inventory results are not appropriate for monitoring trends in backwater habitat abundance.

The fish-sampling data provided for use in this study support the hypothesis that small-bodied fish, whether small adults or juveniles, native or otherwise, in the Colorado River can be found in backwaters, which in most cases are of lower velocity and higher temperatures (at least during spring through early fall months) than the mainstem river. Fish captures within backwaters along the main channel of the Colorado River increase downstream from its confluence with the Little Colorado River at approximately RM 60. While fish were captured in backwaters during all flow regimes sampled, the highest captures were during the experimental fall steady flows of 2008, when dam releases were at 351 m^3/s. Although this season precedes the period when water release temperatures from Glen Canyon Dam are highest, it follows the period of greatest solar warming to the river in Grand Canyon. Owing to reduced solar radiation after fall months, the relatively shallow backwater habitats along the shorelines become colder relative to the water of the main channel, perhaps making them a less advantageous area for juvenile fish attempting to survive the overwintering period. While these data confirm that native fish utilize backwater habitat in Grand Canyon National Park, the data are not conclusive with respect to linking the recruitment success of native juvenile fish in the main channel of the river to the abundance and distribution of backwater habitats or their continuous or intermittent use of such habitats below the dam. Further studies that evaluate utilization of all available habitats by native fish are required to address this question.

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Appendixes

Appendix A. Data from Backwater Inventories Conducted Between February and September 2008

[River miles are downstream from Lees Ferry. River sites as viewed when looking downstream. Source indicates backwaters identified in seining trips conducted from 2003 through 2007 (S), analysis of aerial images (I), identified by both sources (S, I), or during field observations in 2008 (indicated by month). The class is the geomorphic classification described in table 1 of the text. Study site indicates sites selected for detailed topographic surveys (appendix B). The categories for backwater status in February, April, May and July are (0) no backwater present for any discharge within the range of flow fluctuations at time of observation; (1) backwater present only for the lower 50 percent of the range of flow fluctuations at time of observation; (2) backwater present only for the upper 50 percent of the range of flow fluctuations at time of observation; and (3) backwater present across the full range of flow fluctuations at time of observation. The additional categories for backwater status in September include a letter indicating whether a backwater was present (P) or absent (A) at the time of observation and a numerical code that indicates whether a backwater would be present (1) at flows lower than the steady discharge, (2) at flows greater than the steady discharge, or (3) at flows both lower and greater than the steady discharge. A double dash (--) indicates backwaters that were not visited in the September inventory.]

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
1.10	right	S	sb	1.2R	0	0	0	0	0
1.17	right	I	rb	1.2R	0	0	0	0	0
1.27	right	Feb.	rb	1.2R	3	0	0	0	0
1.38	left	S	cm		0	1	0	0	A1
1.58	right	S	bank		0	0	0	0	0
1.69	left	S	bank		3	3	1	0	P1
1.74	left	S	sb		0	0	0	0	0
1.83	right	S, I	rb		2	0	2	0	P1
2.41	left	S	cm		3	0	0	0	0
2.54	left	S, I	rb	2.5L	3	1	0	0	A1
2.69	left	S	rb		3	2	0	0	A1
3.13	left	Apr.	gb		0	1	3	0	A1
3.18	left	Apr.	sb		0	2	2	0	A1
3.22	left	S, I	rb-gb		3	3	0	0	A1
3.35	left	S, I	rb	3.37L	3	2	2	0	A2
3.47	left	S	rb		0	0	0	0	P1
3.53	left	S	rb		3	2	0	0	P1
3.73	left	S, I	rb		0	0	2	0	A2
3.77	left	Feb.	rb		3	2	2	0	A2
4.04	left	S	sb		3	0	0	0	0
4.10	left	Apr.	rb		0	3	3	0	P3
4.16	left	I	sb		1	0	0	0	0
4.18	left	I	rb		0	0	0	0	0
4.20	right	I	rb		2	0	0	0	0
4.39	left	S, I	rb		3	0	3	2	P1
4.50	left	S	bank		0	3	3	2	0
4.54	left	Feb.	cm		1	3	1	0	0
4.70	left	Feb.	sb		2	3	3	2	P2
4.96	left	I	cm		0	0	0	0	0
5.21	left	Feb.	rb		3	0	0	0	0

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
5.50	right	S	cm		0	0	0	0	0
5.88	right	I	bank		1	0	0	0	0
6.07	left	S, I	rb	6.07L	3	0	0	0	0
6.29	right	July	cm		0	0	0	2	0
6.70	right	I	cm		2	0	0	0	0
7.21	left	S	cm		2	0	2	0	A2
7.42	left	S	rb		2	0	2	2	A2
8.49	left	I	gb		0	0	0	0	0
8.85	left	S, I	rb	8.9L	3	3	3	2	P1
9.36	right	S, I	cm		0	0	0	2	0
9.49	right	Feb.	cm		0	0	0	2	A2
9.66	left	Feb.	cm		3	0	0	0	A1
9.84	left	S	cm		0	0	0	0	A1
9.86	right	S, I	rb		0	0	0	0	0
9.93	left	S, I	rb	9.93L	3	0	0	1	A1
10.14	right	I	rb		3	0	0	1	0
10.20	right	S, I	cm		0	0	1	1	0
10.31	left	S	cm		2	0	1	1	A1
10.32	left	Feb.	cm		2	0	1	1	A1
10.46	left	Feb.	rb		3	0	0	1	P1
10.67	left	Feb.	rb		3	2	0	1	0
10.72	left	Feb.	cm		2	0	0	1	P1
10.79	left	Feb.	cm		3	0	0	1	P1
10.97	left	S	rb		0	0	0	1	P1
11.07	left	S	rb		2	0	0	1	0
11.24	left	S	cm		0	0	0	0	0
11.30	right	I	bank		0	0	0	1	0
12.43	left	S	sb		0	0	0	0	0
13.22	left	I	up		3	0	0	0	A1
14.42	right	S	bank		2	0	0	1	A1
15.18	right	S	bank		0	0	0	0	0
15.50	right	S, I	rb		0	1	0	0	A1
15.61	left	S	rb		0	0	0	1	0
15.64	right	Feb.	bank		2	0	0	1	0
16.00	right	Apr.	bank		0	3	3	0	0
16.01	left	S	bank		0	0	0	0	0
16.01	right	Apr.	bank		0	3	3	0	0
16.11	left	S	bank		0	1	1	1	P1
16.65	left	S	sb	16.6L	0	0	0	0	0
17.60	right	S	rb	17.6R	1	3	2	2	A1
18.28	right	July	rb		0	0	0	1	A1
18.59	left	S	cm		3	0	0	0	0
18.86	left	Apr.	bank		0	1	1	1	P1
19.37	right	S	rb		0	0	0	0	0
19.42	left	May	up		0	0	3	0	A1
19.47	left	S	sb		3	3	3	0	0
19.60	left	S, I	rb		1	0	0	2	0
19.61	right	S, I	rb	19.61R	3	0	1	1	A1
19.67	right	Feb.	cm		1	0	0	0	0
19.69	right	S	sb		0	0	0	0	0
19.71	left	S, I	rb		1	0	0	0	0

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
19.72	right	I	rb		0	0	0	0	0
20.10	right	May	bank		0	0	1	0	0
20.13	left	S	up		2	0	0	2	A2
20.56	right	Feb.	cm		1	0	0	0	A1
21.74	left	Feb.	sb		0	0	0	0	0
22.03	right	S, I	rb	22R	1	3	3	0	P3
22.16	right	S	rb		0	0	0	0	A1
22.26	right	Feb.	cm		1	0	0	0	A2
22.29	right	Feb.	cm		1	0	0	0	0
22.47	left	I	cm		0	0	1	0	0
23.06	left	S, I	rb		1	3	1	0	P1
23.09	right	S, I	rb		0	3	3	0	A1
23.39	right	S, I	rb		0	0	1	0	A1
25.07	left	S	up		0	0	0	0	0
25.31	right	I	rb-br		0	0	0	0	0
25.61	right	S	cm		0	0	0	0	0
25.97	right	I	up		1	0	0	1	0
26.08	right	May	cm		0	0	3	0	0
26.26	right	I	rb		0	0	0	1	0
26.56	left	S, I	sb		3	0	1	1	0
26.57	left	I	rb		0	0	1	1	0
26.76	left	S	cm		0	0	0	0	0
27.03	right	I	bank		0	0	0	0	0
27.61	right	Apr.	up		0	1	0	0	0
27.75	left	S	rb		0	3	3	1	P1
27.84	right	Feb.	rb		1	2	0	0	0
27.88	right	Feb.	up		1	0	0	0	0
28.19	right	S	up		0	0	0	0	0
28.30	right	S, I	rb		0	0	1	0	A1
28.85	left	S	sb		1	0	0	1	A1
29.19	right	Feb.	up		1	0	0	1	0
29.27	right	S, I	rb	29.28R	0	3	3	0	P3
29.81	right	S	sb		1	0	0	1	A2
30.41	right	I	st		0	0	0	0	0
30.51	right	S	up		0	0	0	0	0
30.74	right	S, I	rb	30.7R	1	3	3	0	A3
30.79	right	S	rb-ext	30.7R	0	0	0	0	0
30.97	right	S	cm		0	0	0	0	0
31.04	left	I	bank		0	0	0	0	0
31.07	right	I	rb		0	0	0	0	A1
31.17	right	Feb.	cm		2	0	0	0	A1
31.33	right	S	sb		0	0	0	0	0
31.48	right	Feb.	up		3	0	0	0	0
31.50	left	S	rb-br		3	0	0	0	P1
31.57	right	Feb.	cm		2	0	0	0	0
31.71	right	I	up		3	0	0	0	0
32.09	right	Feb.	st		2	0	0	0	0
32.35	right	S, I	sb		0	0	0	0	0
32.46	left	I	bank		0	0	0	0	0
32.56	left	S	cm		0	0	0	0	A1

