U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Prepared in cooperation with the
GRAND CANYON MONITORING AND RESEARCH CENTER

Observations of Environmental Change in Grand Canyon, Arizona

Water-Resources Investigations Report 02–4080

USGS
science for a changing world

COVER PHOTOGRAPH

November 1911. Ellsworth (left) and Emery Kolb displaying native fishes caught in the Colorado River in Grand Canyon during their 1911 expedition (Kolb photograph 5739, courtesy of Special Collections, the Cline LIbrary, Northern Arizona University).

Observations of Environmental Change in Grand Canyon, Arizona

By Robert H. Webb, Theodore S. Melis, and Richard A. Valdez

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 02-4080

Prepared in cooperation with

GRAND CANYON MONITORING AND RESEARCH CENTER

Tucson, Arizona
2002

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
Charles G. Groat, Director

For additional information write to:

Regional Research Hydrologist
U.S. Geological Survey
345 Middlefield Road
Menlo Park, California 94025
http://water.usgs.gov/nrp

Copies of this report can be purchased from:

U.S. Geological Survey
Information Services
Building 810
Box 25286, Federal Center
Denver, CO 80225-0286

CONTENTS

FIGURES

TABLES

CONVERSION FACTORS AND VERTICAL DATUM

CONVERSION FACTORS

Multiply	By	To obtain
inch	2.54	centimeter
feet	0.3048	meters
miles	1.609	kilometers
cubic feet per second	0.02832	cubic meters per second
pound, avoirdupois	0.4536	kilogram
degrees Fahrenheit (°F)	([1])	degrees Celsius

Temperature in degrees Fahrenheit (°F) can be converted to degrees Celsius (°C) as follows:

$°C = 5/9 \times (°F - 32)$.

VERTICAL DATUM

Sea level: In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum *derived* from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Observations of Environmental Change in Grand Canyon, Arizona

By Robert H. Webb, Theodore S. Melis, and Richard A. Valdez

ABSTRACT

Few scientific data have been collected on pre-dam conditions of the Colorado River corridor through Grand Canyon National Park. Using historical diaries, interviews with pre-dam river runners (referred to as the "Old Timers"), and historical scientific data and observations, we compiled anecdotal information on environmental change in Grand Canyon. The most significant changes are the: lowering of water temperature in the river, near-elimination of heavily sediment-laden flows, erosion of sand bars, invasion of non-native tamarisk trees, reduction in driftwood, development of marshes, increase in non-native fish at the expense of native fishes, and increase in water bird populations. In addition, few debris flows were observed before closure of Glen Canyon Dam, which might suggests that the frequency of debris flows in Grand Canyon has increased. Other possible changes include decreases in bat populations and increases in swallow and bighorn sheep populations, although the evidence is anecdotal and inconclusive. These results provide a perspective on managing the Colorado River that may allow differentiation of the effects of Glen Canyon Dam from other processes of change.

INTRODUCTION

The Glen Canyon Environmental Studies (GCES) program, which existed between 1982 and 1996, amassed considerable data about the current ecology and geomorphology of Grand Canyon (U.S. Department of the Interior, 1988; 1995). Most of the research conducted during this program was related to the decade following the large flood of 1983 in Grand Canyon or the controlled flood of 1996 (Webb and others, 1999a). The work of GCES has continued since the establishment of the Grand Canyon Monitoring and Research Center (GCMRC) in 1996. Until recently, research on the effects of Glen Canyon Dam (located 15.5 mile upstream of Lee's Ferry) has mostly focused on processes related to the post-dam Colorado River (Fig. 1). This concentration of effort meets many of the management needs of regulatory agencies but ignores some questions of scientific interest. On-going changes in the regulated river were inherited from a free-flowing river that very few people, and fewer scientists, have experienced.

Initially, our project focused on specific geomorphic questions about the pre-dam river, particularly the frequency of debris flows and their effects on the Colorado River. Debris flows are slurries of water and sediment that transport large boulders into the Colorado River, forming the rapids (Webb and others, 1989, 1999b, 2000) and constraining the sites of eddies (Melis, 1997; Melis and others, 1994). In attempting to understand debris-flow frequency in Grand Canyon, we relied on historic photographs taken between 1872 and the 1970s; in matching them (Melis, 1997; Melis and others, 1994; Webb, 1996), we learned where and when debris flows occurred. The old photographs opened a Pandora's box, yielding far more than just information on debris flows. Insights into longevity and stability of desert plants, invasion of riparian vegetation, effects of burro grazing, changes in rapids, and stability of sand bars were gained from replicated photographs (Webb and Bowers, 1992; Webb and Bowers, 1993; Bowers and others, 1995; Schmidt and others, 1995; Webb, 1996).

Although photographs are an excellent source of unbiased information about the environment of Grand Canyon, they have limitations in terms of spatial coverage and content. For example, photographs are an excellent source for evaluating the frequency of debris flows but are a poor source of information about wildlife populations or the hydraulics of a particular rapid. To gain a broader perspective, we began to discuss the changes we thought had occurred with river

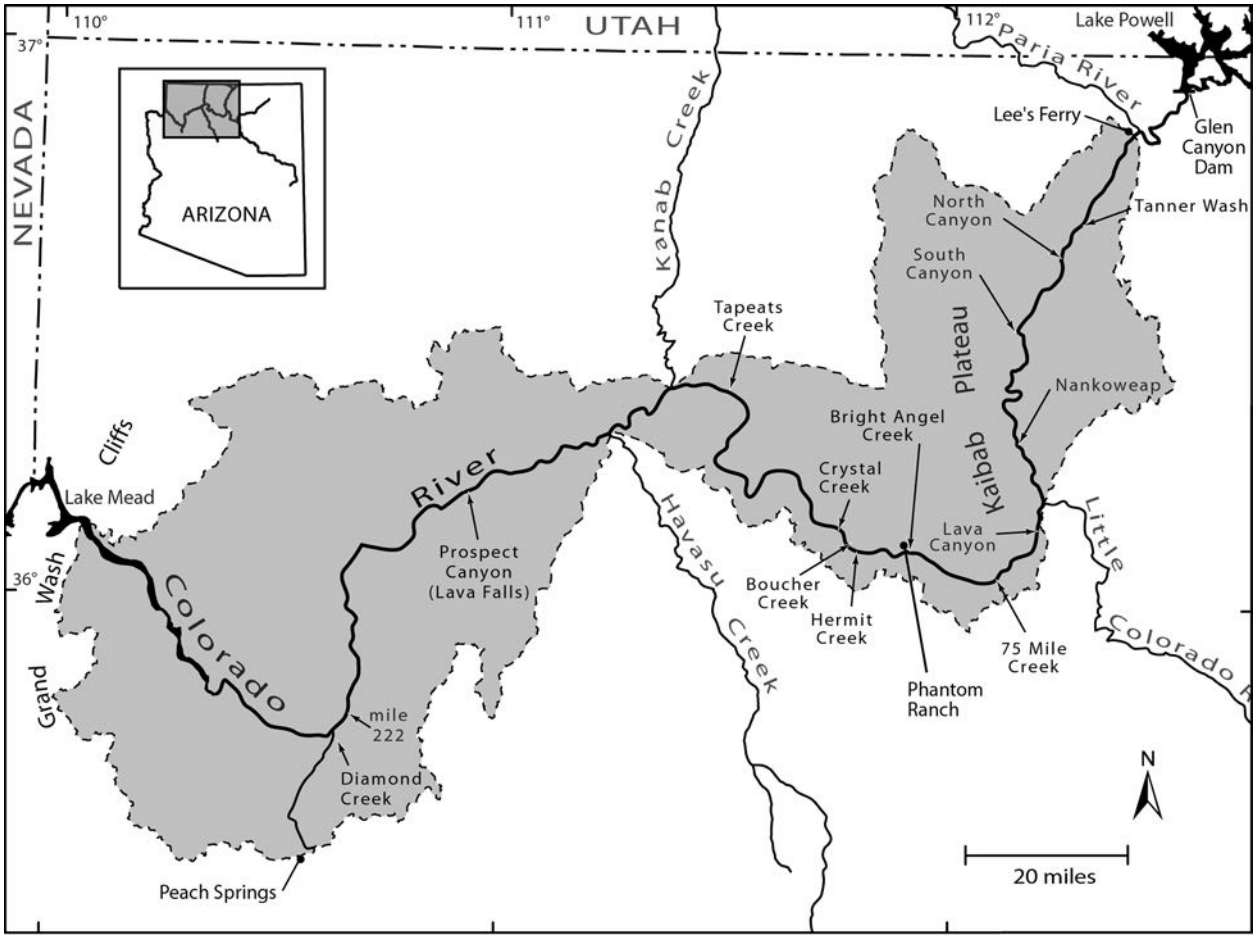

Figure 1. The Colorado River in Grand Canyon, Arizona.

runners who had experienced the unregulated river. In so doing, we realized the discussions would bear greater fruit if they were held in the course of a Grand Canyon trip.

The Old Timer's Trip, from September 8-20, 1994, was designed to gain new insights into Grand Canyon history and environmental change along the Colorado River. We sought to record the direct observations of the participants in pre-dam river trips and to incorporate their journals and photographs in our research. We attempted to test our ideas about the magnitude of change with the people who experienced the changes as they occurred. Our intent here is to relate the changes observed by the Old Timers, combined with other anecdotal information in diaries and other written accounts, and to briefly discuss any independent verification of changes and their importance to scientific knowledge about Grand Canyon.

PURPOSE AND SCOPE

The purpose of this report is to provide anecdotal information on historical changes in the Colorado River corridor through Grand Canyon. This information was obtained from interviews with people who experienced the Colorado River before the construction of Glen Canyon Dam, diaries and other accounts of historical Colorado River expeditions, and scientific observations and data collected before the advent of environmental studies below Glen Canyon Dam. We interpret this anecdotal information and discuss its value in the management of the Colorado River in Grand Canyon.

Units and Nomenclature

We use English units to describe distances along the Colorado River in Grand Canyon (designated as Lee's Ferry to the Grand Wash Cliffs, miles 0-278; see

Fig. 1). Locations of specific sites are given in river miles (Webb and others, 2000; Melis and others, 1994), and the river side -- left or right -- by convention is in the downstream direction. For purposes of locations described in this report, Lee's Ferry (Fig. 1), is designated as river mile 0. Discharges are reported in cubic feet per second (ft^3/s) as reported for U.S. Geological Survey gaging stations.

