Chapter 11

Cultural Resources in the Colorado River Corridor

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Introduction

Cultural resources along the corridor of the Colorado River include archaeological sites and other types of historic properties, as well as resources that are of traditional concern to Native American peoples such as springs, landforms, sediment and mineral deposits, native plant concentrations, and various animal species. All of these resources have the potential to be affected indirectly, and in some cases directly, by the operations of Glen Canyon Dam.

The principal cultural resource goal of the Glen Canyon Dam Adaptive Management Program is to "preserve, protect, manage and treat cultural resources for the inspiration and benefit of past, present and future generations" (Glen Canyon Dam Adaptive Management Program, 2001). The National Park Service (NPS) goal for managing archaeological and historic resources in the Colorado River corridor is in-place preservation with minimal impact to the integrity of the resources. When in-place preservation is not possible, the NPS and other Federal agencies consider data recovery through excavation of archaeological remains to be an appropriate alternative in certain cases. The six Native American tribes who actively participate in the Glen Canyon Dam Adaptive Management Program and have long-standing traditional ties to the Grand Canyon region—Hopi Tribe, Hualapai Tribe, Kaibab Band of Paiute Indians, Paiute Indian Tribe of Utah, Navajo Nation, and Pueblo of Zuni—are generally supportive of in-place preservation goals for cultural resources, but they have widely varying opinions regarding the appropriateness of undertaking intervention measures to mitigate dam and visitor impacts, such as installing check dams to control erosion or conducting excavations to recover information from archaeological sites.

This chapter describes research, monitoring, and mitigation activities during the past 15 yr that have evaluated and addressed ongoing impacts to cultural resources in the Colorado River corridor because of dam operations and other agents of deterioration, such as visitation and rainfall-induced erosion. The chapter begins with a summary of research and inventory activities prior to the early 1990s, which is followed by a summary of the monitoring and research activities initiated in response to the Operation of Glen Canyon Dam Final Environmental Impact Statement (EIS) and the Secretary of the Interior's Record of Decision (ROD)

(U.S. Department of the Interior, 1995, 1996). The chapter ends with some recommendations for the future.

Background

Current information concerning cultural resources is based on a number of previous investigations within the Colorado River corridor in Glen and Grand Canyons. Comprehensive overviews of previous investigations are included in Ahlstrom and others (1993), Fairley and others (1994), and Fairley (2003). These studies documented evidence of human occupation in the Grand Canyon region extending back as far as the Paleo-Indian period, at least 11,000 yr before present. Starting around 4,500 yr ago, petroglyphs, spear points, and uniquely crafted artifacts known as "split twig figurines" were placed at various locations along and near the Colorado River in Glen and Grand Canyons, indicating intermittent use of the area by Late Archaic hunters and gatherers. Sparse and somewhat controversial evidence for use of the canyon by early farming cultures before 1000 B.C. is present in eastern Grand Canyon (Davis and others, 2000); however, the best documented and most intensive use of Grand Canyon by farmers occurred during the 11th and early 12th centuries A.D., during a time period known as Pueblo II. During this time, people with ancestral ties to modern Puebloan cultures built numerous small masonry dwellings, irrigation ditches, erosion control features, and granaries for storing corn, squash, and cotton throughout Grand Canyon (fig. 1). For reasons not yet fully understood (but that are likely due at least in part to climate-induced stressors), these ancestral Puebloan farmers moved away from Grand Canyon around the end of the 12th century, although small groups continued to visit the canyon for seasonal hunting, plant gathering, trading, and ceremonial pilgrimages into the first decades of the 20th century. Following the departure of the ancestral Puebloan occupants, ancestors of the Hualapai, Havasupai, and Southern Paiute moved into the region. Numerous campsites and food processing areas dating to the late prehistoric (A.D. 1300–1540), proto-historic (A.D. 1540–1776), and early historic (A.D. 1776–1850) periods testify to their extensive, and at times intensive, seasonal use of inner Grand Canyon. Descendants of these Yuman and Numic speakers were still residing in and around Grand Canyon when the first European settlers arrived in the region in 1848, and Havasupai, Hualapai, and Southern Paiute people continue to live in and near Grand Canyon to this day. After 1880, however, as Euro-Americans became increasingly enamored with the spectacular scenery and economic potential of the region, the archaeological record becomes increasingly dominated by the material remains of Euro-American miners, trappers, homesteaders, government explorers, and tourists (fig. 2).

Figure 1. Pottery dating to the Pueblo II period is commonly found at archaeological sites along the Colorado River. These formerly buried pot sherds have become exposed by wind (photograph by Amy Draut, U.S. Geological Survey).