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status of backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
32.84	right	Feb.	cm		3	0	0	0	0
33.14	left	S	sb		2	0	0	0	0
33.22	left	S	rb		2	0	0	0	P3
33.30	right	S, I	rb-br		1	0	0	1	P2
33.32	left	S	cm	33.3L	1	0	0	0	0
33.45	left	May	bank		0	0	1	0	A1
33.49	left	S	cm		0	3	0	0	A1
33.51	left	Feb.	cm		1	0	0	0	0
33.58	left	Apr.	cm		0	3	0	0	0
33.64	left	Apr.	sb		0	3	0	0	A1
33.67	right	S	cm		0	0	1	1	A1
33.77	left	Feb.	up		2	0	0	0	0
33.90	right	S	gb		0	0	0	0	0
33.93	left	May	bank		0	0	1	0	0
34.40	right	S	bank		0	0	0	0	0
34.50	right	S	sb		0	0	0	0	0
34.88	right	Apr.	bank		0	1	0	0	0
35.17	right	S	st		0	0	0	0	0
35.20	left	S	cm		0	0	0	0	0
35.30	right	S	cm		0	0	0	1	0
35.41	right	S	bank		0	0	0	0	0
35.47	right	S	cm		0	0	0	1	A2
35.63	right	S, I	rb	35.63R	1	0	0	0	P1
35.96	left	S, I	sb		3	3	0	1	A1
36.20	right	S, I	rb-br		1	0	0	0	A1
36.26	left	S	cm		2	0	0	1	0
36.52	right	S	cm		0	0	0	0	0
37.02	right	May	st		0	0	2	0	0
37.05	right	S, I	sb		0	0	0	2	A1
37.23	right	S	st		2	0	0	0	0
37.31	left	S, I	rb-br		1	0	0	0	P1
37.55	right	Feb.	sb		0	0	0	0	0
37.57	right	S, I	rb	37.55R	0	0	0	0	A1
37.80	left	S	rb		0	0	0	1	P1
37.89	right	S	up		3	0	0	0	A1
37.92	left	S	up		3	0	0	0	0
37.99	left	Feb.	rb		3	0	0	0	0
38.02	left	S	rb		3	0	0	0	A2
38.09	right	S, I	rb		0	3	3	0	A1
38.49	left	Feb.	cm		3	0	0	0	A1
38.68	left	Feb.	cm		2	0	0	0	0
38.83	left	Feb.	cm		2	0	1	0	0
38.88	left	S, I	cm		1	0	0	0	0
38.93	right	S	cm		2	0	0	0	0
38.99	left	Apr.	cm		0	3	0	0	0
39.48	right	Feb.	cm		2	0	0	0	0
39.49	right	S	cm		1	0	0	0	0
39.57	left	Feb.	cm		2	0	0	0	0
39.58	right	S	cm		2	0	1	1	A2

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
39.60	right	Feb.	cm		1	0	0	0	0
39.67	left	S, I	rb		1	0	0	0	P1
39.92	left	Feb.	cm		2	0	0	0	0
40.16	left	S, I	rb		1	3	1	0	A1
40.28	left	Feb.	cm		2	0	0	0	0
40.32	right	S	cm		1	0	0	0	0
40.38	left	S	cm		2	0	0	0	0
40.42	left	Feb.	bank		3	0	0	0	0
40.81	right	Feb.	cm		2	0	0	0	0
41.03	left	I	cm		1	0	0	0	0
41.12	right	S, I	up		0	0	0	0	0
41.26	right	S	st		2	3	0	2	0
41.40	right	S, I	rb	41.3R	2	2	2	3	P3
41.85	right	Feb.	st		2	0	0	0	A2
42.04	right	S	cm		2	0	0	0	A2
42.74	right	S	bank		0	0	0	0	0
42.76	left	Apr.	bank		0	3	0	0	0
43.42	left	S	up	43.4L	0	0	0	0	A1
43.81	left	S, I	sb		3	0	0	0	A1
43.84	left	S	rb		0	0	0	0	0
43.86	left	May	rb-ext		0	0	2	0	0
43.88	left	S	sb		1	3	0	1	0
44.17	right	S	cm		1	0	0	0	0
44.57	left	Feb.	rb	44.5L	1	3	3	0	0
44.59	left	S, I	rb	44.5L	1	3	3	3	P3
45.00	left	S, I	rb	45L	0	0	2	2	P3
45.28	left	S, I	rb		2	2	0	2	0
45.50	left	S	rb		0	0	0	0	0
45.66	left	S, I	rb		3	0	1	0	P1
45.89	right	S	cm		3	1	0	1	0
45.89	left	S, I	rb		1	0	0	0	A1
45.93	right	S, I	rb	45.93R	1	1	1	1	A1
45.99	right	S	rb		1	0	1	1	A1
46.14	left	I	sb		0	1	0	1	0
46.28	right	Feb.	rb		0	0	0	0	0
46.39	left	S, I	rb	46.39L	0	3	1	1	P1
46.79	left	S	cm		0	0	0	0	0
46.82	right	S, I	cm		0	0	0	0	0
46.83	left	Apr.	cm		0	3	0	0	0
46.88	right	I	up		1	0	0	0	A1
47.04	right	S, I	rb		1	0	0	0	A1
47.63	right	S, I	rb	47.6R	2	3	0	1	A1
47.76	right	S	cm		0	0	0	0	0
47.81	left	S	sb		0	0	0	1	0
47.84	right	S	rb		0	0	0	0	0
47.86	left	S	cm		0	0	0	1	0
47.98	left	S, I	rb		1	3	3	1	A1
48.14	right	S	cm		0	0	0	0	0
48.25	left	Feb.	sb		2	0	0	0	0

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
48.34	right	S	gb		0	0	0	1	0
48.47	left	S	cm		0	0	0	2	0
48.65	right	S, I	up		1	3	3	3	A1
48.78	right	S, I	rb	48.79R	1	3	3	0	A3
48.91	right	I	sb		1	0	0	1	0
48.92	left	S, I	rb	48.91L	2	0	0	1	A1
49.11	left	S	cm		0	0	0	0	0
49.31	right	S	up		2	0	0	1	P1
49.36	right	Feb.	rb		2	0	0	0	P1
49.38	left	S	gb		3	0	0	0	A2
49.52	right	I	up		1	2	2	0	A2
49.55	left	S	bank		0	0	0	0	A1
49.84	right	Apr.	bank		0	2	0	0	0
49.98	right	S, I	up		3	2	2	0	A1
50.19	right	S, I	rb	50.1R	0	0	1	0	A1
50.24	right	I	rb-ext		0	0	0	0	0
50.29	left	S, I	rb	50.28L	3	0	0	0	A1
50.34	right	S	rb		2	3	0	0	A1
50.48	left	Feb.	cm		2	0	0	0	0
50.65	left	S, I	rb	50.64L	1	3	0	0	P1
50.73	left	S	rb-ext	50.64L	1	0	1	0	0
50.81	left	S	cm		3	1	0	0	A1
50.84	right	Feb.	cm		1	0	0	0	A2
50.88	right	Feb.	cm		2	0	0	0	0
50.90	left	S, I	rb	50.91L	0	0	0	0	A1
50.92	right	Apr.	bank		0	3	0	0	0
50.95	left	S, I	rb	50.91L	0	0	0	1	P2
51.04	left	S	rb		0	0	0	0	0
51.11	right	I	rb		1	3	0	1	A1
51.40	left	S, I	rb	51.5L	0	0	0	0	A1
51.43	left	Feb.	rb	51.5L	2	0	0	0	0
51.46	left	S	rb-ext	51.5L	0	3	0	0	A1
51.49	right	I	rb		1	3	0	1	A1
51.53	right	Feb.	cm		2	0	0	0	0
51.67	left	S, I	sb		0	0	0	0	0
51.68	left	I	rb		0	0	0	0	P1
51.75	right	I	cm		0	0	0	0	0
51.76	right	I	cm		0	0	0	0	0
51.88	right	I	rb		0	0	0	0	0
52.07	right	I	up		0	0	0	0	A1
52.13	left	May	cm		0	0	3	0	0
53.14	right	Apr.	rb-gb		0	3	3	0	0
53.29	right	S	rb-gb		1	0	3	3	P3
53.30	right	S, I	rb-gb		1	3	3	1	A2
53.54	right	S	sb		0	0	2	0	0
53.95	right	I	rb		0	0	0	1	P1
53.95	left	Apr.	rb		0	3	0	0	0
54.28	right	May	sb		0	0	1	0	0
54.45	right	I	up		2	0	2	1	0

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
54.54	right	S, I	rb	54.6R	1	0	1	1	P1
54.60	right	Feb.	rb-ext	54.6R	3	0	0	0	A2
54.61	left	S, I	rb		0	0	1	0	0
54.66	left	S	rb-ext		0	0	0	0	A1
54.82	right	S, I	cm		1	0	0	0	A1
54.85	left	S, I	rb		3	3	1	1	P1
54.91	left	I	rb		1	0	1	1	A1
55.02	right	S	rb	55.02R	3	2	0	1	A1
55.52	left	S, I	rb		0	0	0	0	A1
55.53	right	S	rb		0	0	0	0	A1
55.74	left	S	rb		3	3	1	0	A1
55.87	right	S, I	rb	55.9R	2	0	0	0	A1
55.92	right	Feb.	rb-ext	55.9R	2	0	0	0	A1
55.95	left	S	cm		2	0	0	0	A1
56.54	right	S	sb	56.6R	1	1	0	0	0
56.54	right	S	sb	56.6R	1	1	0	0	0
57.13	right	I	sb		0	0	0	0	0
57.31	right	S	sb		0	0	3	0	A1
57.32	right	S, I	sb		1	0	3	0	A2
57.53	left	S, I	rb		1	3	3	1	A1
57.55	left	Apr.	cm		0	3	0	0	0
57.75	left	S, I	rb	57.75L	0	0	0	1	A1
58.08	left	I	rb	58.1L	0	3	3	1	0
58.18	right	Feb.	sb		0	0	0	0	0
58.30	left	S, I	rb-gb		0	0	0	0	A1
58.63	right	I	rb		0	2	0	1	0
58.74	right	S, I	rb	58.72R	1	0	2	0	A3
58.80	left	S, I	cm		0	0	2	0	0
59.05	left	S	cm		0	0	0	0	0
59.18	left	S, I	rb	59.19L	1	0	0	1	A1
59.29	left	S	rb-ext		1	0	0	0	A1
59.33	right	S	cm		3	0	0	1	0
59.38	left	I	up		0	0	0	0	0
59.43	left	Feb.	st		2	0	0	0	0
59.48	left	S, I	rb	59.48L	2	3	1	0	A1
59.57	right	Sept.	cm		0	0	0	0	P1
59.64	right	I	rb		0	0	0	0	P1
59.79	left	Feb.	up		1	3	0	0	A1
59.86	left	S, I	rb		1	0	1	1	0
59.90	right	S	cm		1	0	0	0	0
59.98	left	S	cm		0	0	0	0	0
60.56	right	S, I	rb		0	0	0	1	A1
60.61	left	I	rb		0	3	0	0	0
60.88	left	S, I	rb		0	0	0	0	A1
60.93	left	I	rb-ext		0	1	0	0	A1
61.19	right	S, I	rb		0	3	3	1	A1
61.27	left	S, I	rb		3	0	0	3	0
61.30	left	S	rb-ext		0	3	3	0	0
61.43	right	S	rb		1	0	0	0	0