Acknowledgments

We especially thank the Old Timers (listed below) for all their conversations, diaries, and help with this project. Logistical support for the Old Timers' Trip was provided by the Glen Canyon Environmental Studies (GCES) Program of the Bureau of Reclamation. We offer special thanks to Dave Wegner, formerly project manager of the GCES, for his staunch support of our work. Additional funding was provided by the U.S. Geological Survey; the Grand Canyon Monitoring and Research Center; Northern Arizona University, Cline Library, Special Collections and Archives Department; Southwestern Foundation for Education and Historical Preservation; and the University of Utah Special Collections. The pre-trip reception was sponsored by the Cline Library of Northern Arizona University; funding was provided by The Grand Canyon Trust, Arizona Raft Adventures, Red Lake Books, and Grand Canyon River Guides Association.

Lew Steiger and Jeff Robertson donated their time and provided the video cameras used to record oral histories on the trip. Richard Jackson and Kathy Lampros of Hance Partners, donated their photographic expertise to the trip. Videotape and film used during the trip was provided by the Cline Library and the U.S. Geological Survey, and the resulting tapes of interviews are stored at the Cline Library, Northern Arizona University. Brad Dimock generously provided the unpublished diaries of Haldane "Buzz" Holmstrom. Many people loaned their historical photographs of Grand Canyon, most notably Don Harris, P.T. Reilly, Gretchen Luepke, and Bob Euler. Other diaries were collected from private individuals; the Marston Collection, Huntington Library, San Marino, California; Special Collections, the Cline Library, Northern Arizona University; the Field Records Library, U.S. Geological Survey, Denver, Colorado; and the National Archives, College Park, Maryland. We particularly thank all those interviewed for this work, especially the Old Timers.

SOURCES OF INFORMATION

The Old Timers

The Old Timers on the September 1994 trip are discussed in the following brief biographies that show the qualifications of these individuals as observers of environmental change in Grand Canyon.

John Cross Sr. After boating in Glen Canyon with Bert Loper, a well-known early river runner (Lavender, 1985), John Cross Sr. founded Cross Expeditions, an important river-running company. Much of his experience with Grand Canyon occurred during the first years after closure of Glen Canyon Dam. Most of his experience with the unregulated Colorado River occurred in Glen Canyon.

John Cross II. John Cross II ran the Colorado River extensively in the 1960s. He has the distinction of being the first boatman to run the newly enlarged Crystal Rapid in March 1967, and he wrote extensive notes on the impacts of the December 1966 tributary floods on main channel resources.

Lois Jotter Cutter. With Elzada Clover, Lois Jotter Cutter was the first woman to go completely through Grand Canyon in 1938 (Cook, 1987). She co-authored several publications on the plants of Grand Canyon (*e.g.*, Clover and Jotter, 1944), and the 1994 trip was her second. She is one of the first 100 river runners through Grand Canyon.

Kent Frost. After rowing boats for Norm Nevills in the late 1940s, Kent Frost worked with Mexican Hat Expeditions in the early to mid-1950s. He is one of the first 100 river runners through Grand Canyon. His photographs show the condition of riparian vegetation and sand bars in Grand Canyon.

Les Jones. Les Jones was one of the first canoeists to traverse Grand Canyon, beginning in 1953. He made the first river guide to Grand Canyon (Jones, 1962) and ran a trip on extremely low water just after closure of Glen Canyon Dam in 1963. His photographs show many important rapids at low water, and his scroll map documents historical river trips.

Martin Litton. Founder of Grand Canyon Dories, Litton is an outstanding photographer and conservationist. In particular, his photographs document the considerable changes to Lava Falls Rapid. After hiking in at Lava Falls Rapid to meet Mexican Hat Expeditions on several occasions in the early 1950s, Litton rowed the river for the first time in 1955 with P.T. Reilly. Litton currently is the oldest person to have piloted a boat through Grand Canyon.

Garth Marston. Son of the river historian Otis "Dock" Marston, Garth Marston first ran the river in 1942. He rowed boats for Norm Nevills in the 1940s and is one of the first 100 river runners through Grand Canyon. Unlike many of the Old Timers, Marston has continued to take trips through Grand Canyon and has experienced many of the changes directly.

Tad Nichols. An outstanding photographer and cinematographer, Nichols recorded scenes of Grand Canyon for Mexican Hat Expeditions in the 1950s. His photography documents a wide variety of changes in Grand Canyon, particularly in sand bars at Badger Rapid and Redwall Cavern. Nichols died in 2000.

Sandy Nevills Reiff and Woody Reiff. Sandy, a daughter of Norm Nevills, was heavily influenced by her parent's river-running prowess. She has run the Grand Canyon numerous times and possesses the photographic archives of her parents. Woody Reiff boated through Glen Canyon before the dam was built and was the National Park Service ranger at Lee's Ferry in the 1970s. He died in 1998.

Bob Rigg. Bob and his brother Jim obtained Mexican Hat Expeditions with Frank Wright in 1950. Bob ran the river numerous times between 1950 and 1965 as an oar boatman and motor-boatman. He has a remarkable memory of specific places and documented numerous changes to the canyon.

Gene Shoemaker. A world-class scientist, Shoemaker led USGS expeditions to replicate photographs from the second Powell expedition. The 1968 trip resulted in a book (Stephens and Shoemaker, 1987) that documents riverine conditions in Grand Canyon shortly after closure of Glen Canyon Dam. Shoemaker, who died in an automobile accident in 1997, was a world-famous geologist with considerable field experience in Grand Canyon.

Joan Nevills Staveley. The first daughter of Norm and Doris Nevills, Joan first ran the river in 1947. She later acquired Mexican Hat Expeditions with her then-husband, Gaylord Staveley. Joan has a ongoing voice in the politics of the Grand Canyon region and has an active interest in preservation of river running memorabilia.

Other Pre-Dam or 1960s River Runners

Bill Beer. With John Daggett, Beer swam the Colorado River through Grand Canyon in 1955 and wrote a book about it (Beer, 1988). He loaned us photographs of Grand Canyon and gave us what information he remembered about his trips in the 1950s and 1960s. He died in an airplane crash in 2000.

Bob Euler. The archaeologist of Grand Canyon National Park from the 1960s through the 1970s, Euler spent extensive time along the Colorado River. He loaned us his photographs of the river and its tributaries as part of our work. Plagued by poor health, he chose not to join the Old Timers' Trip and died in 2002.

Barry Goldwater. Goldwater first ran the river in 1940 with Norm Nevills and again on a motor trip in 1965. He graciously loaned us all of his photographs, stored at the Center for Creative Photography at the University of Arizona, for use in our work. Goldwater died in 1998.

Don Harris. Harris first ran the Colorado River in Cataract Canyon with Nevills in 1938. Besides having the distinction of being the second river runner to successfully navigate all Grand Canyon rapids, Harris operated a commercial river-running company until the late 1960s. His 1939 diary is an excellent account of Grand Canyon rapids. He is one of the first river 100 runners through Grand Canyon. His photographs and a movie made of his 1939 trip help document changes in Lava Falls Rapid. Because of poor health, he did not accompany us on the Old Timers' Trip but was reunited with Lois Jotter at Lee's Ferry before the start of the trip in September 1994.

P.T. Reilly. P.T. Reilly was a Colorado River boatman and historian who is most noteworthy for his history of Lee's Ferry (Reilly, 1999) and his introduction of dories to Grand Canyon. Reilly made numerous high-water runs through Grand Canyon in the 1950s and introduced Martin Litton to Colorado River boating. He organized one of the first trips to publicize the effects of Glen Canyon Dam on Grand Canyon (Leydet, 1968) and championed against construction of additional dams in Grand Canyon. He loaned all of his diaries to us as well as his extensive collection of photographs. P.T. died in 1996.

Susie Reilly. Susie Reilly accompanied P.T. on his Grand Canyon trips and was one of the first 12 women to go through Grand Canyon by boat. She kept a diary that was used in this work. Susie died in 2001.

Bob Sharp. Sharp, a world-renowned geomorphologist from the California Institute of Technology, first ran the Colorado River through Grand Canyon in 1937 with the Carnegie - Cal Tech Expedition. During that trip, he met Buzz Holmstrom at Diamond Creek (mile 225.8-L). He loaned us his diary, his photographs, and a summary of the trip for our work.

Hal Stephens. Stephens was the photographer for the U.S. Geological Survey expedition in 1968 that replicated photographs taken by the 1871-72 Powell Expedition. With Gene Shoemaker, Stephens reoccupied numerous camera stations that Jack Hillers established in 1872 in Grand Canyon and published his work (Stephens and Shoemaker, 1987). Stephens donated his photographs and negatives to our effort.

Frank Wright. Frank Wright was a Nevills' boatman who purchased Mexican Hat Expeditions with his brother Jim after Nevills' death in 1949. He would not join the Old Timers' Trip owing to his perceived ideas of the changes in Grand Canyon that resulted from construction of Glen Canyon Dam.

Other Interviews. In addition to the Old Timers, we had six guides with long experiences in Grand Canyon: Alistair Bleifuss, Ann Cassidy, Brad Dimock, Brian Dierker, Kenton Grua, and Lew Steiger. These guides provided key information on changes in the river during the 1970s and just before and during the 1983 flood.

Diaries and Other Accounts

Additional information was obtained from the diaries of historic river runners (Table 1). The exploits of these river runners are documented in Lavender (1985). The diaries of Norman D. Nevills and P.T. Reilly were made available as a result of the Old Timers Trip. The diaries of the 1923 U.S. Geological Survey expedition were obtained from the National Archives in College Park, Maryland. Other diaries -- including those of Frank Wright, Georgie White, and Otis "Dock" Marston -- were obtained from the Marston Collection at the Huntington Library in San Marino, California (Table 1). Many diaries from early river trips are published (Table 1). Bill Beer was interviewed in August 1994; he loaned us photographs and movies for our interpretations. After the trip, several participants sent notes and photographs for our use. Specific information on changes near Lee's Ferry are given in Reilly (1999). The combination of diaries, photographs, and direct observations of the Old Timers provide considerable information on pre-dam conditions between 1872 and 1963, particularly between 1938 and 1963.

Repeat Photography

We have replicated approximately 1,400 photographs of Grand Canyon and its tributaries during the course of this project. Photographs were obtained from numerous archives, most notably the National Archives, College Park, Maryland; the U.S. Geological Survey Photographic Library, Denver, Colorado; the Huntington Library, San Marino, California; Special Collections at the Cline Library, Northern Arizona University; the Marriott Library at the University of Utah; the Bancroft Library, University of California at Berkeley; and private individuals. Examples of repeat photography in Grand Canyon appear in Turner and Karpiscak (1980), Stephens and Shoemaker (1987), Webb and others (1991), Webb (1996), Melis and others (1996), Melis (1997), and Webb and others (1999a; 1999b). Although our results here rely primarily on written and oral accounts of change, repeat photography is used to support or refute those observations.