Previous Cultural Resource Research and Inventories

Euro-Americans first noted archaeological remains in the river corridor during the Powell expeditions of 1869 and 1871–72 (Powell, 1875). Powell and his crew found traces of previous human occupation in the canyon in the vicinity of the Little Colorado River, Unkar Creek, Bright Angel Creek, and Shinumo Creek. In the 1950s and 1960s, investigations of archaeological remains in the river corridor became more focused under the direction of the NPS, in part because of anticipated dam developments in Grand Canyon (Taylor, 1958; Euler, 1967a). In the late 1960s and early 1970s, researchers affiliated with the School of American Research, New Mexico, and Prescott College, Arizona, conducted surveys and excavations in the river corridor and adjacent areas to investigate prehistoric settlement patterns (Schwartz, 1965; Euler and Taylor, 1966; Euler, 1967b; Schwartz and others, 1979, 1980, 1981).

Figure 2. The remains of Bert Loper's boat came to rest on the banks of the Colorado River in 1948, shortly after Loper drowned in 24 and 1/2-mile Rapid. This boat is an example of the varied historic artifacts found along the Colorado River in Grand Canyon (photograph by Jeff Sorensen, Arizona Game and Fish Department).

Together, these studies provided the foundational information concerning the numerous and diverse cultural resources existing within the river corridor.

In 1984, NPS archaeologists conducted test excavations at five archaeological sites along the Colorado River in advance of their stabilization (Jones, 1986). Three of these sites were deteriorating primarily because of visitor use, one was deteriorating because of both human and natural impacts, and one was being damaged by erosion from a side channel, all resulting in the need for stabilization measures. At all of these sites, excavations revealed the presence of subsurface stratigraphic cultural deposits extending back many centuries earlier than surface evidence indicated. For example, at one site (AZ B:10:4) near Deer Creek, a buried roasting feature produced calibrated radiocarbon dates ranging between A.D. 610 and 380 B.C., whereas the overlying surface structure contained ceramics dating to the Pueblo I-II period (about A.D. 800–1150) (Jones, 1986, p. 105). At another site (AZ B:16:1) near Whitmore Wash, surface materials of Southern Paiute affiliation were found in association with a fire pit that was radiocarbon dated to A.D. 1230–1340, overlying a roasting feature with a calibrated radiocarbon age of 1365–905 B.C. (Jones, 1986, p. 51). This project was important for highlighting the presence of deeply buried cultural deposits at numerous archaeological sites in the river corridor (fig. 3). These older, underlying deposits are often invisible on the surface because floods, slope wash, and aeolian (wind) processes have deposited sediment on top of earlier cultural remains, obscuring them from view.

In 1990–91, an intensive archaeological inventory was conducted by NPS archaeologists (Fairley and others, 1994) in preparation for the writing of the EIS (U.S. Department of the Interior, 1995). This inventory located 475 sites within the assessed area, which extended from Glen Canyon Dam to Separation Canyon, about 255 RM, and up to the estimated 300,000 cubic feet per second (cfs) flood level. The sites ranged in type from isolated hearths and dispersed lithic scatters to complex multiple-component habitations, many with associated roasting features or masonry structures. The sites ranged in age from Late Archaic, about 2500–1500 B.C., to the mid-20th century. Many sites date to the ancestral Puebloan occupation between A.D. 950 and 1200, while many other sites are affiliated with the ancestral Pai and Paiute use of Grand Canyon from about A.D. 1250 to 1870.

Of the sites within the surveyed area, approximately 336 were considered to be situated within the area of potential effect from dam operations, and many of these sites had identifiable impacts that were believed to be related to dam operations (Fairley and others, 1994, p. 148). Dam-related impacts were categorized as direct, indirect, or potential. Direct impacts included sites where inundation or bank cutting from dam-controlled

Figure 3. The curved masonry wall of a deeply buried prehistoric structure was uncovered during excavations at site AZ C:13:10 in April 1984. No evidence of this structure was visible on the site surface prior to excavation (photograph by Helen Fairley, U.S. Geological Survey).

river flows had occurred within the site in recent years. Indirect impacts included (1) bank slumpage or slope steepening from river flows immediately adjacent to the site, (2) arroyo cutting or other erosion phenomena tied to the effects of dam-controlled flows, and (3) effects of visitor impacts at sites because of changes in recreational use patterns related to recent dam operations. Potentially impacted sites included all those located within the estimated area of inundation from a 300,000-cfs flood. This flood level reflected the former estimated volume of the highest historical flood on record (in 1884) (Hereford and others, 1993; cf. Topping and others, 2003, p. 31) and also the maximum release level possible from Glen Canyon Dam, estimated at 256,000 cfs, combined with a hypothetical 40,000-cfs flood event from the Little Colorado River and other tributary streams.

Of the 336 sites considered to be within the area of potential effect, 33 showed evidence of direct impacts, 138 revealed evidence of indirect impacts, and 238 were categorized as potentially impacted based on their location below the estimated 300,000-cfs level or based on their location in or on unconsolidated Holocene sedimentary deposits (Fairley and others, 1994, p. 148). (The impact numbers exceed total number of sites because many sites exhibited more than one category of impact.)