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
61.44	right	Feb.	rb-ext		1	0	0	0	P1
61.62	right	I	st		0	0	0	0	0
61.66	left	S	cm		0	0	0	0	0
61.95	left	S	gb		0	0	0	0	0
61.97	right	I	gb		0	0	0	0	0
62.30	left	S, I	rb	62.3L	0	0	0	0	A1
62.32	left	Feb.	rb	62.3L	1	0	0	0	A1
62.34	left	Feb.	rb	62.3L	3	0	0	0	A1
62.49	right	S	up		0	0	0	0	P1
62.69	right	I	rb		0	0	0	0	0
63.04	right	S, I	st		0	2	1	0	A2
63.07	left	S, I	rb		1	3	3	0	0
63.09	right	S	rb		1	0	3	2	A3
63.59	left	I	rb	63.6L	0	0	3	0	0
63.62	left	Apr.	rb-ext	63.6L	0	3	2	0	A2
63.74	left	S	sb		0	3	0	0	0
63.90	left	I	up		0	3	0	0	0
64.13	right	S	sb		0	0	0	0	0
64.23	left	S, I	up		0	0	1	0	A1
64.34	left	S, I	rb	64.36L	0	3	3	0	0
64.51	left	I	rb-ext	64.5L	1	3	0	0	A2
64.59	left	May	bank		0	0	3	0	0
64.63	left	S, I	sb		0	3	0	0	0
64.71	left	I	rb		0	3	0	0	P3
64.93	left	S, I	rb	64.93L	0	0	0	0	P1
64.97	right	I	cm		0	0	0	0	0
65.07	right	S	st		0	0	0	0	A2
65.18	right	I	rb	65.1R	0	3	3	3	0
65.31	left	S, I	rb		0	0	0	0	P1
65.77	left	S, I	rb	65.8L	0	3	3	3	0
65.83	right	S	rb-br		3	0	0	0	A2
66.15	left	S, I	rb	66.11L	3	0	3	0	A2
66.64	left	S	gb		0	0	2	0	0
66.83	left	Apr.	gb		0	2	0	0	A1
67.43	left	S, I	rb	67.43L	3	3	1	0	A1
68.15	left	I	cm		0	0	0	0	0
68.52	left	S, I	rb	68.49L	3	0	1	0	A1
68.81	right	S	rb-gb	68.8R	3	3	0	0	A1
69.79	right	S, I	rb		0	0	0	0	P1
69.79	left	Apr.	cm		0	2	0	0	0
69.84	right	I	rb-ext		0	0	0	0	0
69.94	right	S	cm		0	3	0	0	0
70.40	left	S	cm		0	0	0	0	0
71.01	right	S	rb-gb		0	0	0	0	A1
71.07	left	S	rb		3	0	0	0	P1
71.17	left	S	cm		2	0	0	0	A1
71.32	left	S	cm		0	2	0	0	0
71.44	left	S	cm		0	0	0	0	0
71.67	left	I	rb	71.67L	1	0	0	0	A1

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
71.68	right	S	cm		1	0	0	0	P1
71.78	right	S	cm		0	0	0	0	0
71.83	right	S	st		0	0	0	0	0
72.42	right	S, I	rb		2	0	0	0	A1
72.54	right	S	rb	72.54R	0	0	0	0	0
72.71	left	S	rb-gb		0	0	1	0	A2
72.82	right	S	st		0	0	0	0	0
74.03	right	I	gb		0	0	0	0	0
74.16	right	I	gb		0	0	0	0	0
74.19	right	S, I	gb		0	0	0	0	0
74.51	right	S	sb		0	0	0	0	A1
74.95	right	S, I	rb		0	0	0	0	A1
75.54	left	I	cm		0	0	0	0	0
76.34	right	S	rb		0	0	0	0	A1
76.40	left	S	cm		0	0	0	0	0
76.58	left	S	rb		0	3	3	0	A1
76.63	left	S, I	rb-ext		0	0	1	0	0
76.97	right	I	cm		3	0	0	0	A1
76.99	right	I	cm		0	0	0	0	0
77.02	right	I	cm		0	0	0	0	0
77.12	left	I	up		1	0	0	0	A1
78.00	right	I	rb		0	0	0	0	0
78.01	right	S, I	rb-br		1	0	0	0	0
78.04	left	Sept.	up		0	0	0	0	P1
78.60	right	S	st		0	0	0	0	0
78.74	left	S	bank		0	0	0	0	0
84.42	left	S	bank		0	0	0	0	0
84.54	right	S	up	84.6R	0	0	0	0	0
84.57	right	Feb.	up	84.6R	0	0	0	0	P1
87.03	left	S	rb		0	0	0	0	A1
87.51	right	Feb.	rb-br		3	0	0	0	0
87.57	right	Feb.	bank		2	0	0	0	0
87.58	left	May	up	87.6L	0	0	1	0	0
87.61	right	I	rb-br		0	3	3	0	P1
87.89	left	S, I	rb-br	87.87L	0	0	0	1	
88.06	right	S	up	88.1R	3	3	0	0	
88.09	right	Feb.	up	88.1R	2	0	0	0	
89.13	right	Feb.	gb		0	0	0	0	
90.66	right	I	rb-br		0	0	0	0	
90.66	left	I	rb-br		1	0	0	0	
92.22	left	S	rb-br		0	0	0	0	
92.22	right	Apr.	bank		0	2	0	0	
92.36	left	Apr.	cm		0	2	1	0	
92.82	left	I	sb		0	0	0	0	
93.07	left	Feb.	up		3	0	0	0	
93.32	left	I	cm		0	0	0	0	
93.78	left	S, I	rb-br	93.8L	0	0	3	1	
93.79	right	Feb.	rb-br		3	3	0	0	
93.81	right	Feb.	rb-br		1	0	0	0	

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
94.11	right	S	gb		1	0	0	0	
94.24	right	S	gb		1	0	0	0	
94.81	left	Apr.	bank		0	3	0	0	
95.03	right	S	rb		0	0	0	0	
95.93	right	S	rb-br		0	0	0	0	
96.04	left	S	bank		2	0	0	0	
96.13	right	S	bank		0	0	0	0	
96.37	right	S, I	rb-br		0	0	0	0	
96.46	left	S	bank		0	0	0	0	
96.57	right	I	rb-br		0	0	0	0	
97.48	right	I	bank		3	0	0	0	A1
97.49	right	S, I	bank		0	0	3	0	A1
97.54	right	I	rb-br		3	3	0	0	P1
97.72	right	Feb.	cm		1	0	0	0	A1
97.80	left	S	cm		0	0	0	0	0
98.34	left	S	cm		0	0	0	1	0
98.45	right	I	rb-br		0	0	0	1	P1
99.63	left	I	rb		0	1	0	0	P1
100.00	right	I	up		0	2	0	0	A1
101.63	right	S	rb-br		0	0	0	0	0
103.05	right	S, I	rb-br		0	0	0	1	0
104.42	right	I	up	104.4R	0	0	0	0	0
105.84	right	S	cm		0	0	0	0	0
112.56	right	S, I	rb		3	0	0	1	A1
113.94	right	Feb.	up		3	0	0	0	0
114.08	left	S	bank		3	0	0	0	0
114.10	right	Sept.	cm		0	0	0	0	A2
114.39	left	S	bank		0	0	0	1	0
114.46	left	S	bank		0	0	0	1	0
114.68	left	S, I	rb-br		3	3	0	0	0
114.73	left	Feb.	bank		3	0	0	0	0
115.04	left	S	st		2	0	0	0	0
115.08	right	S	st		0	0	0	0	0
115.49	left	S	st		2	0	0	0	0
115.70	left	S	rb-gb		0	0	0	0	0
115.72	left	S	bank		0	0	0	0	0
115.89	left	S, I	rb-br		0	0	0	0	A1
115.94	left	S, I	rb		0	0	0	1	A1
116.21	right	Feb.	sb		3	0	1	0	0
116.31	right	May	up		0	0	1	0	0
116.45	right	Apr.	rb		0	3	0	0	0
116.48	left	S	rb	116.5L	0	0	0	0	A1
116.86	right	Feb.	rb-br		1	0	1	0	0
117.16	left	S	up		0	0	0	0	0
118.08	left	I	rb-br		0	0	0	0	0
118.29	right	S, I	rb-br		2	0	1	0	A1
118.40	right	Feb.	st		0	0	0	0	0
118.58	right	S	cm		1	0	0	0	0
118.76	right	S	rb		0	0	0	0	0

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
118.78	left	I	rb		0	0	1	0	0
118.79	left	May	cm		0	0	1	0	0
119.04	right	S, I	rb	119R	1	2	0	0	A1
119.40	right	S	rb	119.4R	0	0	3	0	0
119.60	left	May	cm		0	0	1	0	0
119.74	right	S, I	rb	119.8R	1	3	1	1	A1
119.91	left	S, I	rb	119.9L	0	3	1	0	A1
119.96	left	S	rb-ext		0	0	0	0	A1
120.13	left	I	rb	120.1L	0	3	0	1	A1
120.14	right	May	rb		0	0	0	0	0
120.32	left	S, I	sb		0	0	0	0	A3
120.48	left	Apr.	cm		0	2	0	0	0
120.50	right	S, I	rb	120.5R	1	3	0	0	0
120.78	right	S	sb		0	3	0	0	0
120.98	left	July	gb		0	0	0	2	A2
121.10	left	S, I	up		0	2	2	1	A1
121.13	left	Apr.	up		0	3	1	0	0
121.34	right	S, I	rb		0	0	0	0	0
121.50	left	S, I	rb	121.6L	1	1	0	0	0
121.55	left	Apr.	rb-ext	121.6L	0	2	1	0	0
121.81	right	S	bank		0	1	0	0	0
121.85	left	S, I	rb	121.9L	0	3	3	3	P1
121.87	left	Apr.	rb-ext	121.9L	0	2	3	3	A1
122.70	right	S, I	rb	122.7R	1	3	3	1	P3
122.93	left	S, I	rb	122.93L	0	3	3	2	A1
122.96	left	Feb.	rb	122.93L	3	0	0	0	0
123.23	left	S, I	rb	123.3L	1	1	1	1	P1
123.56	right	S	up		0	0	0	0	A2
123.71	right	July	rb-gb		0	0	0	3	P3
123.83	left	S	cm		0	0	0	0	0
123.86	left	Feb.	bank		1	0	0	0	0
123.89	right	S	cm		0	0	0	0	0
123.90	left	May	up		0	0	1	0	0
124.08	left	I	up		0	0	0	0	0
124.35	right	S	rb		0	0	1	1	0
125.18	right	S	cm		0	0	0	0	0
125.22	left	I	cm		0	0	0	0	0
126.21	right	Sept.	rb		0	0	0	0	A1
126.23	right	Apr.	st		0	2	1	0	P3
126.29	left	Feb.	cm		1	0	0	0	0
126.38	left	S	cm		3	0	1	0	0
126.83	left	I	rb	126.9L	0	0	0	0	A1
126.86	right	S, I	rb	126.9R	2	0	1	1	P1
127.00	right	July	up		0	0	0	2	A2
127.29	right	S	rb	127.3R	0	1	0	1	A1
127.44	right	I	up		0	0	0	0	0
127.46	right	S, I	up		0	0	0	0	A1
127.86	right	S	bank		0	0	0	0	0
127.96	right	Feb.	bank		1	0	0	0	0