Interviews and Interpretation of Observations

We listened and tried not to intentionally prompt the Old Timers. After an introduction to debris flows, types of sand bars, and the basic purpose of the trip, we simply recorded their responses to the canyon. We deliberately let many sites pass without discussing some obvious changes that have occurred since 1982. In several cases, places identified as critical camping beaches or habitat for endangered species were passed without comment by either the scientists or the Old Timers.

We devised some simple tests of the veracity of the Old Timers' memories. For example, we asked whether Bedrock and Dubendorff Rapids had changed,

Table 1. Diaries from historical river trips in Grand Canyon used in this study

Date of Trip	Author	Part of Canyon	Source of Material
1869	Powell expedition	All	Cooley, 1988
1872	F. S. Dellenbaugh	Lees Ferry to Kanab Creek	Dellenbaugh, 1908
1872	J. K. Hillers	Lees Ferry to Kanab Creek	Fowler, 1972
1890	R. B. Stanton	All	Smith and Crampton, 1987
1890	W. H. Edwards	All	Unpublished diary
1896	G. Flavell	All	Flavell, 1987
1909	J. Stone	All	Stone, 1932
1911	E. Kolb	All	Kolb, 1914
1911	B. Lauzon	Phantom to Grand Wash Cliffs	Unpublished diary
1923	USGS Expedition	All	Unpublished diary
1927	C. Eddy	All	Eddy, 1929
1928	J. Harbin	Phantom to Diamond Creek	Unpublished interview
1937	I. Campbell	All	Unpublished diary
1937	B. Sharp	All	Unpublished diary
1937	B. Holmstrom	All	Unpublished diary
1938	N. Nevills	All	Unpublished diary
1938	L. Jotter	Lees Ferry to Granite Rapid	Unpublished diary
1938	E. Clover	All	Unpublished diary
1938	A. Burg	All	Unpublished postcards
1938	B. Holmstrom	All	Unpublished postcards
1938	W. Johnson	All	Unpublished narrative
1939	D. Harris	All	Unpublished diary
1940	N. Nevills	All	Unpublished diary
1940	B. Goldwater	All	Goldwater, 1940
1940	M. Baker	All	Unpublished diary
1941	N. Nevills	All	Unpublished diary
1942	N. Nevills	All	Unpublished diary
1942	O. Marston	All	Unpublished diary
1947	N. Nevills	All	Unpublished diary
1948	N. Nevills	All	Unpublished diary
1948	F. Masland	All	Masland, 1948
1948	J. Doerr	Phantom to Grand Wash Cliffs	Unpublished diary
1948	O. Marston	All	Unpublished diary
1948	G. Marston	Lees Ferry to Bedrock Rapid	Unpublished diary
1949	P.T. Reilly	All	Unpublished diary
1949	F. Wright	All	Unpublished diary
1949	H. Welty	Lees Ferry to Phantom	Unpublished diary
1950	F. Wright	All	Unpublished diary
1950	S. Reilly	Phantom to Grand Wash Cliffs	Unpublished diary
1951	D. Harris	All	Unpublished diary
1951	F. Wright	All	Unpublished diary
1951	J. Desloge	All	Unpublished diary

Table 1. Diaries from historical river trips in Grand Canyon used in this study

Date of Trip	Author	Part of Canyon	Source of Material
1951	S. Reilly	Lees Ferry to Phantom	Unpublished diary
1952	F. Wright	All	Unpublished diary
1953	P.T. Reilly	All	Unpublished diary
1953	F. Wright	All	Unpublished diary
1953	G. White	All	Unpublished diary
1954	O. Marston	All	Unpublished diary
1954	G. White	All	Unpublished diary
1955	P.T. Reilly	All	Unpublished diary
1955	F. Wright	All	Unpublished diary
1956	P.T. Reilly	All	Unpublished diary
1956	F. Wright	All	Unpublished diary
1957	P.T. Reilly	Lees Ferry to Phantom	Unpublished diary
1957	F. Wright	All	Unpublished diary
1958	P.T. Reilly	Phantom to Lava Falls	Unpublished diary
1959	P.T. Reilly	Lees Ferry to Pipe Creek	Unpublished diary
1962	P.T. Reilly	All	Unpublished diary
1964	P.T. Reilly	All	Unpublished diary

knowing full well that Bedrock had and Dubendorff had not. The Old Timers correctly recognized the changes in Bedrock Rapid and the lack of change in Dubendorff. By listening to the answers, we established the credibility of the Old Timers as very high in remembering specific and detailed information about changes in Grand Canyon. We also established that differences in water level between the pre-dam era and the Old Timer's Trip was extremely important to their memory of specific sites. Several did not remember the debris bars at Vaseys Paradise and the mouth of the Little Colorado River. These bars may have changed significantly, but both bars may have been covered with water when some of the Old Timers passed them.

Some observations may seem trivial or unremarkable. For example, the large invasion of non-native tamarisk is generally recognized by scientists and river runners alike (Turner and Karpiscak, 1980; Stevens, 1989). On the other hand, tamarisk was advancing its distribution before Glen Canyon Dam was built and the rate of its spread is little known (see Graf, 1978). Because of such subtleties, we include the full set of observations. Other changes noted by the Old Timers, particularly those concerning wildlife, are probably inconclusive, a consequence of limited observations and lack of independent scientific verification. We include them anyway, albeit with appropriate caveats, to spur discussion.

SPECIFIC CHANGES OBSERVED IN GRAND CANYON

Aesthetics in Grand Canyon

The aesthetics of river trips were a common theme among the Old Timers. Some, particularly Sandy Nevills Reiff and Joan Nevills Staveley, commented on how clean the canyon is now. Their most recent canyon experiences were just before the current policy of cleaning up trash and hauling human waste from campsites. When they did most of their trips from the late 1950s to the early 1970s, human waste and garbage were buried in sandbars. Others found the noise of aircraft overflights to be oppressive compared to the noise from the rare airplane that passed over the canyon in the pre-dam era.

Several Old Timers missed the effects of a silt-laden river on the quality of the river trip. In particular, they missed the sound of sand scraping on the sides and bottoms of boats. The waves in rapids appeared to be different; the pre-dam sediment-laden waves appeared

Table 2. Dates and observations of the Colorado River being frozen at Lee's Ferry, Arizona, or other points along the river.

Date	Observations
January 1866	River frozen at Crossing of the Fathers in Glen Canyon, allowing Navajo traders to cross on the ice (Webb, 1996, p. 97).
January 15, 1878	River frozen for two weeks. Mormon missionaries crossed on the ice pulling wagons across (Webb, 1996, p. 97 and note 54; Reilly, 1999, p. 75).
December 31, 1879	River frozen for one day, long enough for Mormon colonists to move animals and wagons across the river (Webb, 1996, p. 97).
January 13, 1898	River frozen, R.B. Stanton rowed downstream and had to chop through the ice to reach Lee's Ferry (Reilly, 1999, p. 159-160).
late December, 1898	Animals were crossed over the river on the ice (Reilly, 1999, p. 170).
late December, 1911	Men crossed the river, frozen for several days, on foot (Reilly, 1999, p. 245).
January 1-2, 1925	Navajo traders drove pack mules across the river (Webb, 1996, p. 97). The river was frozen for nearly a month (Reilly, 1999, p. 170).
1928	Completion of Navajo Bridge eliminates observations of the river freezing except in gaging station records (Webb, 1996, p. 225).
1933	Ice affected the gaging record at Lee's Ferry for 64 days, from December 1932 to February 1933.

choppier and seemed to have extra force when hitting the boats and passengers. Many historical river trips experienced sandstorms, which are uncommon now. On his trips in 1937 and 1938, Buzz Holmstrom noted several of these, commenting that "windy all night - sand in everything this morning" (1937) and "sky so full of sand sun blotted out" (1938). Erosion of sandbars, as well as the increased size of sand in the ones that remain, minimize the potential for significant sandstorms along the river corridor at present.

Nevills Staveley was impressed with the high degree of cooperation among guides now, instead of the competitive atmosphere that prevailed on her last trip. Rigg and Nevills Staveley remarked that the deterioration of air quality as a major change; Rigg stated that the sky was much hazier now than when he ran the river and that it significantly degraded the experience. He also lamented the loss of the Bass cableway, which once spanned the river downstream of Bass Rapid (mile 108).

Water Temperature

The cold water released from the bottom of Lake Powell was a very noticeable change to most of the Old Timers, who generally experienced the warm water of summer on their river trips. Generally, the water temperature of releases at the dam are about 49ºF year round, meaning that the river is cold in summer and warm in winter. Historical observations of the river freezing over in winter (Table 2), are important to understanding changes in aquatic habitat as a result of the presence of Glen Canyon Dam as well as potentially understanding the effects of climate on the river. As discussed in Webb (1996), the river froze frequently in the late 19th century, occasionally with enough ice to allow the passage of wagons over its surface at Lee's Ferry (Table 2).

Geomorphology

The Colorado River in Grand Canyon has numerous debris fans, debris bars, and eddies that influence its longitudinal profile. The debris fans generally occur at the mouths of tributaries and create constrictions and rapids. Cobbles and boulders are reworked from the debris fan and transported downstream; these particles accumulate in debris bars that create secondary constrictions and rapids. The primary and secondary rapids are separated by a pool that typically has an eddy on one or both channel margins. Eddies form between the debris fan and debris bar or other downstream obstructions, such as bedrock walls. Sand bars are deposited on both the upstream and downstream sides of the debris fan, as well as on the downstream side of the eddy (Schmidt and Graf, 1990). All of these geomorphic features have changed historically (Webb, 1996) and were mentioned by the Old Timers.

Debris Flows and Floods

Two types of tributary floods occur in Grand Canyon (Melis, 1997; Melis and others, 1994). Debris flows are slurries of water and poorly sorted sediment that transport large boulders into the Colorado River, creating rapids. The sediment concentration of debris

Figure 2. Photographs showing Badger Creek Rapid (mile 8.0).

A. August 1964. In this view of Badger Creek Rapid from the left canyon rim, low water in the Colorado River reveals many of the rocks that constrict the river. The sand bar on river right has significant sand and a few scattered, non-native tamarisk trees (Tad Nichols, no number, courtesy of the photographer).

flows is generally greater than 80 percent. Debris flows occur infrequently; only 60 percent of the tributaries in Grand Canyon have produced debris flows in the last century (Griffiths and others, 1996). Because they transport large boulders, debris flows leave spectacular evidence of their occurrence, and most observers of these floods left a written record or had a vivid memory of the event. In contrast, streamflow floods have a sediment concentration of less than about 40 percent and occur more often. Some observers (*e.g.*, Reilly) could distinguish the two types of floods.