Participating Native American tribes also conducted cultural resource inventories in the early to mid-1990s to identify resources with important traditional cultural values, including but not limited to prehistoric Native American archaeological sites. These studies were conducted by the Hopi Tribe, the Hualapai Tribe, the Navajo Nation, the Southern Paiute Consortium (comprising the Kaibab Band of Paiute Indians and the Paiute Indian Tribe of Utah), and the Pueblo of Zuni (Stoffle and others, 1994, 1997; Hart, 1995; Roberts and others, 1995; Ferguson, 1998; Stevens and Mercer, 1998). Numerous locations of cultural importance were identified and evaluated by the individual tribes, including areas with culturally important biological resources, significant landscape features, mineral locations, and specific archaeological resources. Assessments were conducted by the tribes to identify potential impacts resulting from dam operations and to formulate possible treatment options. These studies have subsequently been used by the Bureau of Reclamation for the identification and preliminary evaluation of traditional cultural properties within the area of potential effect as defined by the Programmatic Agreement for Cultural Resources (see discussion below) (U.S. Department of the Interior, 1995, p. Att-23); however, studies to formally define and evaluate traditional cultural properties have yet to be completed.

Monitoring and Research

Monitoring of Cultural Resources

Before the 1990s, the NPS annually monitored a sample of archaeological sites in the Colorado River corridor. These initial monitoring efforts focused primarily on sites prone to impacts from visitors. After the comprehensive inventory of the river corridor was completed in 1991, the NPS expanded its monitoring program to encompass the full suite of resources located within the hypothetical area of potential effect from dam operations. In the mid-1990s, the Southern Paiute Consortium and the Hualapai and Hopi Tribes also initiated their own monitoring programs to track changes in resource conditions at culturally important locations in the river corridor (Stoffle and others, 1995; Ferguson and others, 1997).

Since 1994, monitoring of historic properties that are eligible to be listed in the National Register of Historic Places—nationally, regionally, and locally significant prehistoric and historic sites, structures, objects, and places of traditional cultural importance—has been conducted under the auspices of a Programmatic Agreement for Cultural Resources. The agreement exists between the Bureau of Reclamation, NPS, Advisory Council on Historic Preservation, Arizona State Historic Preservation Office, and six affiliated Native American tribes. Current monitoring protocols, established under interim guidelines of the Programmatic Agreement for Cultural Resources, document the presence of all types of impacts occurring to archaeological resources in the river corridor, regardless of ultimate cause.

In addition to the NPS monitoring efforts, the Hopi Tribe, Hualapai Tribe, and Southern Paiute Consortium conduct annual monitoring trips to assess changes to their traditional cultural resources and to assess the general health of the ecosystem through their own traditional value system. Tribal monitoring has been conducted both through and outside of the programmatic agreement, as not all resources of tribal concern meet the established definitions of National Register-eligible historic properties.

The Programmatic Agreement for Cultural Resources is concerned with tracking and mitigating dam effects at approximately 318 National Register-eligible archaeological sites in the river corridor: 54 in Glen Canyon National Recreation Area and 264 in Grand Canyon National Park (Leap and others, 2000, p. I-8). Approximately 160 of these sites are actively monitored at the present time. All sites currently monitored fall within the affected environment as defined by the EIS (U.S. Department of the Interior, 1995). The monitoring is carried out by staff from the NPS, working with cooperators from Northern Arizona University. National Park Service archaeologists conduct monitoring trips several times each year and produce annual monitoring reports, which are submitted to the Bureau of Reclamation in partial fulfillment of an ongoing cooperative agreement (Leap and others, 2000). Currently, archaeological sites above Lees Ferry are not being monitored (Chris Kincaid, Glen Canyon National Recreation Area, oral commun., 2004); only sites downstream of Lees Ferry are routinely monitored.

Archaeological sites are currently selected for monitoring and remedial treatments based on interim protocols established under the programmatic agreement. These protocols include judgmentally selecting sites for monitoring based on perceived susceptibility or likely vulnerability to erosion or visitor impacts. Sites are monitored on a cycle that varies from semiannually to annually, biennially, or once every 3, 4, or 5 yr (Leap and others, 2000). Monitoring cycles are assigned on the basis of perceived levels of stability or visitor use, but the monitoring cycles are not rigidly adhered to and frequently change. For example, of the 91 sites monitored in fiscal year 2001 (FY01), 55% (n = 50) were monitored more or less frequently than their assigned monitoring cycle, and 18% were reassigned to a new monitoring cycle based on perceived changes in their stability. Sites that are stable or show no signs of visitor use are not included in the current monitoring program. This bias in site selection was intentionally designed to focus attention on those sites that were theoretically at greatest risk from damage from visitor use and erosion and were most likely to require preservation treatments in the foreseeable future; however, the deliberate emphasis placed on monitoring sites that are assumed to be most threatened limits the usefulness of the resulting data for drawing systemwide conclusions about status and trends of site condition, rates of impacts, or overall effects of dam operations on historic properties.