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
133.81	right	S, I	cm		1	0	0	0	0
133.84	right	I	cm		1	0	0	0	A1
134.27	right	S	rb-br		0	0	0	1	A1
134.91	right	S	st		0	0	0	0	0
134.93	right	S	st		0	0	0	0	0
136.43	left	S	rb-br		0	0	0	0	0
136.52	left	S	rb-br		1	0	0	0	0
137.32	left	I	cm		0	0	0	0	0
137.56	right	S	cm		0	0	0	0	A1
137.59	right	S	rb		0	0	0	0	A1
137.66	left	S, I	rb	137.7L	3	3	1	1	P1
137.76	left	S, I	rb		2	0	0	0	0
138.00	right	S, I	rb		0	3	0	0	0
138.23	left	Feb.	rb		3	0	0	0	A2
138.97	left	S	rb		3	2	1	0	A1
139.14	left	S, I	up		3	3	1	1	A1
139.34	right	S	sb		0	0	0	0	0
139.59	right	I	up	139.6R	1	0	1	1	0
140.01	right	S	bank		0	0	0	0	0
140.35	left	S, I	up		0	0	0	1	A1
141.41	left	S	rb		0	0	1	1	0
141.50	left	I	rb		1	0	0	0	0
141.65	left	Feb.	cm		3	0	0	0	0
142.18	right	S	rb		0	0	1	1	A1
143.06	right	S	rb		1	2	0	0	0
143.86	left	S	st		0	0	1	1	A1
145.38	left	S	cm		0	0	0	0	0
145.71	left	S	rb		0	0	0	0	0
145.84	left	S	rb	145.9L	3	0	1	1	0
146.42	right	I	rb		0	0	0	0	A1
146.72	left	Feb.	bank		3	0	0	0	0
146.88	left	May	sb		0	0	1	0	0
148.21	right	S	bank		3	0	1	0	A1
148.40	left	S	st		0	0	0	0	0
148.75	left	S	st		0	0	0	0	0
151.31	right	S	rb		0	0	3	0	A1
151.48	left	S	up		0	0	0	0	0
151.96	right	Feb.	bank		3	0	0	0	0
151.97	left	Feb.	bank		1	0	0	0	A1
152.20	left	S	rb		0	0	1	0	0
155.71	right	S	st		0	0	1	0	0
155.72	right	Feb.	sb		3	0	0	0	0
155.84	right	S	rb		0	0	0	0	0
157.22	right	I	rb-br		1	0	0	0	0
159.70	left	S	st		3	0	0	1	A2
159.91	right	S	cm		0	0	0	1	A1
160.11	right	S	cm		0	0	0	0	0
160.63	right	S	rb		0	0	0	1	A1
160.67	right	S	rb		0	0	1	0	0

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
161.25	left	S	cm		3	0	1	1	P1
161.25	right	S	up		1	0	0	1	A1
161.48	right	S	rb		0	0	0	0	0
161.49	left	S	bank		0	2	0	1	A1
161.55	right	S	up		1	0	0	1	A1
161.59	left	S	bank		0	0	0	0	A1
161.67	right	S	rb		3	0	0	0	A1
161.83	right	S	sb		2	0	0	0	0
161.93	left	S	sb		0	0	0	2	A1
162.00	right	S, I	sb		0	0	0	0	0
162.10	left	S, I	up		0	0	0	0	0
162.15	left	S, I	rb		3	2	0	0	A1
162.26	left	S	up		2	0	0	0	A2
162.83	right	S	cm		0	0	0	0	0
163.29	right	I	up		0	3	0	0	0
163.56	right	I	rb		1	0	0	0	0
164.34	left	I	cm		0	0	0	0	0
164.43	left	S, I	st		3	0	1	1	P1
164.49	left	Feb.	sb		1	0	1	1	0
164.96	right	S, I	up		2	0	0	1	A1
165.30	left	S, I	rb	165.3L	0	3	1	1	A1
165.33	left	Apr.	rb-ext	165.3L	0	3	1	1	0
165.45	left	S, I	rb		0	0	0	0	0
165.50	left	May	rb		0	0	1	0	0
165.65	right	S, I	rb	165.7R	2	0	0	2	A1
165.80	right	S, I	rb		0	0	0	1	0
165.91	left	S	rb		1	0	0	0	P1
165.97	right	S, I	rb		1	0	1	1	0
166.08	right	S	rb		0	2	0	0	0
166.26	left	I	rb		0	0	0	0	0
166.30	right	I	up		0	0	0	0	0
166.38	right	I	rb		2	0	0	0	0
166.53	right	S	cm		0	0	0	0	0
166.66	right	May	bank		0	0	1	0	0
166.88	left	S	up		3	0	1	2	P3
167.35	right	S	cm		0	0	0	0	0
167.42	right	S	gb		1	0	1	0	0
167.47	right	Feb.	cm		1	0	0	1	A1
167.50	right	S, I	rb		1	0	0	0	P1
167.67	right	Feb.	cm		3	0	0	1	P1
167.75	left	Feb.	st		2	0	0	0	0
167.80	left	S	rb		3	0	1	1	0
167.85	right	S, I	rb		0	0	1	1	A1
168.04	right	S, I	rb	168.1R	1	0	0	1	A1
168.06	left	S, I	rb		1	0	0	1	P1
168.14	right	S	bank		1	0	0	1	A1
168.17	right	S, I	rb		0	0	0	0	A1
168.25	right	I	rb		0	0	0	0	A1
168.32	right	S, I	rb		1	0	0	1	P1

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
168.44	right	S, I	up		1	0	0	0	A1
168.49	right	S	st		1	0	0	0	0
168.75	left	S, I	rb-br		0	0	1	0	0
168.76	right	S, I	rb		0	0	1	0	A1
168.86	left	S	rb		0	0	0	0	0
168.94	left	S	cm		1	0	0	0	0
169.06	left	S	cm		0	0	0	0	A1
169.18	left	S, I	rb		3	3	0	0	A1
169.22	right	S	rb		1	3	0	1	A1
169.30	left	S	bank		1	0	0	0	A1
169.35	left	S	cm		0	0	0	0	P1
170.23	left	S	cm		0	0	0	0	P1
170.60	right	S, I	rb		0	0	0	0	0
170.75	right	I	sb		0	0	0	0	0
170.89	left	S, I	rb		1	0	0	0	A1
171.06	left	Feb.	rb		1	0	0	0	A1
171.25	left	May	rb		0	0	1	0	0
171.70	right	S, I	rb		1	0	0	0	0
171.78	left	S, I	up		1	2	0	1	A1
172.13	left	I	rb		0	2	1	0	A1
172.22	left	S	rb-ext		0	0	0	0	0
172.55	left	S, I	rb	172.6L	2	3	3	1	A1
172.70	left	S	rb	172.7L	1	3	1	1	P1
172.92	left	Feb.	rb		1	0	0	0	0
173.07	right	S	rb		0	0	1	1	A1
173.09	left	S	rb		1	0	0	1	0
173.28	left	I	up		0	0	0	0	A1
173.29	right	I	rb		0	0	2	0	0
173.48	right	S, I	rb		0	0	1	1	A1
173.51	right	Apr.	rb-ext		0	3	0	0	0
173.65	right	I	up		0	0	0	0	0
173.81	right	I	rb		1	0	0	0	A1
173.91	right	I	cm		0	0	0	0	0
174.21	right	S	up		0	0	0	0	0
174.34	left	S, I	rb		3	0	0	1	A1
174.47	right	I	rb		0	0	0	0	A1
174.60	left	Feb.	gb		0	0	0	0	0
174.70	left	I	rb		0	0	0	0	0
175.14	left	S	sb		0	0	0	0	0
175.39	right	S, I	rb	175.4R	0	0	0	1	P3
175.68	right	I	rb		0	0	0	0	0
176.04	right	S, I	rb	176.1R	0	3	3	1	A1
176.11	right	Apr	rb-ext	176.1R	0	3	3	0	A1
176.39	right	S	rb		1	0	0	0	A1
176.58	right	S	cm		0	0	0	0	0
176.67	left	I	cm		0	0	0	0	A1
176.94	right	S, I	rb		0	3	3	1	A1
177.04	right	I	up		1	0	0	1	0
177.06	left	S	rb		1	0	1	0	0