The Old Timers remember few new debris-flow deposits, and only a few debris flows are recorded in diaries. We showed the Old Timers the 1994 Jackass Creek (mile 7.9-L) debris-flow deposits at Badger Creek Rapid (mile 8.0) and discussed this geomorphic process with them extensively (Fig. 2). We then asked them if they had seen any similar deposits along the river during their river experiences. Rigg remembered when the debris fan of Boucher Creek (mile 96.7-L) changed radically in 1951 or 1952. When he first saw it, mud was still oozing out from between the boulders. Using Robert Brewster Stanton's photographs from 1890, we had identified the Boucher Creek debris flow as one of the largest in the last century in Grand Canyon but had not known the exact year it occurred (Melis, 1997; Webb, 1996).

The highest frequency of debris flows in Grand Canyon occurs at Lava Falls Rapid (mile 179) from Prospect Canyon (mile 179.4-L; Webb and others, 1999b). In 1954, Georgie White arrived at Lava Falls on July 24 and saw Prospect Creek (mile 179.4-L) running at "full force." Large boulders were entering the river in a manner White likened to a "big black lava flow." White's observations are only the second eyewitness account of a Grand Canyon debris flow, after Robert Brewster Stanton's account of a debris flow in South Canyon (mile 31.6-R; Smith and Crampton, 1987). Jones remembered that the debris fan of Prospect Canyon (mile 179.4-L) was paved with fine

Figure 2. Badger Creek Rapid (mile 8.0)(continued).

B. October 1968. Nichols approximately matched his earlier photograph and documents an increase in the sand bars and tamarisk growth. The increased sand likely was deposited during the high releases from Glen Canyon Dam in the summer of 1965. The rapid is unchanged (Tad Nichols, no number, courtesy of the photographer).

gravel on his trip in early October 1963; it made his portage of Lava Falls Rapid much easier. Our photographic evidence of this debris flow suggested that it occurred between August and September 22, 1963; Jones' recollection corroborates our independent estimate.

The occurrence of five of the six debris flows at Prospect Canyon in the 20th century were known only from photographs taken by river runners or scattered observations. The movies and photographs taken during Harris' trip in July 1939 show what Lava Falls Rapid looked like before the September 1939 debris flow, which was the largest of the 20th century (Webb and others, 1999b). Reilly's photographs span the three debris flows of 1954, 1955, and 1963. He observed the effects of the debris flow of 1955 in Prospect Canyon (mile 179.4-L) and wrote that the 1956 high water had sliced into the newly deposited debris fan, leaving a 15-foot-high bank. This observation was verified in Nichols' photographs, which show the boats of a Mexican Hat Expeditions trip being portaged over that bank. Finally, during an August 1967 trip with Georgie White, passenger Gretchen Luepke photographed the 1966 debris-flow deposits at both Lava Falls Rapid (mile 179.5) and Bright Angel Creek (mile 87.8-R). Her photographs verify what John Cross II observed in March 1967 on the first trip to experience Lava Falls after the 1966 debris flow.

Other river runners did not observe or chose not to record debris-flow deposits. Frank Wright wrote detailed trip logs (Table 1), yet he failed to record either the Boucher Creek deposition or the two debris flows at Prospect Canyon despite the fact that others on his trip either remembered them, wrote about them, or photographed them.

P.T. Reilly meticulously noted the signs of recent flooding in tributary canyons. Most of what he observed can be attributed to streamflow floods, not debris flows. He observed new mud and silt in the mouth of Shinumo Creek (mile 108.6-R) in 1949. In

Figure 2. Badger Creek Rapid (mile 8.0)(continued).

C. September 5, 1994. A debris flow from Jackass Creek (mile 7.9-L) on August 19, 1994, constricted Badger Creek Rapid. Most of this constriction was removed by the 1996 controlled flood release from Glen Canyon Dam. The sand bar on river right is depleted, probably as a combined result of the high-water years of 1983-1986 and wind deflation. Other changes include the increase in tamarisk (Robert H. Webb, Stake 2862).

1954-1955, a flood removed large redbud trees from the mouth of an unnamed canyon at mile 38.7-R, and a "heavy flood" down Red Canyon (mile 76.7-L) cut a channel 5-feet deep and 40-feet wide. Also in 1955, a flood cut a large swath through a sand bar at Spring Canyon (mile 204.3-R). A flood in Deer Creek (mile 136.2-R) in 1956 filled the pool with sediment and rearranged boulders in the mouth, and a Diamond Creek (mile 225.8-L) flood changed the channel at its mouth. Reilly was particularly impressed with the effects of tributary flooding in 1961; a new deposit filled much of the pool beneath Deer Creek Falls and the mouth of Tapeats Creek (mile 133.8-R) shifted downstream. The latter flood is now thought to be a debris flow (Melis and others, 1994). Although he accurately described changes he saw in the 1950s, he made additional observations on dam-related and other changes during trips in 1982 and 1984. A few of the later observations were inaccurate; for example, Reilly erroneously thought that the Quigley grave at President Harding Rapid (mile 43.2) was removed by a flood between 1964 and 1982, but the grave is still present.

The relatively few observations of debris-flow deposits before Glen Canyon Dam is significant. Before the Old Timer's Trip, we already knew from repeat photography and historical records that many debris flows had occurred in the last 15 years and that few could be identified from the pre-dam era. It is unlikely that Colorado River floods completely removed the evidence before the Old Timers could see the changes. Most pre-dam river trips occurred in the summer months, when debris flows are most likely to occur, or in the fall, before the spring floods could rework the deposits. In fact, Reilly and Nevills each saw evidence of streamflow floods, not debris flows.

Both Litton and Cross II commented on the extensive channel changes associated with the December 1966 flood in Bright Angel Creek (mile 87.8-R). Historical photographs, notably those by

Figure 3. Photographs showing The sand bar downstream from Tapeats Creek (mile 133.9-R).

A. July 1952. This view downstream from the below the mouth of Tapeats Creek (mile 133.8-R) shows a large sand bar with few rocks or boulders exposed. This sand bar was frequently used for layovers in the 1950s; the passengers of Mexican Hat Expeditions trips fished for trout in the creek (Kent Frost, no number, courtesy of the photographer).

Luepke and Euler, had suggested that the initial phase of the flood was a debris flow because of the new debris fan that was created. We already knew that changes in the debris fan under the Silver Bridge were among the most extensive of the last century in Grand Canyon, but Litton and Cross II reinforced the hypothesis that the early stage of the 1966 flood was a debris flow followed by higher flood waters bearing less sediment. Melis and others (1997) have reported that such multi-phased floods, starting as a debris flow and ending with intense streamflow, are common in Grand Canyon tributaries. The 1995 Bright Angel Creek debris flow had a similar effect on the river and left similar evidence.

Most of the Old Timers, particularly Jones, were impressed by the large number of recent debris-flow deposits along the river. Some Old Timers did not remember evidence of debris flows specifically, but they recognized small changes in places they had previously visited. Frost knew that the mouth of South Canyon (mile 31.6-R) had changed since his last visit. We previously had documented the occurrence of the debris flow using matched photographs from 1890 and those of Goldwater (1940) and Bill Fahrni (1934). The year of the debris flow causing the change is still unknown, but it occurred between 1940 and 1965.

The Old Timers have contributed greatly to our knowledge of debris-flow frequency with their photographs and memories. For example, Nichols consistently took photographs of Badger Creek Rapid from the left canyon rim. His photographs document changes in the sand bars and tamarisk and provides the basis for determining whether any debris flows had occurred prior to one in August 1994 (Melis, 1997; Melis and others, 1994). We also used many of Reilly's photographs to document debris-flow frequency in Grand Canyon, particularly at Lava Falls Rapid (Webb and others, 1999b).

The Old Timers recognized the large change at the mouth of Tapeats Creek, where many of them had spent considerable time. The channel mouth shifted upstream during a 1961 flood. They also noticed the large decrease in sand present (see below), which in part was related to channel change at the mouth. The

Figure 3. The sand bar downstream from Tapeats Creek (mile 133.9-R) (continued).

B. March 1, 1995. Large rocks and boulders are now exposed because of severe beach erosion. New sand was deposited here during the 1996 controlled flood but was quickly removed (Steve Tharnstrom, Stake 2676).

1961 flood may have had a small debris-flow component to it; the rapid was filled in on the top right side.

Rockfalls

Rockfalls were rarely noted or observed in the pre-dam era. Reilly recorded any rockfalls he observed; he particularly mentions a 1,500-lb boulder falling at Diamond Creek in 1949. On one of his last river trips in 1982, Reilly observed that many rockfalls had occurred since his previous trip in 1964. Rigg also mentioned the lack of rockfalls when he ran the river. This was thought to be significant because we witnessed a rockfall at Eminence Camp (mile 44-L) on the Old Timers Trip in 1994, which Shoemaker noted was the first he had seen in Grand Canyon. Many recent rockfalls were pointed out by trip participants. Since the Old Timers' trip, a major rockfall in 1999, significantly limited navigation through the right side of President Harding Rapid (mile 43.3).

Rapids

The Old Timers recognized some obvious and some subtle changes in rapids. The change in Crystal Rapid (mile 98.3), which many of the Old Timers had not seen before, is the most dramatic of any noted, although Rigg was also impressed with the changes in Lava Falls Rapid. Cross II had a wealth of information on changes to rapids in the first decade after closure of Glen Canyon Dam (1963), and shared his notes with us of what he saw during the first river trip after the December 1966 storm. Lava Falls Rapid changed on the left side in 1966 owing to many large boulders being deposited in a former "sneak" run; we subsequently identified the cause as a debris flow from Prospect Canyon (mile 179.4-L). Bright Angel Rapid (mile 87.9) also changed slightly in 1966.

Although the Old Timers could not agree when House Rock Rapid (mile 16.9) changed, the body of observations points to more than one event. Litton associated the change with the 1966 storm but had no specific evidence to support the observation. Dierker claims the largest change occurred before 1969, when

Figure 4. Photographs showing Deer Creek Falls (mile 136.1-R).

A (left). September 10, 1923. Deer Creek Falls was photographed by every early river trip. This series shows the waterfall from river right on its debris fan. The large sandbar on the left side of the view is part of what attracted rivers to camp here (E.C. LaRue 547, courtesy of the U.S. Geological Survey Photographic Library).

B (right). August 15, 1940. The annual flood of the Colorado River always reached the base of the waterfall, and the sandbar was annually renewed. The width of the waterfall changes as chock stones are added or removed from the slot. Although this photograph was taken from a different perspective than the 1923 view, new rocks are apparent on the debris fan (B.M. Goldwater, unnumbered, courtesy of the Center for Creative Photography, University of Arizona).

he started working in Grand Canyon, and that subsequent floods constricted the river further. Rigg remembered small changes between 1959 and 1965 but thought the constriction was much worse now. Taken together, these observations indicate a typical pattern of several, closely-timed debris flows in one tributary, with little change before or after. The same course of events unfolded in other tributaries, including Prospect Canyon, where six debris flows and several other floods altered Lava Falls Rapid between 1939 and 1995.