The main goals of the current monitoring program are to document site impacts and evaluate the need for site protection measures such as erosional control check dams. Changes in the numbers, types, and locations of site impacts are documented in yearly reports prepared by the NPS and Northern Arizona University cooperators (see Leap and others, 2000, for a listing of annual reports through 1999; see also Leap and Kunde, 2000; Dierker and others, 2001, 2002; Leap and others, 2003). These reports discuss the results of site-specific evaluations, identify specific changes occurring at individual sites, and make recommendations about future protection measures, including data recovery. The reports do not track systemwide trends in site condition or evaluate changes in site condition relative to dam-controlled flows.

Currently, archaeological site-monitoring activities conducted under the programmatic agreement involve repeat site visits, visual assessments of site impacts, and qualitative assessments of overall condition, which are documented through the use of repeat photography and completion of a two-page checklist of impacts. As described in the FY02 annual monitoring report (Dierker and others, 2002, p. 2),

> Archaeologists qualitatively assess impacts to sites via repeat observations. The degree of impact is categorized as "present" or "absent," with physical erosion further categorized as "active" or "inactive." Active erosion is defined as obvious recent movement, disturbance, or rearrangement of sediment or artifacts onsite. Inactive erosion is defined as a (less obvious) perception that past geophysical processes are discernable at the site, but are not presently at work.

Visitor impacts are recorded as present or absent in five categories: social trails, artifact collection piles, evidence of onsite camping, criminal vandalism, and other impacts (fig. 4). Physical impacts are recorded as present or absent and either active or inactive within the following eight categories: surface erosion, gullying,

Figure 4. Visitors frequently remove artifacts from their original locations and concentrate them in "collection piles," resulting in loss of information about the original context of the artifacts (photograph by Helen Fairley, U.S. Geological Survey).

Figure 5. An erosional gully cutting headward into a prehistoric roasting feature (photograph by Amy Draut, U.S. Geological Survey).

arroyo cutting, bank slumpage, aeolian/alluvial erosion or deposition, side canyon erosion, animal-caused erosion, and other erosion (fig. 5). Impacts that the NPS views as being directly related to dam operations include bank slumpage and gullying/arroyo cutting in locations where drainage systems are actively entrenching to achieve grade with the present-day "highest discharge" terrace levels formed under dam-controlled flows. The precise role of dam operations relative to other erosional forces—precipitation events, human trampling, wind, and other "natural" and "cultural" agents of erosion—in causing or exacerbating erosion of archaeological sites in the river corridor remains a topic of continuing controversy in the scientific community.

Because the current archaeological site monitoring program does not measure or otherwise attempt to quantify impacts or rates of change in either a relative or absolute sense, it is difficult to draw any specific conclusions about overall trends in resource condition in relation to either the interim operating flows of 1991–95 or the modified low fluctuating flow (MLFF) alternative implemented in 1996 (U.S. Department of the Interior, 1996). Two conclusions can be drawn, however, by using the currently available monitoring information: (1) archaeological sites continue to receive impacts from visitor use and erosion, and (2) archaeological site conditions are likely to continue to deteriorate (at an unknown rate) because impacts from visitor use and erosion are ongoing and not likely to diminish in the foreseeable future.

Erosion Control with Check Dams

Beginning in 1995, the NPS began installing rock and brush check dams at selected archaeological sites in the river corridor in an attempt to control erosion. Check dams were first piloted as an erosion control measure in an area below the Little Colorado River known as "Palisades," where gullies bisect two archaeological sites (AZ C:13:99 and AZ C:13:100). National Park Service archaeologists had monitored and documented a progressive deepening and widening of the drainages in the Palisades area since 1978. Continuing channel erosion caused the collapse and disappearance of numerous slab-lined cists and portions of masonry structures in the late 1980s and early 1990s, hence the decision to initiate erosion control measures. With assistance and supervision from the Zuni Conservation Project (a team of soil conservation experts from the Pueblo of Zuni), NPS archaeologists installed 70 check dams at the two sites by using a variety of local materials and construction styles (Leap and Coder, 1995; Leap and others, 2000).

Since the initial pilot project in 1995, NPS archaeologists have installed approximately 280 check dams at 29 different archaeological sites (Leap and others, 2000). Currently, 260 erosion-control features are actively monitored and maintained at 27 sites (Leap and others, 2003, p. 58). An evaluation of check dam effectiveness conducted in 2002 (Pederson and others, 2003) found that the brush checks built with a "basket weave" technique seemed to work best and caused less damage to surrounding terrain upon failure than did check dams built

Figure 6. Members of the Zuni Soil Conservation Project constructing a check dam by using the basket-weave technique (photograph courtesy of Grand Canyon National Park).

with rocks or logs (fig. 6). The researchers observed that brush checks tended to fail in their central sections or get ripped out as a woody mass, whereas the more rigid rock and log checks were often flanked by the gullies via lateral slope erosion, further exacerbating erosional impacts to the sites. Pederson and others (2003) concluded that brush checks were less damaging than stone checks and that check dams, without routine maintenance, could cause more harm than good; however, check dams could temporarily slow rates of erosion provided they were routinely maintained. These findings are considered somewhat tentative and in need of further verification because they were based on observations conducted over the course of a single monsoon season in 2002, which was one of the driest monsoon seasons on record.