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
177.38	left	I	rb		0	0	0	0	A1
177.48	left	S, I	rb		1	2	0	1	A1
177.60	left	May	st		0	0	1	0	0
177.76	left	I	rb		0	0	0	0	0
177.93		S	gb		3	0	0	0	A1
178.04	left	S	cm		2	0	0	0	A2
178.18	right	S	rb		0	3	1	0	A1
178.26	right	S, I	rb		0	0	1	0	A1
178.41	right	S, I	rb		1	0	1	1	P1
178.63	left	Feb.	rb		1	3	0	0	0
178.68	right	I	rb		0	0	0	0	0
178.79	left	S, I	rb		0	0	1	0	0
178.98	left	S, I	rb		0	0	1	0	A1
179.06	right	S	rb		0	0	0	0	0
179.28	right	S, I	rb	179.3R	3	0	0	0	A1
180.50	left	S	gb		0	0	1	0	A1
181.21	left	S, I	rb		0	2	0	0	0
181.37	right	S, I	rb	181.4R	1	1	0	1	P1
181.58	left	S, I	up		3	0	0	0	0
181.64	left	Feb.	rb		1	0	0	0	0
181.68	left	S, I	rb		1	0	0	0	A1
181.80	right	S, I	rb		0	0	0	0	A1
181.93	left	S	cm		0	0	0	0	0
182.12	right	Sept.	sb		0	0	0	0	P1
182.18	left	S, I	rb		0	0	0	0	P1
182.33	left	S	up		0	3	0	0	A1
182.39	right	S	up		0	0	0	0	0
182.61	right	S	gb		0	0	0	0	0
182.78	right	S, I	rb		0	3	0	0	A1
182.94	right	S, I	sb		1	0	2	0	A1
183.29	right	S, I	rb	183.3R	0	2	1	0	P1
183.73	left	S	cm		1	0	0	0	0
183.85	left	S	rb		0	0	0	0	0
184.47	right	I	rb-gb		0	0	0	0	0
184.53	right	Apr.	rb-gb		0	1	1	0	0
184.77	right	S	cm		1	0	0	0	0
184.80	right	Feb.	cm		0	0	0	0	A1
184.82	left	Apr.	cm		0	2	0	0	0
184.93	left	S, I	rb		1	0	2	0	A1
185.50	left	S, I	up		0	0	0	1	0
185.53	left	S	up		2	0	0	0	0
185.82	right	S, I	rb		0	1	0	0	0
186.00	left	S, I	rb		1	0	0	1	A1
186.03	right	Feb.	up		1	0	0	0	0
186.38	right	S, I	rb		3	3	2	1	0
186.58	left	S, I	up		0	0	0	1	0
186.74	left	I	rb		0	3	0	0	0
186.77	left	S, I	rb-ext		0	0	0	0	0
186.77	right	I	rb		0	0	0	0	A1

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
186.87	left	I	rb		0	0	0	0	A1
187.04	right	S	rb		0	0	0	0	0
187.10	left	S, I	rb		1	0	0	1	A1
187.15	left	S	rb-ext		0	0	0	0	A1
187.27	right	S, I	cm		0	0	0	0	0
187.85	right	Apr.	cm		0	2	0	0	0
187.95	right	S, I	rb	188R	0	3	1	0	A1
187.99	right	S	rb	188R	1	0	0	0	A1
188.48	right	Feb.	st		2	0	0	0	0
189.82	right	S, I	gb		0	0	0	0	A1
190.03	left	Feb.	up		2	0	0	0	0
190.22	left	I	bank		0	0	0	0	0
190.24	left	I	bank		0	0	0	0	0
190.39	right	I	gb		0	2	0	0	0
190.41	right	Apr.	gb		0	3	1	0	A1
190.50	left	S, I	bank		2	0	0	0	A1
190.53	left	S	bank		3	0	0	0	A1
190.69	left	S, I	up		0	0	0	0	A1
190.83	left	S, I	rb		0	0	1	0	0
191.52	right	Sept.	gb		0	0	0	0	P1
191.80	right	S, I	rb		0	0	1	0	A1
191.91	left	S, I	rb		0	0	0	0	A1
191.95	right	S, I	rb		1	0	0	0	0
192.09		S	gb		0	0	1	0	A1
192.14	left	S	cm		0	0	0	0	0
192.24	left	S	rb		2	0	0	0	A1
192.40	right	S	gb		0	0	0	1	A1
192.42	left	I	rb		0	0	0	0	A1
192.50	right	S	gb		0	0	0	0	A1
192.78	right	S, I	rb-gb		0	0	0	0	A1
193.37	left	I	rb		0	0	0	0	0
193.83	right	I	cm		0	0	0	0	0
194.03	left	I	rb-br		0	0	0	0	0
194.53	right	S, I	rb		1	0	1	1	A1
194.56	left	S, I	rb	194.6L	1	3	0	2	P1
194.60	right	S	rb-ext		2	0	0	0	0
195.55	right	S, I	cm		0	0	0	0	0
196.05	right	S, I	rb	196.1R	1	2	1	0	A1
196.19	left	S	gb		0	0	0	0	A1
196.31	right	Feb.	sb	196.4R	1	0	0	0	0
196.35	right	Feb.	rb	196.4R	1	0	0	0	0
196.37	right	S, I	rb	196.4R	2	0	0	1	A1
197.07	left	S	rb		0	0	0	0	0
197.20	left	May	cm		0	0	1	0	0
197.28	right	S	rb		0	0	1	0	P1
197.89	right	S, I	rb	197.9R	1	0	1	0	0
198.00	left	S, I	sb		0	1	1	1	P1
198.02	right	Feb.	rb		3	3	3	0	0
198.06	left	Feb.	rb		0	0	0	0	0

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
198.15	left	S	up		0	0	1	0	0
198.20	right	I	sb		0	0	0	0	0
198.25	left	S, I	rb		0	3	0	0	A1
198.37	right	S, I	rb		0	0	1	0	0
198.90	right	S	st		3	0	0	0	P3
199.28	right	Apr.	gb		0	1	0	0	A2
199.51	left	S, I	rb	199.5L	1	0	2	0	P1
199.53	right	S	rb	199.5R	0	3	3	0	A1
199.86	left	May	gb		0	0	2	0	0
200.32	left	S, I	rb		1	0	0	0	A1
200.50	right	S, I	sb		1	0	1	0	0
200.54	left	S	rb		0	0	1	0	A1
200.64	left	S, I	cm		0	0	0	0	A1
200.89	left	I	rb		0	0	0	1	P1
200.95	right	S, I	rb		0	3	3	0	A1
200.96	left	I	rb-ext		0	0	0	0	0
201.28	right	S, I	rb		0	2	0	0	P1
201.31	right	S	rb-ext		0	2	0	0	0
201.65	right	S, I	rb	201.7R	1	3	3	1	A3
201.72	right	Feb.	bank		1	0	0	0	A1
201.80	right	Sept.	cm		0	0	0	0	P1
202.64	right	Feb.	cm		0	0	0	0	0
202.77	right	S	rb		0	0	0	0	A1
202.86	right	S, I	rb		1	0	1	0	A1
203.14	left	Apr.	cm		0	2	1	0	0
203.22	left	I	gb		0	0	0	0	0
203.35	left	May	gb		0	0	3	0	A1
203.43	right	I	rb		1	0	1	0	0
203.51	left	S, I	rb		0	0	0	0	0
203.55	left	I	rb-ext		0	0	0	0	A1
203.81	left	S, I	rb		0	3	0	0	0
204.17	right	S, I	rb		0	0	0	0	A1
204.36	right	S, I	rb	204.4R	0	3	3	1	A1
204.42	right	S	rb-ext		0	0	3	0	0
204.60	left	I	rb		1	0	1	0	A1
204.66	right	Feb.	sb		3	0	0	0	0
204.66	left	S	rb		0	0	2	0	A1
204.67	right	S	sb		3	0	0	0	0
204.69	left	S	rb		0	0	0	0	0
204.84	right	Feb.	rb		1	0	2	0	A2
204.89	right	S, I	rb-ext		0	0	0	0	0
205.21	right	S, I	rb		3	0	0	0	0
205.22	left	S	rb	205.2L	0	3	3	3	A3
205.23	right	S, I	rb		3	0	0	0	A1
205.73	left	Feb.	sb		2	0	0	0	0
206.66	right	S, I	rb	206.7R	0	3	3	0	A2
207.08	right	Apr.	bank		0	3	0	0	0
207.45	right	S	cm		0	0	0	0	0
207.72	right	S	gb		0	0	0	1	A1

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
207.94	left	S, I	rb-gb		1	3	0	0	0
207.97	right	S	sb		0	0	0	0	0
208.11	right	Feb.	cm		1	0	0	0	0
208.40	left	S, I	rb		1	0	0	0	A1
208.56	right	S	cm		0	0	1	0	0
208.61	left	I	rb-br		0	0	0	0	0
209.00	right	Feb.	st		3	0	2	0	0
209.62	left	S	gb		3	3	0	0	A1
210.64	right	S	cm		0	0	0	0	0
210.77	right	S	rb		1	0	0	0	A1
211.01	right	Feb.	cm		3	0	0	0	0
211.12	right	S	rb		0	0	0	0	A1
211.37	left	S, I	rb	211.4L	0	0	0	0	A1
211.62	left	S, I	rb		1	3	1	0	P1
211.83	right	S, I	rb-gb	211.8R	3	0	0	0	P1
211.86	right	I	rb-ext	211.8R	0	0	0	0	A1
212.85	left	S	cm		0	0	0	0	0
213.01	right	S, I	rb	213R	0	1	1	0	A1
213.27	left	S	up	213.3L	0	0	0	0	0
213.27	right	I	rb		0	0	0	0	0
214.44	right	S	rb	214.5R	0	0	1	0	P1
214.55	left	I	rb		0	0	0	0	A1
214.55	right	May	sb		0	0	2	0	0
214.67	left	S	bank		0	0	0	0	0
214.85	right	I	cm		0	0	0	0	0
214.89	right	S, I	cm		0	0	0	0	0
214.94	left	I	cm		0	0	0	0	0
215.30	left	I	rb		3	0	1	0	0
215.51	left	S	rb		1	0	0	0	0
215.83	left	I	rb		0	0	0	0	0
215.95	right	I	cm		0	0	0	0	0
216.37	left	Apr.	up		0	2	0	0	A1
216.64	right	S, I	rb	216.6R	0	2	0	0	0
216.67	right	Apr.	rb-ext	216.6R	0	3	0	0	0
217.08	left	I	up		0	3	0	0	0
217.09	left	Apr.	up		0	3	0	0	0
217.45	left	I	rb		2	0	0	0	A1
218.03	left	Apr.	sb		0	2	2	0	0
218.54	right	I	bank		0	0	0	0	0
219.38	left	S	rb		2	0	0	0	0
219.47	right	I	sb		0	0	0	0	0
219.80	right	I	sb		0	0	0	0	0
220.05	right	S	cm		0	0	0	0	A1
220.14	right	S	up	220.1R	0	0	0	0	0
220.14	left	Apr.	rb-ext		0	2	3	0	0
220.38	right	S, I	cm		0	0	0	0	A1
220.40	left	Sept.	rb		0	0	0	0	P1
220.49	right	S	cm		0	0	0	0	P1
220.59	left	I	rb-br		0	0	1	0	0