Dimock provided photographs and observations about the 1984 debris flow in Monument Creek (mile 93.5-L). His trip photographed an enormous wave that formed briefly just after the event. After successfully photographing (and running) the wave, Dimock said he never saw it or anything like it again in Granite Rapid. Dimock also noted changes on the left side of Soap Creek Rapid (mile 11.3; 1979-1982), which he attributed to a rockfall, and the reworking of the right side of House Rock Rapid (mile 16.9) by the 1983 flood.

Figure 4. Deer Creek Falls (mile 136.1-R) (continued).

C (left). July 1, 1972. Because of flood control operations of Glen Canyon Dam, riparian vegetation has increased along the river. This lush growth of native and non-native species is typical of conditions in 1972 in Grand Canyon (matches A, Raymond M. Turner, Stake 692).

D (right). November 3, 2001. A flood in the summer of 2001 stripped much of the riparian vegetation out of the mouth of Deer Creek. In the 1980s and 1990s, floods of this magnitude have occurred every 2-4 years. Again, the rocks have been removed from the debris fan and cobbles cover its surface. Debris fans are aggrading throughout Grand Canyon, and the fan at the mouth of Deer Creek is no exception (matches B, Tom Brownold, Stake 2985).

One of the most perceptive observations came from Reilly. He mentioned changes caused by the 1955 debris flow at Lava Falls, such as fewer holes and smoothing of the rapid as the spaces behind the large boulders were filled with smaller ones. Sediment eroded from the fan filled in much of the eddy downstream to the Warm Springs, making the lining operation easier.

Sand Bars

Our work with repeat photography, particularly with the Stanton photography of 1889-1890, suggests that sand-bar erosion was severe and decreases with distance downstream from Glen Canyon Dam (Schmidt and Graf, 1990; Schmidt and others, 1995; Webb, 1996). We wanted the Old Timers' opinion on that conclusion. Most of the Old Timers lamented the current status of sand bars in Grand Canyon, particularly in Marble Canyon (miles 0 to 61); they often pointed to sand bars and noted how small they

Table 3. List of known driftwood fires in Grand Canyon, 1937-1964

Year	Date	Diarist	Location	Relative Size
1937	Nov 9	I. Campbell	Dubendorff Rapid	Large
1937	Nov 15	I. Campbell	Gateway Rapid	Large
1937	Nov 16	I. Campbell	Lava Falls Rapid	Large
1938	Jul 11	N. Nevills	Tanner Canyon	Large signal fire
1938	Oct 20	W. Johnson	Above Lava Canyon	Large
1940	Aug 5	N. Nevills	Boulder Narrows	Large
1940	Aug 7	N. Nevills	Vaseys Paradise	Small
1940	Aug 8	N. Nevills	Saddle Canyon	Large
1940	Aug 8-20	N. Nevills	All scouts of rapids	Small but many
1940	Aug 20	N. Nevills	Diamond Creek	Large (cabins)
1941	Jul 17	N. Nevills	Nankoweap Canyon	Large
1941	Jul 18	N. Nevills	Nankoweap Canyon	Large
1942	Jul 14	O. Marston	North Canyon	Unknown
1942	Jul 16	N. Nevills	Vaseys Paradise	Unknown
1942	Jul 17	N. Nevills	Nankoweap Canyon	Large
1942	Jul 19	N. Nevills	Tanner Canyon	Signal fire
1942	Jul 27	N. Nevills	Fern Glen Canyon	Large
1947	Jul 12	N. Nevills	Navajo Bridge	Unknown
1947	Jul 15	N. Nevills	Nankoweap Canyon	Unknown
1947	Jul 17	N. Nevills	Palisades Creek	Brush fire
1947	Jul 17	N. Nevills	Lava Canyon	Small
1947	Jul 17	N. Nevills	Tanner Canon	Large signal fire
1947	Jul 18	N. Nevills	Unkar Creek	Large
1948	Jul 14	O. Marston	mile 35	Small
1948	Jul 14	N. Nevills	mile 40	Unknown
1948	Jul 14	N. Nevills	Buck Farm Canyon	Unknown
1948	Jul 15	N. Nevills	Nankoweap Canyon	Unknown
1948	Jul 16	N. Nevills	Tanner Canyon	Large signal fire
1948	Jul 23	O. Marston	Elves Chasm	Small
1948	Jul 23	N. Nevills	Mile 118	Unknown
1949	Jul 14	P.T. Reilly	President Harding Rapid	Large
1949	Jul 15	P.T. Reilly	Nankoweap Canyon	Unknown
1949	Jul 16	P.T. Reilly	Nankoweap Canyon	Unknown
1950	Jul 14	F. Wright	President Harding Rapid	Large
1951	Jul 15	S. Reilly	Bert’s Canyon	Unknown
1951	Jul 15	S. Reilly	Nankoweap Canyon	Large
1951	Jul 16	S. Reilly	Tanner Canyon	Large signal fire
1951	Jul 25	F. Wright	mile 180.5	Unknown
1952	Jul 23	F. Wright	mile 137	Unknown
1952	Jul 26	F. Wright	Whitmore Wash	Unknown
1953	Jul 12	F. Wright	Salt Water Wash	Unknown
1953	Jul 14	F. Wright	Nankoweap Canyon	Unknown
1955	Jul 2	P.T. Reilly	Fern Glen Canyon	Unknown

Table 3. List of known driftwood fires in Grand Canyon, 1937-1964

Year	Date	Diarist	Location	Relative Size
1955	Jul 4	P.T. Reilly	Spring Canyon	Large
1955	Jul 5	P.T. Reilly	Spring Canyon	Large
1955	Jul 13	F. Wright	Hance Rapid	Signal fire
1956	Jun 19	P.T. Reilly	24 1/2-Mile Rapid	Unknown
1956	Jun 20	P.T. Reilly	President Harding Rapid	Unknown
1956	Jun 30	P.T. Reilly	Fern Glen Canyon	Large
1956	Jul 13	F. Wright	Hance Rapid	Signal fire

were. The Old Timers remarked on the severe beach erosion in the reach downstream from Nankoweap Rapid (mile 53-54) and at the mouth of the Little Colorado River (mile 61.5-L), Elves Chasm (mile 116.5-L), Stone Creek (mile 131.9-R), Tapeats Creek (mile 133.8-R; Fig. 3), Deer Creek Falls (mile 136.1-R; Fig. 4), and the mouth of Kanab Creek (mile 143.5-R).

Comments about beach erosion decreased downstream of Havasu Creek (mile 156.9-L), which may or may not be significant. They either continued to see eroded bars and felt it not worth additional comment, or the bars may not have been as eroded as upstream, as reported in Schmidt and others (1995) and Webb (1996). Although the Old Timers noted the increase in riparian vegetation, none of them associated this increase with a lack of campsites. Most of their comments came at heavily used sites, not generic sand bars. In no case did the Old Timers specifically contradict our interpretations of historic photographs.

Both Reilly and Beer lamented the loss of camping beaches during trips they made in the 1980s. During a 1984 trip, Reilly observed erosion of sand bars at Tuckup Canyon (mile 164.5-R), National Canyon (mile 166.4-L), and Fern Glen (mile 168.0-R). Beer, in particular, remembers the sound of sand bars calving off into the river as he swam by in April 1955. Rigg noted that several sand bars he had camped on were now either reduced or eliminated. Nichols commented on the reductions in sand bars at the mouth of the Little Colorado River (mile 61-L), Elves Chasm (mile 116.5-L), and Deer Creek Falls (mile 136.2-R). Cross II pointed out a large reduction in the sand bar at the mouth of Stone Creek as an example of extreme erosion.

Reilly observed the relation between sand-bar erosion, tributary flows, and pre-dam river flows. He observed bank calving during a 3-4 foot rise in the river in 1956 that resulted from storm runoff. At Tapeats Creek (mile 133.8-R) in 1962, Reilly watched as the river eroded the sand bar below the rapid. He saw large channels cut through sand bars during storm runoff in 1953. These incidents were mentioned primarily because Reilly considered sand bar erosion a hazard to sleeping boatmen, not because he was concerned that sand bars were diminishing.

Cross II, who ran the river frequently in the years after closure of Glen Canyon Dam, described the slow, progressive loss of sand bars in Marble Canyon through the 1960s. He believed that wind erosion and human impacts, not large clear-water releases such as the 1965 high flows, were the dominant reasons for sand bar erosion from 1963 through about the mid-1970s. He used the separation bar at Soap Creek Rapid (mile 11.3) as an example of a campsite that, from his memory, just gradually blew away.

Rigg thought that the sand-bar erosion downstream from Nankoweap Creek was probably the greatest of any place in Grand Canyon. What formerly was a sand-lined channel is now a reach lined with gravel bars. We had previously recognized the extent of sand-bar erosion in this reach (Webb, 1996).

Channel Bars

The Old Timers were impressed with changes in three debris-bar-controlled rapids. The Rock Garden at Crystal Rapid (mile 98.4) formed as a consequence of the 1966 debris flow and subsequent reworking by the Colorado River. No pre-dam river runners (or their photographs) documented the presence of a debris bar below Crystal Rapid before 1966. Shoemaker, Rigg, and Nichols felt that the debris bars at the mouth of the Little Colorado River and Vaseys Paradise (mile 31.8-R) had aggraded significantly, although they admitted that the perceived changes could, at least partly be attributed to differences in water level. Pre-dam river runners, particularly Reilly, ran left of the island at the

mouth of the Little Colorado River (mile 61.5); such a run today is more difficult although possible at discharges above 20,000 ft^3/s in the Colorado River.

There are subtle implications to these observations. The 1973 flood in the Little Colorado River changed the bar at the mouth significantly; Shoemaker specifically asked us to match Stephens' 1968 photograph to verify this. The debris flow out of South Canyon (mile 31.6-R), which occurred between 1940 and 1965, could have added significantly to the material in the debris bar opposite Vaseys Paradise (mile 31.9). This relation between debris bars and the parent debris fan represents another documented case of the relation between debris flows and the course of the Colorado River.

Driftwood

Before closure of Glen Canyon Dam in 1963, fires were set by some Old Timers in the enormous driftwood piles lining the river corridor. This activity was undertaken at the request of the National Park Service and the Bureau of Reclamation, who were concerned about the effect of driftwood on navigation in Lake Mead. These fires caused a considerable reduction in the amount of dead biomass below the old high-water zone. Driftwood accumulated over a thousand years (Ferguson, 1971), and its destruction over a few decades represents an acceleration in the release (and loss) of nutrients into the atmosphere and into the sands adjacent to the river.