Test Flow Impacts on Cultural Resources

Many of the archaeological resources along the corridor of the Colorado River are situated on or contained within the Holocene sedimentary deposits, which form dunes and terraces (fig. 7). The sediment resource has declined, and the alluvial terraces have eroded since the completion of Glen Canyon Dam. A systemwide method for regenerating the river terraces and redistributing sediment is considered an essential component to maintaining integrity of cultural resources in place.

The 1996 beach/habitat-building flow, or controlled flood, presented an opportunity to study the effects of high-flow discharge from Glen Canyon Dam on alluvial terraces and margin deposits along the river corridor. Although the effects of the 1996 beach/habitat-building flow of 45,000 cfs on archaeological sites could not be predicted, the hope was that it could provide systemwide mitigation to most cultural sites in the Colorado River corridor through the accumulation of additional sediment at higher elevations than normally would occur under the MLFF alternative (Balsom and Larralde, 1996, p. 3). Mitigation and monitoring of archaeological sites, ethnobotanical resources, and sediment accumulation at the mouths of arroyos were undertaken to evaluate the effects of this experimental high flow. In addition, rates of terrace retreat were studied in the Glen Canyon reach to determine whether terraces containing archaeological sites were negatively affected by the high flows (Balsom and Larralde, 1996).

Figure 7. A buried Pueblo II structure is becoming exposed by erosion near Unkar Delta (photograph by Amy Draut, U.S. Geological Survey).

The overall findings of the cultural resource studies done in conjunction with the 1996 beach/habitat-building flow were that the 45,000-cfs flow had either no effect, no adverse effect, or in some instances a beneficial effect on cultural resources (Balsom and Larralde, 1996, p. 25). In a few locations, however, especially in the Glen Canyon reach, loss of sediments occurred in a manner that, in the long run, could be detrimental to cultural resources. Follow-up studies conducted by the Hopi Tribe (Yeatts, 1998) and by Northern Arizona University researchers (Hazel and others, 2000) found that sediment deposited in arroyo mouths by the 1996 beach/habitat-building flow persisted in some locations for several years, especially where brush check dams had been installed in the lower reaches of the drainages. These studies, however, did not specifically evaluate whether the sediment plugs diminished the rate of down-cutting in upper reaches of the affected gullies. Nevertheless, the studies demonstrated that backfilling of some erosional channels could be accomplished by periodic high-flow events and that high, sediment-enriched flows offer one potential means of conducting systemwide mitigation for effects of dam operations on cultural resources.

Since 1996, several additional test flows have taken place, including the 2000 low summer steady flows experiment, the 2003–05 fluctuating nonnative fish suppression flows, and the November 2004 experimental high flow. No specific cultural resource monitoring programs were conducted in conjunction with the 2000 low summer steady flows or the 2003–05 fluctuating nonnative fish suppression flows; however, analysis of the sediment mass balance under the 2003 and 2004 winter nonnative fish suppression flows showed that the fluctuating flows eroded material above and beyond the amount supplied by tributaries within the previous year. Also, analysis showed that higher levels of very fine grained material were entrained during the initial few days of the 2003 and 2004 high fluctuating flows, suggesting the possibility that fine sediments that were derived from predam deposits contributed to the sediment being transported out of the system (David Topping, U.S. Geological Survey, oral commun., 2005). Although not conclusive, this information suggests that there may be some additional loss of predam terrace deposits, where most archaeological sites are situated, occurring under the experimental fluctuating nonnative fish suppression flows.

During the 2004 experimental high flow, one of the areas monitored during the 1996 beach/habitat-building flow and two additional sites upstream in Marble Canyon were monitored to determine whether sandbars would be created in the vicinity of archaeological sites, in locations where the new sandbars could serve as sources of sediment for windborne redeposition on downwind archaeological sites. An additional aim of this research was to document whether sediment would be deposited in the mouths of arroyos that currently bisect some archaeological sites and whether these sediment "plugs" would be retained long enough to help reduce the rate of downcutting in affected arroyos because of the temporary elevation increase at the arroyo mouths. Preliminary observations indicate that large sandbars did form upwind of the site areas and that sediment did backfill arroyos; however, at the time this report was being written, it was still too early to determine whether the 2004 experimental high flow would benefit the archaeological sites over the long term. U.S. Geological Survey scientists will be monitoring the fate of the new sandbars and associated archaeological sites over the next year to determine whether and to what degree the newly formed sandbars contribute sediment to the windborne deposits that blanket sites located at higher elevations.

The Role of Windborne Sediment in Preserving Archaeological Sites

In addition to the monitoring activities previously described, several research projects have been initiated and supported through the Glen Canyon Dam Adaptive Management Program over the past decade to improve overall understanding of how Glen Canyon Dam operations may be affecting archaeological sites in the Colorado River corridor below the dam (Thompson and others, 2000; Draut, 2003; Pederson and others, 2003; Draut and others, 2005; Wiele and Torizzo, 2005).