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
221.43	left	Apr.	bank		0	3	0	0	A1
221.54	right	S, I	rb		1	0	0	0	A1
221.69	left	S, I	rb		0	0	0	0	A1
222.14	right	S	sb		0	2	0	0	0
222.34	left	S	rb	222.3L	2	0	1	0	0
222.46	left	S, I	rb		0	0	1	0	A1
222.63	left	S, I	gb		1	0	0	0	A1
222.85	left	S	rb		0	0	0	0	A1
223.15	left	Apr.	rb		0	3	0	0	0
223.36	left	I	rb		1	3	2	0	P1
223.73	left	I	cm		0	0	0	0	A1
225.45	left	May	cm		0	0	1	0	0
225.48	right	I	rb	225.5R	0	0	0	0	0
225.71	right	S	sb		0	0	0	0	0
228.09	left	Feb.	rb	228.1L	0	0	0	0	--
228.75	left	Feb.	bank		1	0	1	0	--
229.64	right	Feb.	up		0	0	0	0	--
233.10	right	Feb.	bank		0	0	0	0	--
233.89	left	Feb.	bank		3	0	0	0	--
234.38	right	Feb.	bank		1	0	0	0	--
234.41	right	Feb.	bank		1	0	0	0	--
235.23	left	Apr.	up		0	1	0	0	--
237.82	right	Apr.	bank		0	3	0	0	--
238.54	left	Apr.	rb-br		0	3	0	0	--
238.74	left	Feb.	rb		0	0	0	0	--
238.79	right	Apr.	rb-br		0	3	1	0	--
238.81	right	Apr.	rb-br		0	3	1	0	--
239.39	left	Apr.	rb-br		0	3	0	0	--
239.55	right	Apr.	rb	239.6R	0	0	0	0	--
239.81	right	Apr.	st		0	3	3	0	--
240.53	left	Apr.	bank		0	0	0	0	--
240.56	right	Feb.	bank		3	0	3	0	--
240.60	left	Feb.	up		2	3	3	0	--
240.62	left	Feb.	up		3	0	0	0	--
240.65	left	Apr.	rb		0	3	0	0	--
241.45	right	Apr.	bank		0	1	0	0	--
241.49	right	Feb.	rb-br		0	1	0	0	--
241.76	left	Apr.	bank		0	1	0	0	--
242.17	right	Apr.	bank		0	1	0	0	--
242.29	right	Apr.	bank		0	1	0	0	--
242.49	left	Apr.	bank		0	3	0	0	--
242.79	left	Feb.	bank		1	0	0	0	--
242.94	right	Feb.	rb-br	242.9R	3	0	0	0	--
243.65	right	Apr.	bank		0	3	0	0	--
243.66	left	Apr.	cm		0	3	2	0	--
244.15	left	Apr.	bank		0	3	0	0	--
244.20	left	Feb.	bank		1	0	0	0	--
244.33	left	Apr.	bank		0	1	0	0	--
245.05	left	Apr.	bank		0	1	0	0	--

Appendix A. Data from backwater inventories conducted between February and September 2008.--Continued

River mile	River side	Source	Class	Site[1]	Status in backwater inventory				
					Feb.-08	Apr.-08	May-08	July-08	Sept.-08
247.81	left	Apr.	bank		0	3	0	0	--
248.27	left	Feb.	cm		1	0	0	0	--
248.80	right	Feb.	cm		0	3	0	0	--
248.83	right	Apr.	cm		0	0	3	0	--
249.56	right	Feb.	bank		1	0	0	0	--
250.01	right	Apr.	cm		0	0	1	0	--
250.06	left	Feb.	rb-br		3	1	0	0	--
250.53	right	Feb.	rb-br		1	0	0	0	--
253.26	right	Feb.	rb		1	0	0	0	--
256.76	right	Feb.	bank		1	0	0	0	--
257.00	right	Feb.	bank		1	0	0	0	--
257.57	left	Feb.	rb		3	0	0	0	--
257.96	right	Apr.	cm		0	3	3	0	--

[1]A study site may appear in multiple lines in the inventory because several study sites have multiple backwater locations.

Appendix B. List of Sandbar Monitoring and Backwater Monitoring Study Sites, the Date and Time of Each Survey, and the Discharge at Time of Survey

[Site location is in river mile (downstream from Lees Ferry), with left (L) and right (R) side of river when looking downstream indicated. Site code is the label used to identify each site in the backwater processing files, and indicating whether data were used in analyses presented in text: Y indicates data were used in analyses; Z indicates no backwaters were present during study period and site was included with zero values; N indicates site was not included in analyses]

Location		Site code		Site type[1]	Date of survey[2]				Discharge at time of survey (m^3/s)[2]			
					Feb.-08	Apr.-08	May-08	Oct.-08	Feb.-08	Apr.-08	May-08	Oct.-08
1.2	R	1R	Y	SBM	2-Feb.	28-Mar.	17-May	11-Oct.	285	278	232	355
2.5	L	3L	Y	SBM*	2-Feb.	28-Mar.	17-May	11-Oct.	322	352	318	394
3.37	L	3_4L	Y	BWM**	2-Feb.	29-Mar.	17-May	20-Sept.	292	268	289	351
6.07	L	6L	Y	BWM	3-Feb.	29-Mar.	17-May	20-Sept.	266	283	339	351
8.9	L	9L	Y	SBM	3-Feb.	29-Mar.	17-May	12-Oct.	252	300	369	358
9.93	L	10L	Y	BWM	3-Feb.	29-Mar.	17-May	20-Sept.	289	270	375	351
16.6	L	16L	Y	SBM*	3-Feb.	29-Mar.		12-Oct.	282	279		384
17.6	R	17R	Y	BWM	3-Feb.	30-Mar.	18-May	21-Sept.	295	219	272	351
19.61	R	19R	Y	BWM	4-Feb.	30-Mar.	17-May	21-Sept.	264	219	270	
22	R	22R	Y	SBM**	3-Feb.	29-Mar.	17-May	12-Oct.	284	267	265	366
29.28	R	29R	Y	BWM	4-Feb.	30-Mar.	17-May	22-Sept.	259	217	276	349
30.7	R	30R	Y	SBM**	4-Feb.	30-Mar.	19-May	13-Oct.	266	257	336	365
33.3	L	33L	Y	SBM	5-Feb.	30-Mar.		13-Oct.	264	220		347
35.63	R	36R	Y	BWM	4-Feb.	30-Mar.	19-May	23-Sept.	269	226	341	
37.55	R	37R	N	BWM	4-Feb.	31-Mar.		23-Sept.	266	255		
41.3	R	41R	Y	SBM*	5-Feb.	31-Mar.	19-May	14-Oct.	303	316	294	357
43.4	L	43L	Z	SBM	6-Feb.	31-Mar.	19-May	14-Oct.	282	273	301	368
44.5	L	44L	Y	SBM*	6-Feb.	31-Mar.	19-May	14-Oct.	270	237		345
45	L	45L	Y	SBM**	7-Feb.	31-Mar.	20-May	15-Oct.	320	227	385	358
45.93	R	46R	Y	BWM	5-Feb.	31-Mar.	20-May	24-Sept.	330	313	377	356
46.39	L	46L	N	BWM	5-Feb.	31-Mar.						
47.6	R	47R	Y	SBM*	7-Feb.	31-Mar.	20-May	15-Oct.	339	307	343	361
48.79	R	49R	Y	SBM	5-Feb.	31-Mar.	20-May	24-Sept.	286	269	394	346
48.91	L	49L	Y	SBM	5-Feb.	31-Mar.	20-May	24-Sept.	301	273		
50.1	R	50R	Y	SBM*		1-Apr.	20-May	15-Oct.		292	309	360
50.28	L	50L	Y	BWM	5-Feb.	1-Apr.	20-May	24-Sept.	275	319	313	355
50.64	L	50_6L	N	BWM	6-Feb.	1-Apr.			342	307		
50.91	L	50_9L	Y	BWM	6-Feb.	1-Apr.	21-May	24-Sept.	342	284	394	355
51.5	L	51L	Y	SBM**	8-Feb.	2-Apr.	21-May	15-Oct.	335	328	414	358
54.6	R	54R	Y	SBM	6-Feb.	1-Apr.	21-May	16-Oct.	334	287		358

Appendix B. List of sandbar monitoring and backwater monitoring study sites.--Continued