The magnitude and number of fires set along the river corridor by pre-dam river runners was large (Table 3). The effects could be seen for years; for example, signs of the 1940 fire at the mouth of Saddle Canyon (mile 47.0-R) were still prominent in 1942. The reduction in driftwood was substantial owing to the deliberately set fires and subsequent use of firewood for cooking fires. Rigg remembers seeing huge piles of driftwood on every debris bar below Lava Falls Rapid; now, there is little driftwood on these bars. Many Old Timers indicate the decrease in driftwood is one of the major changes in the river corridor. The number of pre-dam fires, combined with the presence of Glen Canyon Dam, may have been largely responsible for the current state of depleted firewood in the canyon.

Another contributing factor to the reduction in driftwood could have been its use in campfires just after closure of Glen Canyon Dam. During the first 15 years of river running on the regulated river, wood was the primary fuel for cooking. It seems improbable that the large piles of driftwood could have been diminished by typical kitchen use, but Grua remembers large piles that were depleted between 1969 and 1980. As early as 1967, Cross II wrote about the abundance of new driftwood introduced to the main channel during the 1966 tributary floods, adding in his notes that "firewood would not be a problem" during the 1967 river season. Nevills Reiff thought there was more driftwood now than when she last was on the river in 1972. She also felt the ban on summer wood fires has had a major effect on increasing the amount of driftwood, which now is added only during infrequent tributary floods.

Riparian and Desert Vegetation

Riparian vegetation is a highly valued resource in the western United States owing to its high productivity, diversity of species, and habitat for wildlife. The Colorado River through Grand Canyon had only sparse riparian vegetation before Glen Canyon Dam (Turner and Karpiscak, 1980; Webb, 1996). Tamarisk, a non-native species, was introduced to the western United States in the late 19^{th} century and spread through the Colorado River drainage (Johnson, 1991). Although Graf (1978) reported that tamarisk spread upstream through Grand Canyon between 1910 and 1923, observations of the Old Timers, combined with repeat photography and diaries, suggests otherwise.

Riparian Vegetation

All the Old Timers observed the huge increase in riparian vegetation along the Colorado River. The change was considered both good and bad: good for shade and wildlife, bad for environmental aesthetics and camping space. The Old Timers recognized tamarisk as the major contributor to the increase. A excellent example of the increase in tamarisk is at Lee's Ferry. Although Graf (1978) claims that tamarisk is visible in 1923 photographs at this site, we see no evidence of tamarisk in historical photographs of Lee's Ferry or Grand Canyon (including those examined by

Table 4. Pre-dam locations of tamarisk and native trees in Grand Canyon.

Year	Notes
1869	Few native trees are noted. The canyon is described as barren.
1872	Few native trees are noted.
1890	Several trees are noted and photographed. No tamarisk is visible (Webb, 1996).
1923	USGS expedition photographs show no tamarisk, nor do the diaries mention it. They photographed the Goodding willow at Granite Park and large cottonwoods at mile 196 and 222.
1937	Sharp notes large increase in native willow trees downstream from Lava Falls Rapid.
1938	Clover observed "some tamarisk coming in now on sandbars" in the vicinity of Saddle Canyon (mile 47). Otherwise, she specifically noted few tamarisk trees between Lees Ferry and Lake Mead. She notes "weedy baccharis" but no tamarisk at Spring Canyon (mile 204).
1938	Huge cottonwood trees were reported at President Harding Rapid (Cook, 1987) and the expedition slept under a "huge willow" at mile 194. Nevills observed the deltaic deposits at the head of Lake Mead were covered with tamarisk.
1940	Goldwater notes a large cottonwood tree was present at mile 220.
1942-47	Nevills observed invasion of tamarisk at the mouth of Spring Canyon.
1947	Nevills expedition finds shade under tamarisk trees at Kanab Creek in 1947.
1948	Nevills expedition finds shade under tamarisk trees at Whitmore Wash (mile 185); Doerr notes that willow trees were also present. Marston notes that "willows decorate wide sandy beaches" near mile 190. Doerr and Nevills report that a large willow across from Pumpkin Spring (mile 213) was being gnawed by beavers. Masland rested under a large willow tree at Diamond Creek. Doerr reports canyon mouths on Lake Mead supported dense stands of young tamarisks and willows.
1951	S. Reilly noted "beautiful green tamarisks" at Badger Rapid. The camp at Salt Water Wash had "many tamarisks" as well as the debris fan at President Harding Rapid. Reilly especially noted "the smell of tamarisks" in the vicinity of Tanner Rapid.
1950s	P.T. Reilly notes tamarisk at Bridge (mile 237) and Spring Canyons. Tamarisk was noted at Beamer's Cabin up the Little Colorado. He does not note cottonwood or other native trees.
1955	P.T. Reilly notes the willows and tamarisk at Spring Canyon were damaged by a flash flood. Beer photographs in 1955 show widespread tamarisk.
Early 1960s	Litton observed that tamarisk on the Lake Mead delta was periodically destroyed by rises in the elevation of the lake; he photographed the barren delta.
Early 1960s	Frost remembers a cottonwood tree at the mouth of Kanab Creek.
1970	Martin (1971) notes huge increase in tamarisk.
1977	J.N. Staveley remembers seeing the cottonwood tree at mile 220.

Graf) taken before Lois Jotter Cutter's 1938 photograph at Badger Rapid. Cutter spent considerable time at Lee's Ferry in 1938, amid extensive media coverage of her river trip. She remembered some willows where the boats landed, but not the extensive stands of tamarisk that now are present; her notes indicate that tamarisk was present (Clover and Jotter, 1944). Other diaries from Lee's Ferry residents discuss flowering tamarisk in 1936 (Reilly, 1999, p. 393) and it is reported as occurring in Glen Canyon upstream from Lee's Ferry between 1933 and 1938 (Woodbury and Russell, 1945). It is likely that tamarisk did not arrive at Lee's Ferry until the late 1920s or early 1930s, whereupon it became established on the higher terraces.

Other places, such as the mouth of the Little Colorado River (miles 61-L), were devoid of tamarisk before Glen Canyon Dam. The first definite evidence of tamarisk here appears in mid-1950s photographs taken by members of Mexican Hat Expeditions trips, as well as Les Jones. Rigg and Nichols, who were on those trips, stated they did not initially recognize the mouth of the Little Colorado River when they arrived in 1994, in part because of the dense stand of tamarisk and willows, the eroded sand bars, and the low stage of the Colorado River.

Tamarisk was rare enough in the pre-dam era that its presence along the unregulated river was recorded in diaries (Table 4). In 1938, tamarisk was sparse. By the 1950s, tamarisk was present at places where it had not been seen in 1938 (for example, Spring Canyon, mile 204.3-R). Tributary floods played a role in limiting its spread; the willows and tamarisk that had invaded the mouth of Spring Canyon were

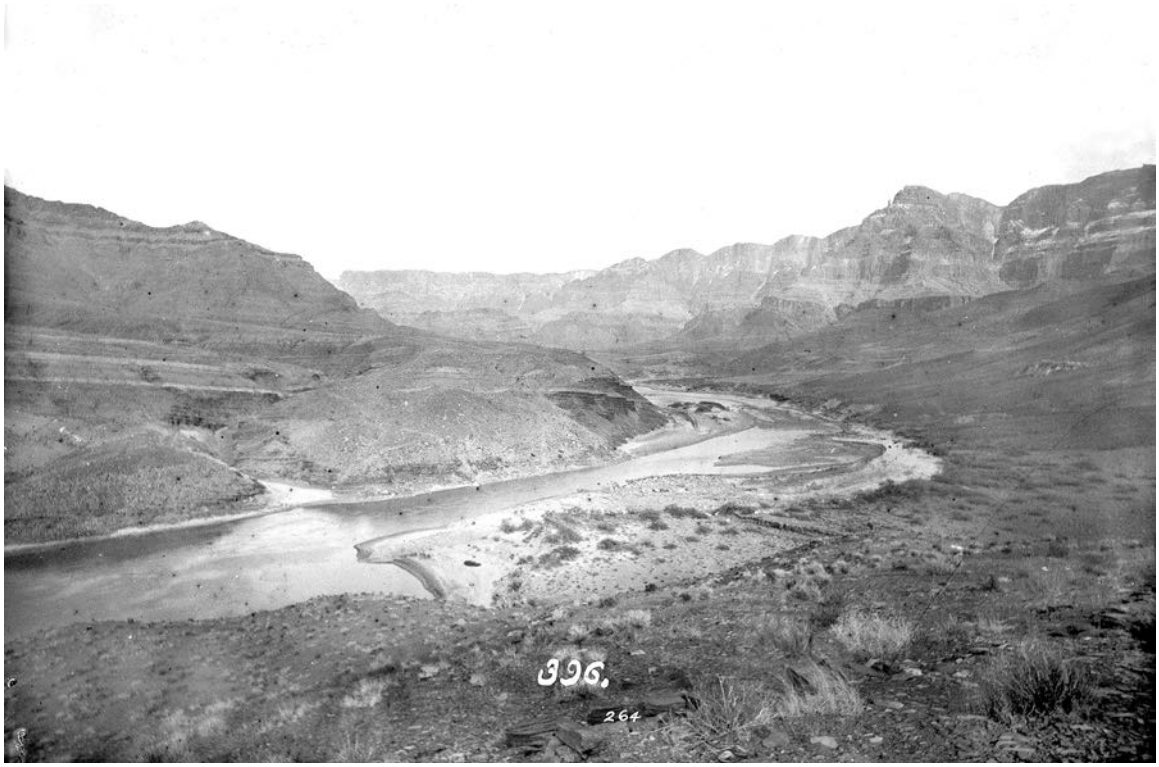

Figure 5. Photographs showing The marsh at Cardenas Creek (mile 70.9-L).

A. January 23, 1890. Robert Brewster Stanton took this upstream view at 3:00 PM during the climb to what is now called Cardenas Hilltop Ruin. Except for scattered mesquite and what appears to be clumps of willows, little riparian vegetation is present along the Colorado River (R.B. Stanton 396, courtesy of the Still Picture Branch, National Archives, College Park, Maryland).

damaged by a flash flood in 1955, and tamarisk on the Lake Mead delta was periodically destroyed by rises in the elevation of the lake.

Large native trees were rare (Table 4). Photographs taken in 1923 showed a small grove of cottonwood trees at mile 222-L; these trees are no longer present. Bob Sharp observed an increase in native willow trees downstream from Lava Falls in 1937, implying that few trees were present upstream. Others, particularly Dock Marston, had similar observations in later years (1948). Shade was eagerly sought but rarely found under trees during the Nevills' expeditions, and the locations of large trees were specifically noted in diaries. By the 1950s, native trees were rarely mentioned, but the presence of tamarisk high enough to provide shade was recorded. With the exception of a large catclaw acacia (now gone) at the mouth of Nankoweap Creek (mile 52.2-R), no leguminous trees or netleaf hackberry trees, were specifically mentioned by the Old Timers.