Of particular interest is whether and how postdam changes in overall sediment supply and flow regimes downstream of the dam may be contributing to the erosion of high-elevation dunes and terraces bordering the Colorado River, where many archeological sites occur. These terraces are bisected by numerous arroyos and gullies draining to the river, and many of the erosion channels pass through or by archaeological features. Pieces of anecdotal and empirical (aerial photography) evidence indicate that these gullies have been increasing in size, depth, and abundance over the past four decades (Hereford and others, 1993). The question that both dam managers and NPS managers are seeking to answer is, "To what extent is the ongoing erosion of these higher elevation terraces related to dam operations?"

Scientists generally agree that gullies are formed in response to specific, and often unusually intense, precipitation events (e.g., Webb, 1985). If precipitation is responsible for the establishment of gullies and arroyos, what might dam operations have to do with the ongoing erosion of the predam terraces? The answer lies in understanding the dynamic nature of the predam fluvial system in contrast with the present-day, dam-controlled hydrologic system, which is also very dynamic but in fundamentally different ways (Topping and others, 2003). The predam system was generally characterized by high seasonal variability and low daily variability. Flows during the winter months were typically quite low, often running at less than 3,000 cfs. The flows usually stayed low until late April or early May, when runoff from the Rocky Mountains started making its way to the Gulf of California. Spring flows typically peaked in June or early July, with additional spikes in late summer in response to localized monsoon storm events. The annual spring snowmelt floods ranged between about 35,000 and 120,000 cfs and averaged around 55,000 cfs, with peak flows of 120,000 cfs reoccurring about once every 6 yr (Topping and others, 2003). The highest known flood in historic times occurred in 1884 with an estimated flow of 210,000 ± 30,000 cfs. In 1921, a flood of 170,000 cfs was measured at the Grand Canyon gage (Topping and others, 2003, p. 31). Floods even larger than this are known from the geomorphic record (O'Connor and others, 1994).

The high spring flows typically carried huge sediment loads. An analysis of the historical predam sediment transport records from the Lees Ferry gage and Grand Canyon gage shows that the monthly sediment loads during May averaged around 13.9 to 17.6 million tons (12.6 and 16 million Mg) per month, respectively, which is close to 20% of the annual amount transported each year (Topping and others, 2000b). As flood waters receded, sand was deposited at and below the flood stage along the river banks. After these flood deposits dried out, wind transported the fluvial sediment farther inland, where some of it covered archaeological sites and formed coppice dune fields around mesquite thickets.

Today, virtually 100% of the sediment load that used to be transported by the river through Grand Canyon is trapped upstream in Lake Powell. Two major tributaries below Glen Canyon Dam, the Paria River and the Little Colorado River, contribute the bulk of the current sediment coming into the river system. Taken together, the contributions of sand from various sources provide Grand Canyon with approximately 16% of its predam levels (see chapter 1, this report). Compounding the effects of this drastic reduction in sediment, the dam is operated to meet peak power demands, so in the postdam era prior to the Record of Decision (1963–96) the Colorado River fluctuated by as much as 25,000 cfs on a daily basis, and the daily discharge range exceeded 10,000 cfs on 43% of all days (before the dam, daily ranges in excess of 10,000 cfs occurred on only about 1% of all days) (Topping and others, 2003). Furthermore, flows higher than 9,000 cfs essentially guarantee that any fine-grained sediment coming into the system will be transported downstream to Lake Mead in a period of a few weeks to a few months (Topping and others, 2000 a, b; Rubin and others, 2002), and analysis of the continuous discharge record from Lees Ferry gage and the Grand Canyon gage demonstrates that flows greater than this level have dominated the postdam record (Topping and others, 2003, p. 48).

The reduction in sand supply translates into a reduction in the size, height, and volume of sandbars throughout the river corridor (Hazel and others, 1999; Schmidt and others, 2004). Furthermore, because dam-controlled flows are generally constrained below 25,000 cfs, sand and silt are no longer being deposited at higher elevations where fine sediment would be less susceptible to riverine transport, more readily available for inland transport by wind, and able to backfill the lower reaches of arroyos and gullies that dissect the terraces.

Aeolian (windborne) sediment has previously been shown to play an important role in the formation and subsequent reworking of terraces where many archaeological sites are located (Hereford and others, 1993, 1996), and aeolian deposition has been hypothesized to play an important role in mitigating the effects of runoff erosion (Lucchitta, 1991). In order to improve our understanding of how changes in sediment supply and river flow dynamics are affecting the archaeological sites, a study was initiated in 2003 to examine the role of aeolian sediment in preserving archaeological sites from several different perspectives: (1) the relative importance of aeolian sedimentation in the past compared to today, both as a terrace-forming process and also in backfilling incipient rills and gullies; (2) the extent to which aeolian sand cover may be diminishing throughout the ecosystem under current sediment-limited conditions; (3) the extent to which current rates of aeolian transport vary at different locations under varying ecological and geomorphic parameters throughout the river corridor; and (4) the extent to which aeolian transport rates and downwind aeolian sand cover could potentially increase when new bars are formed in optimal locations relative to the areas where archaeological sites occur.