Location		Site code		Site type[1]	Date of survey[2]				Discharge at time of survey (m^3/s)[2]			
					Feb.-08	Apr.-08	May-08	Oct.-08	Feb.-08	Apr.-08	May-08	Oct.-08
55.02	R	55_0R	Y	BWM	6-Feb.	1-Apr.	21-May	25-Sept.	319	310	333	356
55.9	R	55R	Y	SBM*	8-Feb.	2-Apr.	21-May	16-Oct.	318	275	328	348
56.6	R	56R	Z	SBM		2-Apr.	21-May	16-Oct.		252	303	372
57.75	L	57L	N	BWM	7-Feb.	1-Apr.						
58.1	L	58L	Y	SBM	8-Feb.	3-Apr.	23-May	17-Oct.	307	337	511	368
58.72	R	59R	N	BWM	7-Feb.	2-Apr.			313	322		
59.19	L	59L	Y	BWM	7-Feb.	2-Apr.	23-May	25-Sept.	340	321	418	356
59.48	L	60L	Y	BWM	7-Feb.	2-Apr.	23-May	25-Sept.	329	342	433	355
62.3	L	62L	Y	BWM	8-Feb.	2-Apr.	23-May		308	385	334	
63.6	L	63L	Y	SBM	9-Feb.	3-Apr.	24-May	17-Oct.	337	340	397	340
64.36	L	64L	Y	BWM**	8-Feb.	2-Apr.	24-May	25-Sept.	306	369		
64.5	L	64L	Y	BWM	8-Feb.	2-Apr.	24-May	25-Sept.				
64.93	L	64_9L	Y	BWM	8-Feb.	2-Apr.	24-May	17-Oct.	344	363	439	364
65.1	R	65R	Y	SBM	9-Feb.	4-Apr.	24-May	17-Oct.	372	332	410	387
65.8	L	65L	Y	SBM**	8-Feb.	3-Apr.	24-May	17-Oct.	375	347	424	368
66.11	L	66L	Y	SBM	9-Feb.	3-Apr.	24-May	18-Oct.	296	315	353	363
67.43	L	67L	Y	BWM	9-Feb.	3-Apr.	24-May	26-Sept.	295	384	305	
68.49	L	68L	Y	BWM	9-Feb.	3-Apr.	25-May	26-Sept.	351	381	439	
68.8	R	69R	Y	SBM*	10-Feb.	5-Apr.	25-May	18-Oct.	279	341	420	344
71.67	L	72L	Y	BWM	9-Feb.	4-Apr.	25-May	18-Oct.	347	358	438	365
72.54	R	73R	N	BWM	9-Feb.	4-Apr.			351	355		
84.6	R	84R	Y	SBM	11-Feb.	6-Apr.		27-Sept.	309	279		353
87.6	L	87L	Z	SBM*	11-Feb.	6-Apr.		19-Oct.	334	329		368
87.87	L	87_8L	N	BWM	10-Feb.	5-Apr.		27-Sept.	279	306		
88.1	R	88R	Y	SBM	11-Feb.	6-Apr.		19-Oct.	327	300		337
93.8	L	93L	Y	SBM*	12-Feb.	7-Apr.		20-Oct.	322	276		360
104.42	R	104R	Y	SBM*	12-Feb.	7-Apr.		20-Oct.	323	303		360
116.46	L	116L	Y	BWM	11-Feb.	5-Apr.		28-Sept.	285	356		
119.03	R	119R	Y	BWM	11-Feb.	6-Apr.	27-May	29-Sept.	290	288	322	
119.4	R	119_4R	Y	SBM*	12-Feb.	8-Apr.		21-Oct.	319	299		372
119.8	R	119_8R	Y	SBM**	12-Feb.	8-Apr.	27-May	21-Oct.	317	318	386	368
119.91	L	119_9L	Y	BWM	11-Feb.	6-Apr.	27-May	29-Sept.	294	280	346	361
120.1	L	120L	Y	BWM	11-Feb.	6-Apr.	27-May	21-Oct.	297	297	372	363
120.5	R	120R	Y	BWM	11-Feb.	6-Apr.	27-May	21-Oct.	297	302	407	363
121.55	L	121L	Y	BWM	12-Feb.	6-Apr.	27-May	21-Oct.	325	303		363
121.85	L	122L	Y	BWM	12-Feb.	7-Apr.	27-May	21-Oct.	342	267		372
122.71	R	122R	Y	SBM*	12-Feb.	8-Apr.	27-May	21-Oct.	343	337	411	363
122.88	L	122_9L	Y	BWM	12-Feb.	7-Apr.	28-May	21-Oct.	323	269	332	366
123.25	L	123L	Y	SBM**	13-Feb.	8-Apr.	28-May	21-Oct.	358	286	360	376
126.85	R	126R	Y	BWM	12-Feb.	7-Apr.	28-May	29-Sept.	292	266	347	361

Appendix B. List of sandbar monitoring and backwater monitoring study sites.--Continued

Location		Site code		Site type[1]	Date of survey[2]				Discharge at time of survey (m^3/s)[2]			
					Feb.-08	Apr.-08	May-08	Oct.-08	Feb.-08	Apr.-08	May-08	Oct.-08
126.85	L	126L	Y	BWM	12-Feb.	7-Apr.	28-May	29-Sept.	292	266	347	361
127.29	R	127R	Y	BWM	12-Feb.	7-Apr.	28-May	29-Sept.	345	265		
137.7	L	137L	Y	SBM*	13-Feb.	9-Apr.		22-Oct.	336	284		362
139.6	R	140R	Y	SBM*	13-Feb.	9-Apr.		22-Oct.	346	299		380
145.85	L	145L	Y	SBM*	13-Feb.	9-Apr.	29-May	22-Oct.	346	327	327	365
165.3	L	165L	Y	BWM	13-Feb.	7-Apr.	29-May	30-Sept.	348	328	343	
165.65	R	166R	Y	SBM	13-Feb.	10-Apr.	29-May	30-Sept.	359	338	347	340
168.06	R	168R	Y	BWM	13-Feb.	8-Apr.	30-May	1-Oct.	335	300	384	360
172.6	L	172L	Y	SBM**	14-Feb.	10-Apr.	30-May	23-Oct.	344	297	362	346
172.7	L	173L	N	BWM	14-Feb.	9-Apr.	30-May	1-Oct.	377	363	381	360
175.39	R	175R	Y	BWM	14-Feb.	9-Apr.	30-May	1-Oct.	383	365	365	360
176.05	R	176R	Y	BWM	14-Feb.	9-Apr.	30-May	1-Oct.	366	332	355	360
179.3	R	179R	Y	BWM	14-Feb.	9-Apr.	30-May	2-Oct.	365	344		
181.37	R	181R	Y	BWM	15-Feb.	10-Apr.	31-May	2-Oct.	391	363	432	
183.3	R	183R	Y	SBM*	15-Feb.	11-Apr.	31-May	24-Oct.	386	363	417	369
187.95	R	188R	Y	BWM	15-Feb.	10-Apr.	31-May	2-Oct.	384	363	420	
194.6	L	194L	Y	SBM*	15-Feb.	11-Apr.	31-May	24-Oct.	376	349	377	363
196.1	R	196R	Y	BWM	16-Feb.	10-Apr.	31-May	25-Oct.	383	352	391	
196.37	R	197R	Y	BWM	16-Feb.	10-Apr.	31-May					
197.9	R	198R	Y	BWM	16-Feb.	11-Apr.	31-May	25-Oct.	390	354	372	
199.5	L	200L	Y	BWM	16-Feb.	11-Apr.	11- June	25-Oct.	357	296	448	
199.5	R	200R	Y	BWM**	16-Feb.	11-Apr.	11- June	25-Oct.	357	296	462	
201.65	R	201R	Y	SBM	10-Feb.	11-Apr.	1-June	25-Oct.	350	353	405	369
204.35	R	204R	Y	BWM	17-Feb.	12-Apr.	1- June	3-Oct.	345	342	421	
205.22	L	205L	Y	BWM	17-Feb.	12-Apr.	1-June	3-Oct.	346	341	402	
206.66	R	207R	Y	BWM	17-Feb.	12-Apr.	1-June		364	348		
211.37	L	211L	Y	BWM	17-Feb.	12-Apr.	2-June	4-Oct.	357	357	460	
211.83	R	212R	Y	BWM	17-Feb.	12-Apr.	2-June	4-Oct.	378	356	460	
213.01	R	213R	Y	BWM	17-Feb.	13-Apr.	2-June	4-Oct.	376	340	442	
213.27	L	213L	Z	SBM*	17-Feb.	12-Apr.	2-June	26-Oct.	344	338	433	362
214.5	R	214R	Y	SBM	17-Feb.	12-Apr.	2-June	26-Oct.	363	343	453	374
216.58	R	217R	Y	BWM	18-Feb.	13-Apr.	3-June	4-Oct.	343	337		
220.1	R	220R	Z	SBM	17-Feb.	12-Apr.		26-Oct.	449	415		438
222.34	L	222L	N	BWM	18-Feb.	13-Apr.			348	330		
225.5	R	225R	Y	SBM**	18-Feb.	13-Apr.	3-June	26-Oct.	372	328	391	364
228.12	L	228L	N	BWM	18-Feb.	13-Apr.						
239.55	R	239R	N	BWM	19-Feb.	14-Apr.						
242.93	R	243L	N	BWM	19-Feb.							

[1]SBM is for sandbar monitoring site and BWM is for backwater monitoring site. Sites with * have a remote film camera and sites with ** have a remote digital camera.

[2]Blank cells indicate site was not surveyed at that time.

Appendix C. Relations Between Water Surface Elevation and Discharge for Study Sites

[Site code is the label used to identify each site (see appendix B). Y, data were used in analyses; 0, no backwaters were present during study period and site was included with zero values; N, site was not included in analyses. The number of stage observations is the number of independent observations. Each observation consists of one or many measurements of water surface elevation that were averaged. Z, elevation in meters; Q, discharge in cubic meters per second. Stage-discharge relations for SBM sites were determined by Hazel and others (2006a) where additional information is available. Relations are only valid for the range of flows observed, which is from about 227 to 1,274 m^3/s]

Site code	Site type[1]		Number of observations of stage	Equation	R^2
1R	SBM	Y	--	$Z = 9.20E+02 + 1.64E-04Q - 1.51E-09Q^2$	--
3L	SBM	Y	--	$Z = 9.20E+02 + 1.70E-04Q - 1.41E-09Q^2$	--
3_4L	BWM	Y	11	$Z = 9.17E+02 + 9.35E-03Q - 3.90E-06Q^2$	0.98
6L	BWM	Y	7	$Z = 8.20E+02 + 9.12E+01Q^{1.36E-02}$	0.88
9L	SBM	Y	--	$Z = 9.09E+02 + 2.34E-04Q - 2.23E-09Q^2$	--
10L	BWM	Y	9	$Z = 9.09E+02 + 5.91E-03Q - 1.23E-06Q^2$	0.99
16L	SBM	Y	--	$Z = 8.95E+02 + 1.47E-04Q - 1.14E-09Q^2$	--
17R	BWM	Y	9	$Z = 8.90E+02 + 8.44E-03Q -3.02E-06Q^2$	1.00
19R	BWM	Y	10	$Z = 7.94E+02 + 8.49E+01Q^{1.96E-02}$	0.99
22R	SBM	Y	--	$Z = 8.78E+02 + 2.91E-04Q - 2.45E-09Q^2$	--
29R	BWM	Y	11	Z = 8.59E+02 + 4.57E-03Q - 5.43E-07Q2	0.98
30R	SBM	Y	--	$Z = 8.54E+02 + 2.41E-04Q - 1.89E-09Q^2$	--
33L	SBM	Y	--	$Z = 8.49E+02 + 1.83E-04Q - 8.87E-10Q^2$	--
36R	BWM	Y	8	$Z = 7.52E+02 + 8.73E+01Q^{1.68E-02}$	0.94
37R	BWM	N	na	na	na
41R	SBM	Y	--	$Z = 8.40E+02 + 1.67E-04Q - 9.15E-10Q^2$	--
43L	SBM	0	--	$Z = 8.38E+02 + 7.16E-03Q - 1.95E-06Q^2$	
44L	SBM	Y	--	$Z = 8.36E+02 + 1.86E-04Q - 1.34E-09Q^2$	--
45L	SBM	Y	--	$Z = 8.35E+02 + 1.44E-04Q - 5.59E-10Q^2$	--
46R	BWM	N	8	$Z = 8.35E+02 + 3.65E-03Q - 2.69E-07Q^2$	0.99
46L	BWM	N	na	na	na
47R	SBM	Y	--	$Z = 8.33E+02 + 1.66E-04Q - 1.26E-09Q^2$	--
49R	SBM	Y	--	$Z = 8.32E+02 + 1.01E-04Q - 1.59E-11Q^2$	--
49L	SBM	Y	--	$Z = 8.32E+02 + 1.00E-04Q + 4.21E-11Q^2$	--
50R	SBM	Y	--	$Z = 8.29E+02 + 1.78E-04Q - 1.24E-09Q^2$	--
50L	BWM	Y	9	$Z = 8.29E+02 + 7.86E-03Q - 3.40E-06Q^2$	0.99