Early river runners rarely saw exotics other than tamarisk. None of the Old Timers remembered seeing camelthorn, a noxious exotic, during their river-running experiences. Clover and Jotter (1944) found Bermuda grass in the Lake Mead delta, and Reilly observed it at Tapeats Creek and "several other places in the canyon" in 1956. The Bermuda grass in western Grand Canyon may have originated from the sacks of seed lost in the January 1910 flood in Havasu Creek (Melis and others, 1996; Webb, 1996), from plantings around the ranger stations at Bright Angel Creek and Phantom Ranch, or (much later than the initial observation) from the golf courses and other developments at Page, Flagstaff or Williams, Arizona, or possibly, Kanab, Utah.

Marshes

Cutter confirmed the photographic evidence that no marshes were present along the river (Fig. 5) that were not fed by perennial tributaries or springs. The known marshes -- for example, the warm springs below

Figure 5. The marsh at Cardenas Creek (mile 70.9-L) (continued).

B. February 26, 1993. Marshes, prime riparian habitat in Grand Canyon and elsewhere, provide habitat to native fishes and wildlife, particularly birds. Young native fish use the backwaters as protection from predators, and birds frequently nest in the dense vegetation. The marsh at Cardenas Creek, for example, is nesting habitat for southwestern willow fly catchers, which is an endangered species. But marshes were not present in 1890; they exist solely because of the flood control by Glen Canyon Dam. Most of the increased riparian vegetation in the view is tamarisk, although willow, arrowweed, mesquite, and other native species also have increased (Tom Wise, Stake 1440).

Lava Falls Rapid (mile 179) and Three Springs Canyon (mile 215.7-L) -- were observed by Clover and Jotter (1944), who collected plant specimens from these sites. In the 1950s, Reilly observed that the marsh in the mouth of Three Springs Canyon had a patch of cane 100 feet across; it also contained willows, tamarisk, and cattails. Riparian vegetation surrounding the springs at Deer Creek Falls (mile 136.3-R), Vaseys Paradise (mile 31.8-R), and on the right side of Hance Rapid (mile 76.7-R) shows prominently in historic photographs. Rigg and Nichols stopped at Cardenas Creek (mile 70.9-L) before Glen Canyon Dam and agreed that the area now supporting a marsh was sand and rocks. Reilly reported willows at Cardenas Creek but did not specifically mention tamarisk, which he saw elsewhere. Cutter commented that the current large amount of reeds along the river corridor did not resemble anything she saw in 1938.

Desert Vegetation

Cutter thought the desert above the river appeared greener in 1995, than in 1938. Both years had relatively wet winters and normal summers. From replication of the Stanton photographs from 1890, we attribute the difference to a large increase in brittlebush (Webb and Bowers, 1993). Jotter stated that she and Clover would certainly have listed now-common species such as snakeweed and tamarisk if they had been present at any of their sampling locations. This allows use of their plant lists (Clover and Jotter, 1944) as a baseline for evaluating invasions or increases of common species. At the site where the type specimen of beavertail cactus (*Opuntia basilaris* var. *longiaureolata*) was collected in 1938, we could find nothing that matched the original plant, which has not been recollected. We believe the variety they collected may have been a hybrid.

Table 5. Waterbird sightings in Grand Canyon compiled from selected historic diaries.

Year	Diarist	Date	Notes
1869	J.W. Powell		No waterbirds noted (summer).
1872	F.S. Dellenbaugh		No waterbirds noted (summer).
1890	R.B. Stanton	Feb 26	Shot at a duck near Cove Canyon.
		Feb 28	Shot a duck at 205 Mile Rapid.
1890	W.H. Edwards	Feb 14	Shot a duck, saw two others at Turquoise Rapid.
		Feb 28	"Lots of ducks" near 205 Mile Rapid.
1896	G. Flavell		No waterbirds noted (fall).
1909	J. Stone		No waterbirds noted (fall).
1911	E. Kolb		No mention of waterbirds (fall/winter).
1923	USGS Expedition		They caught a duck, which was sick or wounded, at Kanab Creek.
		Sep 24	Great Blue Heron at about Parashant.
		Sep 25	"Saw a few ducks today - the first for a few days." Just above Spring Canyon.
			Later, just before exiting the canyon, they mention they want to shoot a few ducks to supplement their food supply.
		Oct 15	Shot four ducks at the Grand Wash Cliffs.
		Oct 16	Shot five more ducks near Smiths Ranch (outside of the canyon).
1927	C. Eddy		No mention of waterbirds (summer).
1937	B. Sharp	Oct 11	Duck seen in upper part of Roaring Twenties, duck seen below Vaseys. 7 ducks were seen at Lava Canyon Rapid, another flock of 15-20 ducks, and another duck near Horn Creek. Downstream, they saw several Great Blue Heron.
1937	I. Campbell	Oct 18	"Flight of Redwing Blackbirds" near Kwagunt Rapid.
1937	B. Holmstrom	Nov 11	"Water ouzels" at Deer Creek Falls.
		Nov 19	"A few ducks" at mile 192.
1938-1949	N. Nevills		No waterbirds noted in the Nevills diaries (summer).
1938	E. Clover		No waterbirds noted (summer).
1938	L. Jotter		No mention of wildlife.
1938	B. Holmstrom		No mention of wildlife sightings.
1938	A. Burg	Oct 16	Shot a duck between Badger and Soap Creek Rapids.
1938	W. Johnson		Ducks and geese were seen on the Green River but not Grand Canyon.
1940	B. Goldwater		Pretty sparse on wildlife, but does contain the following statement:
		Aug 19	"Ducks and geese are constantly rising from the water in front of us."
			He specifically notes Red-Breasted Mergansers.
1940	M. Baker	Aug 7	Kassin's Kingbirds at Vaseys Paradise.
		Aug 9	Nine American Egrets between Sockdolager and Grapevine Rapids; saw many Red Breasted Mergansers and a flock of Blue-Winged Teal.
		Aug 12	Immature Black Crowned Night Heron, five Cinnamon Teal near Horn Creek; American Egret near Shinumo Creek.
		Aug 14	Curlew seen above Waltenberg Rapid.
		Aug 17	Gadwalls, Red-Breasted Mergansers, and Great Blue Herons were "plentiful."
		Aug 18	Two Avocets near Whitmore Wash. Black Phoebe and White-Faced Glossy Ibis at Diamond Creek.
1942	O. Marston	Jul 24	Two ducks and a Great Blue Heron at Shinumo Creek.
		Jul 26	Four ducks at the mouth of Tapeats Creek.
		Jul 28	Great Blue Heron near Lava Falls Rapid.

Table 5. Waterbird sightings in Grand Canyon compiled from selected historic diaries.

Year	Diarist	Date	Notes
		Jul 30	Several Great Blue Herons near Diamond Creek.
		Jul 31	Heard geese flying by during the night at Diamond Creek.
1948	F. Masland	Jul 13	Blue-Winged Teal at Vaseys Paradise.
1948	O. Marston	Jul 13	Blue-Winged Teal at Vaseys Paradise.
1948	J. Doerr	Jul 20	Two Great Blue Herons between Granite and Hermit Rapids.
		Jul 22	Great Blue Heron at Tapeats Creek.
		Jul 28	Great Blue Herons at mile 214.
1949	P.T. Reilly		No mention of waterbirds.
1953	P.T. Reilly		No mention of waterbirds.
1954	O. Marston	Jun 14	Two Snowy Egrets near Lava Falls.
1955	P.T. Reilly	Jul 2	Two Blue-Winged Teal at mile 155.4.
		Jul 5	Great Blue Heron between 205 and 217-Mile Rapids.
		Jul 6	Blue-Winged Teal at Separation Canyon.
1956	P.T. Reilly	Jun 27	Two Mallards at Tapeats Creek.
1957	P.T. Reilly		No mention of waterbirds.
1958	P.T. Reilly	May 21	Two ducks at Crystal.
		May 21	Three Mallards at Hakatai.
1959	P.T. Reilly	Jun 22	Three ducks above Soap Creek.
		Jun 23	Duck at mile 14.
1962	P.T. Reilly	Jul 9	Two ducks at mile 152.
1964	P.T. Reilly	Apr 28	Five Blue-Wing Teal at mile 17.4.
		May 10	Snowy Egret below Kanab Creek.
		May 11	Snowy Egret at mile 160 and two above National; Blue Wing Teal at mile 163; four ducks above National.
		May 12	Two Great Blue Heron above Lava Falls.
		May 13	Two egrets at mile 214; two Blue-Winged Teal at mile 221; Great Blue Heron and Snowy Egret at 225.4.

Terrestrial Animals

One of the largest problems with interpreting anecdotal information is the vague or imprecise use of common names of animals. In the following sections, we attempt to connect the names used by the Old Timers and in diaries with the animals that we believe they are referring to. Much of this information, while interesting, is inconclusive if only for the reason that it is imprecise in terms of scientific names.

Birds and Bats

Water birds were commonly observed on early river trips (Table 5). Even as early as 1890, Edwards noted the presence of "lots of ducks" downstream from Lava Falls Rapid. In 1937, Sharp reported many duck sightings (Table 5). In 1940, Goldwater may have summed up the frequency of observance: "Ducks and geese are constantly rising from the water ahead of us." Species mentioned by name include Red-Breasted Mergansers, Mallards, and Blue-Wing Teal. Snowy egrets commonly were seen near or with other water birds. Great Blue Heron were commonly seen, particularly in western Grand Canyon. Water birds have greatly increased along the river since closure of Glen Canyon Dam (Stevens and others, 1997). The Old Timers with us on the 1994 trip found nothing unusual in the current water bird population along the river, with the exception of Great Blue Herons, which they felt had decreased.

Hummingbirds occasionally were observed, sometimes flying about the drifting boats. Reilly specifically mentions seeing a Ruby-Throated Hummingbird at mile 155.8 and a Black-Chinned Hummingbird between Hermit and Boucher Rapids in 1956. Bats were commonly observed, particularly in the early morning hours. Nevills saw many bats at the

mouth of Havasu Creek (mile 157); Reilly saw bats at Spring Canyon (mile 204.3-R). Fresh bat guano was seen by early visitors to Christmas Tree Cave (mile 134-R). The Old Timers specifically mentioned a decrease in bats.

Cutter, Nevills Reiff, and Nevills Staveley mentioned a large increase in swallows in the "Furnace Flats" reach of the river (miles 65 to 73). The change was attributed to an increase in insects using tamarisk. Litton's opinion was that the swallows are possibly a different species from the one that typically lived next to the unregulated river. Although Cliff Swallows were common before Glen Canyon Dam, Violet-Green Swallows are common now. Litton attributes the change to lack of mud along the river that Cliff Swallows need for nest construction.