To study these issues, Draut (2003; Draut and Rubin, in press) established wind-transport monitoring instruments at six locations throughout the corridor of the Colorado River (fig. 8). These monitoring stations measure the amount of sand being transported by varying wind speeds at different times of the year and under different sediment supply conditions. Preliminary results from the first year of data (Draut and Rubin, in press) indicated that wind speeds and predominant directions vary widely throughout the river corridor and that trans-

Figure 8. U.S. Geological Survey scientists installing a weather station near RM 65. These devices measure wind velocity and direction at six locations along the Colorado River (photograph by Amy Draut, U.S. Geological Survey).

port conditions are also highly variable, limiting efforts to model sediment-transport rates for the system as a whole.

To determine the extent to which aeolian sediment formed the material in which archaeological sites are embedded, Draut worked collaboratively with NPS archaeologists, U.S. Geological Survey scientists, and other researchers to evaluate subsurface deposits at a nonrandom sample of archaeologically rich locations throughout the river corridor (Draut and others, 2005). These investigations focused on describing the various geomorphic processes that have contributed to the formation and preservation of archaeological sites by closely examining the sedimentary structures preserved in subsurface contexts (fig. 9). Preliminary findings indicated that aeolian deposits were common throughout the prehistoric landscape of the river corridor and were important factors in the formation of many sites but that wind deposition was clearly not the only matrix-forming process at work in the past. Aeolian sediment blankets the surface of many archaeological sites, but often these windborne deposits cover substrates that are both fluvially (from the river) and colluvially (from the slope) derived (Draut and others, 2005).

In terms of understanding how dam operations could be altered to enhance the sediment supply available for redeposition by the wind, Draut is tracking the fate of several sandbars that formed during the November 2004 experimental high flow near previously established sediment-transport monitoring stations (Draut and Rubin, in press). During 2005–06, Draut will evaluate the extent to which aeolian processes may contribute to the erosion of the newly formed sandbars and track the amount of sediment transported by the wind from the sandbars to nearby archaeological features. This information will allow researchers to assess the relative importance of fluvial and aeolian processes in maintaining the sedimentary matrices of archaeological sites located above the level of dam-controlled flows in the river corridor.

Figure 9. A U.S. Geological Survey scientist examines stratigraphy exposed in the wall of an arroyo near RM 209 (photograph by Amy Draut, U.S. Geological Survey).

Ethnobotanical Resources and Other Tribally Valued Resources

The Hopi and Hualapai Tribes and Southern Paiute Consortium have monitored a variety of culturally important resources in the Colorado River corridor since the mid-1990s. The monitored resources of concern include culturally valued plants and plant gathering locations, traditionally valued mineral resources, landscape features, traditional use areas, and archaeological sites.

Since 1995, the Southern Paiute Consortium has monitored culturally important resources in the corridor of the Colorado River to assess their condition relative to Glen Canyon Dam operations and visitor use, to educate and train tribal members in resource monitoring, and to educate tribal members and the general public about the traditional importance of Grand Canyon to the Southern Paiute people (Stoffle and others, 1995; Drye and others, 2001; Bullets and others, 2003, 2004). Approximately 20 individual locations are monitored by the Southern Paiute Consortium on a 6-yr cycle. Some locations are visited every year, while others are visited only once or twice over the 6-yr period. Locations of importance include traditional plant areas, rock art, specific perennial tributaries, and archaeological sites with evidence of use by Southern Paiute ancestors. The general assessment from Southern Paiute Consortium monitoring during the past 5 yr is that most of the monitored resources appear to be in relatively good condition, although concerns about visitor trails at archaeological sites, visitor behavior around certain traditionally significant locations in Grand Canyon, and drought stress on plants have been noted. To date, no specific recommendations regarding Glen Canyon Dam operations have been forthcoming from these monitoring efforts.

The Hualapai Tribe monitored traditional cultural resources in conjunction with the 1996 beach/habitat-building flow (Jackson and others, 1997) and again in 2001, 2002, 2003, and 2004 (Jackson and others, 2004 a, b). Beginning in 2001, the baseline conditions of 15 previously documented traditional cultural locations in Grand Canyon and of 5 previously undocumented locations were evaluated by Hualapai tribal members and consultants using a numerical condition index rating system. Several additional sites were added to the monitoring program in 2002–04, resulting in a total of 28 traditional cultural locations receiving 1 or more years of monitoring. Natural and cultural impacts were ranked on a 5-point scale, from 0 (absent) to 4 (severe). Impact ratings averaged over all 20 sites indicated that human impacts, both visitor- and dam-related, were more problematic than were natural impacts. Negative dam-related impacts included water stress on vegetation because of the lack of periodic inundation of higher elevation plant communities, continuing nonnative plant encroachment, and the loss of beach area from dam-controlled flows. Effects from the diminishing surface elevation of Lake Mead, accompanied by vegetation encroachment of nonnative plants, primarily tamarisk (*Tamarix ramosissima*), were also noted. Throughout the corridor of the river, human impacts from trailing, artifact movement, and onsite camping were observed to be a problem, with the latter impacts rated as heavy to severe in several cases. On Lake Mead, the wakes of motor boats are also thought to contribute significantly to beach erosion (Jackson and others, 2004b). Based only on the 2001 monitoring results, human impacts were the most significant impacts observed at most sites, with 13 of the 20 locations rated as having heavy (3) to severe (4) human impacts. In contrast, only 5 of these 20 locations monitored in 2001 were assigned similar natural impact ratings, and most of the impacts were from rodent burrowing and side canyon flash floods. Overall in 2001, the average rating for all natural impacts was 1.8, whereas the average human impact rating was 2.6. In future years, repeated analyses of the same sites will allow Hualapai tribal members to determine whether or not conditions are improving or deteriorating relative to 2001 baseline conditions, but at this time (2005), comparative data are insufficient for conducting this analysis.