Appendix C. Relations between water surface elevation and discharge for study sites.--Continued

Site Code	Site Type[1]		Number of observations of stage	Equation	R^2
50_6L	BWM	N	na	na	na
50_9L	BWM	Y	10	$Z = 8.29E+02 + 5.54E-03Q - 4.43E-07Q^2$	1.00
51L	SBM	Y	--	$Z = 8.29E+02 + 1.73E-04Q - 1.41E-09Q^2$	--
54R	SBM	Y	--	$Z = 8.20E+02 + 1.44E-04Q - 9.20E-10Q^2$	--
55_0R	BWM	N	9	$Z = 8.20E+02 + 5.61E-03Q - 1.78E-06Q^2$	1.00
55R	SBM	Y	--	$Z = 8.19E+02 + 1.24E-04Q - 1.02E-09Q^2$	--
57R	SBM	0	--	--	--
57L	BWM	N	na	na	na
58L	SBM	Y	--	$Z = 8.10E+02 + 1.79E-04Q - 1.47E-09Q^2$	--
59R	BWM	N	na	na	na
59L	BWM	Y	11	$Z = 8.08E+02 + 4.91E-03Q - 1.03E-06Q^2$	1.00
60L	BWM	Y	9	$Z = 8.08E+02 + 4.70E-03Q - 9.09E-07Q^2$	1.00
62L	BWM	N	9	$Z = 7.92E+02Q^{2.40E-03}$	0.93
63L	SBM	Y	--	$Z = 7.98E+02 + 2.38E-04Q - 2.43E-09Q^2$	--
64L	BWM	Y	8	$Z = 7.96E+02 + 6.02E-03Q- 1.57E-06Q^2$	1.00
64_5L	BWM	Y	na	na	na
64_9L	BWM	Y	9	$Z = 7.97E+02 + 2.44E-03Q+ 3.59E-07Q^2$	1.00
65R	SBM	Y	--	$Z = 7.96E+02 + 1.22E-04Q - 7.79E-10Q^2$	--
65L	SBM	Y	--	$Z = 7.96E+02 + 1.23E-04Q - 1.01E-09Q^2$	--
66L	SBM	Y	--	$Z = 7.94E+02 + 5.04E-05Q - 8.69E-11Q^2$	--
67L	BWM	Y	7	$Z = 7.89E+02 + 6.05E-03Q - 1.63E-06Q^2$	1.00
68L	BWM	Y	8	$Z = 7.86E+02 + 3.46E-03Q - 5.72E-07Q^2$	1.00
69R	SBM	Y	--	$Z = 7.76E+02 + 1.17E-04Q - 9.36E-10Q^2$	--
72L	BWM	Y	8	$Z = 7.77E+02 + 3.22E-03Q - 7.80E-07Q2$	1.00
73R	BWM	N	na	na	na
84R	SBM	Y	--	$Z = 7.25E+02 + 1.76E-04Q - 9.49E-10Q^2$	--
87L	SBM	0	--	$Z = 7.16E+02 + 2.13E-04Q - 2.01E-09Q^2$	--
87_8L	BWM	N	na	na	na
88R	SBM	Y	--	$Z = 7.16E+02 + 1.66E-04Q - 1.34E-09Q^2$	--
94L	SBM	Y	--	$Z = 6.97E+02 + 1.61E-04Q - 1.51E-09Q^2$	--
104R	SBM	Y	--	$Z = 6.58E+02 + 1.87E-04Q - 1.49E-09Q^2$	--
116L	BWM	Y	8	$Z = 6.19E+02 + 6.97E-03Q - 1.53E-06Q^2$	1.00
119R	BWM	Y	11	$Z = 6.16E+02 + 3.46E-03Q + 4.69E-07Q^2$	0.99
119_4R	SBM	Y	--	$Z = 6.14E+02 + 2.04E-04Q - 1.42E-09Q^2$	--
119_8R	SBM	Y	--	$Z = 6.13E+02 + 2.00E-04Q - 1.39E-09Q^2$	--
119_9L	BWM	Y	13	$Z = 6.14E+02 + 6.05E-03Q - 1.29E-06Q^2$	0.99
120L	BWM	Y	9	$Z = 6.12E+02 + 1.06E-02Q - 4.19E-06Q^2$	0.99
120R	BWM	Y	9	$Z = 6.14E+02+8.02E-04Q + 1.88E-06Q^2$	1.00
121L	BWM	Y	13	$Z = 6.10E+02 + 8.81E-03Q - 2.99E-06Q^2$	0.99

Appendix C. Relations between water surface elevation and discharge for study sites.--Continued

Site Code	Site Type[1]		Number of observations of stage	Equation	R^2
122L	BWM	Y	9	$Z = 6.10E+02 + 7.14E-03Q - 2.10E-06Q^2$	0.98
122R	SBM	Y	--	$Z = 6.08E+02 + 2.08E-04Q - 1.72E-09Q^2$	--
122_9L	BWM	Y	11	$Z = 6.08E+02 + 6.44E-03Q - 1.73E-06Q^2$	0.99
123L	SBM	Y	--	$Z = 6.07E+02 + 2.21E-04Q - 2.06E-09Q^2$	--
126R	BWM	Y	12	$Z = 5.94E+02 + 7.75E-03Q - 2.78E-06Q^2$	1.00
126L	BWM	Y	7	$Z = 5.94E+02 + 8.38E-03Q - 2.85E-06Q^2$	1.00
127R	BWM	N	9	$Z = 5.92E+02 + 9.58E-03Q - 3.23E-06Q^2$	1.00
137L	SBM	Y	--	$Z = 5.62E+02 + 1.98E-04Q - 1.45E-09Q^2$	--
140R	SBM	Y	--	$Z = 5.57E+02 + 2.12E-04Q - 1.61E-09Q^2$	--
145L	SBM	Y	--	$Z = 5.40E+02 + 2.35E-04Q - 1.78E-09Q^2$	--
165L	BWM	N	10	$Z = 5.92E+02 + 4.42E-03Q - 1.06E-07Q^2$	0.99
166R	SBM	Y	--	$Z = 5.05E+02 + 3.22E-04Q - 3.72E-09Q^2$	--
168R	BWM	N	10	$Z = 5.06E+02 + 4.22E-03Q - 3.98E-07Q^2$	0.99
172L	SBM	Y	--	$Z = 4.97E+02 + 1.71E-04Q - 1.15E-09Q^2$	--
173L	BWM	N	8	$Z = 4.97E+02 + 5.38E-03Q - 1.07E-06Q^2$	1.00
175R	BWM	Y	9	$Z = 4.93E+02 + 3.10E-03Q + 6.81E-07Q^2$	0.99
176R	BWM	Y	9	$Z = 4.91E+02 + 3.30E-03Q - 4.65E-08Q^2$	1.00
179R	BWM	N	8	$Z = 4.86E+02 + 6.21E-03Q - 1.65E-06Q^2$	1.00
181R	BWM	Y	10	$Z = 4.75E+02 + 4.98E-03Q - 1.01E-06Q^2$	1.00
183R	SBM	Y	--	$Z = 4.70E+02 + 1.96E-04Q - 1.50E-09Q^2$	--
188R	BWM	N	7	$Z = 4.62E+02 + 4.86E-03Q - 1.21E-06Q^2$	1.00
194L	SBM	Y	--	$Z = 4.47E+02 + 1.82E-04Q - 1.41E-09Q^2$	--
196R	BWM	Y	12	$Z = 4.43E+02 + 6.24E-03Q - 1.93E-06Q^2$	0.99
197R	BWM	N	7	$Z = 9.73E+01 + 3.10E-03Q - 5.07E-08Q^2$	0.98
198R	BWM	Y	8	$Z = 4.40E+02 + 4.06E-03Q - 6.60E-07Q^2$	1.00
200L	BWM	Y	8	$Z = 4.37E+02 + 4.99E-03Q - 1.27E-06Q^2$	0.99
200R	BWM	Y	6	$Z = 4.37E+02 + 4.03E-03Q - 6.73E-07Q^2$	1.00
201R	SBM	Y	--	$Z = 4.30E+02 + 4.78E-04Q - 6.50E-09Q^2$	--
204R	BWM	Y	9	$Z = 4.30E+02 + 4.08E-03Q - 6.59E-07Q^2$	0.99
205L	BWM	Y	8	$Z = 4.29E+02 + 4.53E-03Q - 1.09E-06Q^2$	0.98
207R	BWM	N	10	$Z = 4.22E+02 + 4.33E-03Q - 1.04E-06Q^2$	1.00
211L	BWM	Y	7	$Z = 4.09E+02 + 5.78E-03Q - 7.82E-07Q^2$	1.00
212R	BWM	Y	7	$Z = 4.09E+02 + 3.39E-03Q + 7.89E-07Q^2$	1.00
213R	BWM	N	9	$Z = 4.04E+02 + 7.20E-03Q - 1.12E-06Q^2$	1.00
213L	SBM	0	--	$Z = 4.04E+02 + 9.56E-03Q - 2.51E-06Q^2$	--
214R	SBM	Y	--	$Z = 4.29E+02 + 1.11E-04Q - 1.62E-11Q^2$	--
217R	BWM	Y	12	$Z = 4.01E+02 + 4.09E-03Q - 1.38E-07Q^2$	0.98
220R	SBM	0	--	$Z = 3.94E+02 + 3.88E-03Q - 5.323E-07Q^2$	--
222L	BWM	N	na	na	na
225R	SBM	Y	--	$Z = 3.81E+02 + 1.85E-04Q - 1.97E-09Q^2$	--

Appendix C. Relations between water surface elevation and discharge for study sites.--Continued

Site Code	Site Type[1]		Number of observations of stage	Equation	R^2
228L	BWM	N	na	na	na
239R	BWM	N	na	na	na
243L	BWM	N	na	na	na

USGS

Grams and others—**2008 High-Flow Experiment at Glen Canyon Dam: Morphologic Response of Eddy-Deposited Sandbars and Associated Aquatic Backwater Habitats along the Colorado River in Grand Canyon National Park**—Open–File Report 2010–1032