The Hopi Tribe initiated an ethnobotanical project in 1998 to evaluate traditional plant resources in the corridor of the Colorado River (fig. 10). This study, completed in 2001, identified over 128 plant species in Grand Canyon that were traditionally used for ceremonies, medicines, food, and other necessities of daily life (Lomaomvaya and others, 2001). Beginning in 2002, the Hopi Tribe initiated a multiyear project to evaluate whether terrestrial ecosystem data currently being collected by cooperating university scientists (Kearsley and others, 2002) could be useful to the Hopi Tribe for assessing resource conditions from a Hopi perspective. The results of this initial study indicated that the terrestrial ecosystem data could be usefully interpreted from a Hopi perspective, provided that the data were translated from scientific categories and terminology into Native American categories and terminology (Huisinga and Yeatts, 2003). In 2003, the Hopi Tribe initiated a pilot study to begin assessing the terrestrial ecosystem data from a native Hopi perspective. Results of this pilot study are anticipated to be available in spring 2005.

Figure 10. Hopi elders discuss and document the uses of culturally valued plants in the Colorado River corridor. The photograph was taken at RM 43 below the 100,000-cfs water-surface elevation (photograph courtesy of Michael Yeatts and the Hopi Tribe).

Summary

Resource monitoring of archaeological and traditional cultural resources suggests that archaeological resources continue to be impacted both by physical processes such as surface erosion and gullying and by recreational visitors. Although surface erosion and visitor impacts would undoubtedly be occurring without the presence or continuing operation of Glen Canyon Dam, the manner in which the dam is currently operated prohibits the retention of sediment within the river corridor. The diminishing supply of sediment appears to be contributing to and exacerbating the rate and amount of erosion occurring at all levels within the ecosystem. In addition to impacts from Glen Canyon Dam operations, visitor impacts such as trailing, trampling, and collection of artifacts are contributing to the degradation of many archaeological sites in the river corridor and of several locations of traditional importance to Native American people.

Tribal assessments of dam-related impacts to ethnobotanical resources in the river corridor offer somewhat mixed results. For the most part, the Southern Paiute Consortium has identified satisfactory conditions for traditional plant resources, although there is some evidence of plant deterioration, probably from ongoing drought conditions. Meanwhile, the Hualapai Tribe has expressed concern over the condition of certain key botanical resources (e.g., the willow tree (*Salix* sp.) at Granite Park), and they have noted an apparent increase in nonnative plants such as Bermudagrass (*Cynodon dactylon*) and camel thorn (*Alhagi maurorum*) at specific locations in the river corridor.

Under the current NPS monitoring program, frequency of monitoring is tied to perceived levels of erosion or visitor use, with those sites showing more evidence of active erosion or more frequent visitor use being monitored more frequently than those showing less impact. As one would expect from a monitoring program that is weighted towards tracking impacts at the more threatened and heavily visited sites, annual monitoring results show relatively high levels of physical and visitor-related impacts.

Because the current data set is lacking measurements related to rates or degrees of erosion, it is not possible to determine whether or to what degree rates of erosion at archaeological sites may have changed in recent years under the MLFF regime. The NPS monitoring program is undergoing a reevaluation and redesign in 2005 to better meet the needs of the Glen Canyon Dam Adaptive Management Program for information related specifically to effects of Glen Canyon Dam operations on National Register-eligible historic properties. Once revised monitoring protocols are implemented in 2006, it will be possible to track rates and trends in gully formation and downcutting relative to different flow regimes and to make systemwide assessments of resource condition over time.

The limited monitoring, in conjunction with the 1996 beach/habitat-building flow and 2004 experimental high flow, indicates that the creation of sandbars above the level of normal dam operations may have beneficial effects on archaeological sites in two respects: (1) by creating sources of sediment for subsequent wind-borne redeposition at archaeological sites located upwind of the newly formed sandbars and (2) by temporarily raising the effective base level to which terrace channels are downcutting in the short term, thereby temporarily slowing the rates of downcutting and headward migration of erosional gullies. For these measures to be effective over the long term, however, periodic high flows under sediment-enriched conditions would need to be repeated at relatively frequent intervals.

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