Otis "Dock" Marston and P.T. Reilly occasionally saw eagles (most likely Golden Eagles). Frank Masland (1948) mentions two Golden Eagles in western Grand Canyon. On the Old Timers Trip, several participants saw the peregrine falcons and mentioned that these raptors were not something they had not seen along the pre-dam river corridor. Most Old Timers were surprised when we saw several turkeys on the 1994 trip. Cross II, however, remembered seeing turkeys at the mouth of Boucher Creek (mile 96.7-L) in the early 1960s.

Insects

Various types of insects were bothersome to pre-dam river runners. Stanton had problems with bugs at Hance Rapid (mile 76.8) in 1890; he described "flies, millers, and moths flying about." Goldwater complained that his body was covered with welts from nocturnal bug bites at the end of his 1940 trip. Nevills and Goldwater mention "deer flies" at mile 68 that were so bad that they kept the river runners up all night in 1940; Mildred Baker also mentions mayflies at Tanner Rapid (mile 68) at the same time. In 1937, Holmstrom wrote that "lots of spiders & gnats & ants" were at a camp near mile 160. Reilly discusses "many large black flies" that pestered their trip at mile 80 in 1964; he wrote about the "hum of everpresent flies" in 1956. In some years (1942), Nevills complained vehemently about flies at Diamond Creek; in others (1947), he observed no flies. Nevills blamed their abundance on the presence of livestock, which likely refers to feral burros that once roamed parts of the canyon.

Red ants were particularly bothersome all throughout the river corridor. Both Nevills and Reilly complained about them in 1942 and 1957, respectively. In particular, Nevills found that "bugs and red ants are a nuisance" at Spring Canyon (mile 204.3-R). Reilly notes aphids on plants at Hermit Rapid (mile 95.1) in 1958, and scorpions are routinely mentioned in the diaries. Baker saw velvet ants at Diamond Creek (mile 225.8-L) in 1940 but did not indicate if they were bothersome.

The frequency of complaints about obnoxious bugs increases in diaries of trips taken after low-water runoff in the Colorado River with some notable exceptions, particularly with respect to red ants. This could explain why some pre-dam river runners (*e.g.*, Nichols) do not remember pestilent insects, whereas others (*e.g.*, Reilly) complained vehemently about them. Nichols was on river trips in mid-summer, after recession of the spring flood, while Reilly frequently timed his trips to coincide with the peak discharge of the spring flood (typically, mid-May to mid-June).

Beavers

Beavers were commonly observed in the pre-dam river, as they are today. For example, Edward McKee recorded evidence of beaver at four sites downstream from Bright Angel Creek (mile 87.8-R) in 1937; on the same trip, Sharp observed beaver sign at sites throughout Grand Canyon and at the same time Holmstrom noted beaver tracks at mile 192. The presence of beavers typically resulted in an entry in Reilly's diary, so sightings could be cataloged. Even more notes were made on the effects of beavers on riparian vegetation. The exception is the experience of George Flavell (Flavell, 1987), who found no beaver to trap in summer 1896.

Otters

Sightings of river otters were common on some historic river trips. Edwards observed two otters at Turquoise Rapid (mile 102.1) on February 14, 1890. He expressed surprise and mentioned he had never seen otters before. Stone (1932) reported otter tracks at about every camp down to Waltenberg Rapid (mile 112.3). In 1911, Lauzon "scared up an otter" near Serpentine Rapid (mile 106.1) and nearly shot one on the lower Colorado River. On his 1937 trip, McKee reported otter tracks at the mouth of Tapeats Creek

Table 6. Sightings of bighorn sheep in Grand Canyon during pre-dam river trips.

Year	Date	Trip	Location	Number of Sheep	Source
1869	Aug-Sep	Powell	Grand Canyon	0	Cooley, 1988
1872	Aug 27	Powell	Near Cardenas Creek	2	Dellenbaugh, 1908
1890	Feb 5	Stanton	Bright Angel Creek	tracks	Unpublished diary
	Feb 27	Stanton	Whitmore Wash	15	Unpublished diary
1896	Oct 25	Flavell	near Fossil Canyon	1	Flavell, 1987
	Oct 25	Flavell	near Deer Creek	2	Flavell, 1987
1909	Nov 9	Stone	Above Havasu Creek	5	Stone, 1932
	Nov 10	Stone	National/Mohawk Canyons	1	Stone, 1932
1911	Dec 28	Kolb	Deer Creek	1	Unpublished diary
	Jan 12	Kolb	About mile 265	5	Unpublished diary
1923	Sep 6	USGS	Specter Chasm	tracks	Unpublished diary
	Sep 8	USGS	mile 133	1	Unpublished diary
	Sep 13	USGS	mile 152	2	Unpublished diary
	Oct 1	USGS	Granite Springs Canyon	1	Unpublished diary
1937	Oct-Nov	Campbell	Grand Canyon	0	Unpublished diary
	Oct-Nov	Sharp	Grand Canyon	3	Unpublished diary
1938	July 29	Nevills	Diamond Creek	1	Unpublished diary
1938	Oct	Holmstrom	Grand Canyon	0	Unpublished diary
		Johnson	Grand Canyon	0	Unpublished diary
1940	Aug	Nevills	Grand Canyon	0	Goldwater, 1940
1941	July	Nevills	Grand Canyon	0	Unpublished diary
1942	July 27	Nevills	National Canyon	7	Unpublished diary
	July 27	Marston	Fern Glen Canyon	7-8	Unpublished diary
	July 28	Nevills	Whitmore Wash	5	Unpublished diary
	July 28	Marston	Whitmore Wash	5	Unpublished diary
	July 29	Marston	Spring Canyon	1	Unpublished diary
1947	July	Nevills	Grand Canyon	0	Unpublished diary
1948	July	Nevills	Grand Canyon	0	Unpublished diary
	July 24	Doerr	Surprise Valley	dung	Unpublished diary
	July 26	Doerr	mile 190	1	Unpublished diary
1949	Jul y23	Nevills	Mile 122	9	Unpublished diary
1950	July	Wright	Grand Canyon	0	Unpublished diary
1951	July 23	Wright	mile 144	several	Unpublished diary
1952	July	Wright	Grand Canyon	0	Unpublished diary
1953	July	Wright	Grand Canyon	0	Unpublished diary
1954	June	Marston	Grand Canyon	0	Unpublished diary
1955	June 28	Reilly	Elves Chasm	4	Unpublished diary
	July 15	Wright	Elves Chasm	3	Unpublished diary
1956	June-July	Reilly	Grand Canyon	0	Unpublished diary
	July	Wright	Grand Canyon	0	Unpublished diary
1957	June	Reilly	Grand Canyon	0	Unpublished diary

Table 6. Sightings of bighorn sheep in Grand Canyon during pre-dam river trips.

Year	Date	Trip	Location	Number of Sheep	Source
	July	Wright	Grand Canyon	0	Unpublished diary
1958	May 22	Reilly	Forster and Stone Creek	tracks	Unpublished diary
1959	June	Reilly	Grand Canyon	0	Unpublished diary
1962	July 4	Reilly	Boucher Creek	10	Unpublished diary
	July 4	Reilly	Elves Chasm	2	Unpublished diary
1964	May 8	Reilly	near Elves Chasm	2	Unpublished diary

(mile 133.8-R) and again at mile 190. A member of Reilly's 1959 trip saw an otter at mile 19. Otters are now rarely seen in Grand Canyon although credible observers recorded their presence in the 1970s (Carothers and Brown, 1991).

Large Mammals

Bighorn sheep may have increased along the river corridor since the first river runners (Table 6). Beginning with the first Powell expedition (Cooley, 1988), few river trips saw large mammals along the river corridor. Trips before the turn of the century saw the largest numbers. The most common sightings of bighorn sheep were between Elves Chasm (mile 116.5-L) and mile 126, in the vicinity of Havasu Creek (mile 157), and occasionally in western Grand Canyon.

Bighorn sheep sightings now are more common. Nevills-Staveley was surprised to see bighorn sheep near Navajo Bridge; no historic river trips had ever seen them so far up canyon (Stockwell, 1989, p. 13). According to Grua, these sheep were introduced onto the Paria Plateau in 1980, and they subsequently migrated into Marble Canyon (miles 0 to 61). Several people indicated they saw more bighorn sheep on the Old Timers Trip than on any other. From the experience of those on the trip who frequently observed the river in the 1990s, we felt we saw very few.

Burro sightings became more common through the 1940s and 1950s. The sightings followed the known distribution of the animals. In 1938, Clover and Jotter observed burros on both sides of the river at Diamond Creek (mile 225.8-L). Reilly observed burros at the mouth of Hermit Creek (mile 95.0-L) in 1962. The most apparent populations of burros along the river were downstream of Whitmore Wash (mile 188.1-R). Nevills saw a domestic sheep at Spring Canyon (mile 204.3-R) in 1942; the Stone Expedition killed domestic sheep near Salt Water Wash (mile 11.8-L) in 1909 (Stone, 1932).

Signs of deer were recorded in diaries, particularly in the reach from about mile 35 to Phantom Ranch (mile 87.8-R). Jotter and Clover saw a deer at the mouth of Kwagunt Creek (mile 56.0-R) in 1938. Holmstrom noted deer tracks at the mouth of Tapeats Creek in 1937. Nevills saw a large buck at mile 71-L in 1947. Reilly saw tracks at Buck Farm Canyon (mile 41.0-R) and Kwagunt Rapid (mile 56.1) and saw a doe at Tanner Canyon (mile 68.5-L). "Dock" Marston saw many deer in Lava Canyon (mile 65.5-R) in 1948. Several Old Timers mentioned deer swimming in front of the boats in the 1950s; Cross II stated he observed deer swimming 6 times on his trips in the 1960s. The most downstream report of deer was by McKee, who found "weathered" antlers on ledges 600 feet above the river at Tapeats Creek.

Mountain lions were observed on a Nevills trip in 1947 (mile 215) and a Reilly trip in 1956 (mile 177). Reilly commonly mentioned seeing bobcats or bobcat tracks. He saw a bobcat at mile 200, and bobcat tracks at Unkar Creek (mile 72.6-R), Lava Canyon (mile 65.5-R), Nankoweap Creek (mile 52.2-R), Kwagunt Creek (mile 56.0-R), Stone Creek (mile 131.9-R), Fern Glen (mile 168.0-R), Whitmore Wash (mile 188.1-R), and Gneiss Canyon (mile 235.9-L). McKee saw sign of bobcats at the foot of the Bass Trail (mile 107) and at mile 176. Frost had a special memory of seeing a bobcat in the vicinity of Three Springs Canyon (mile 215.7-L).

Ringtail cats were also seen during pre-dam river trips, but only one of the Old Timers remembered food thefts by ringtails. Several Old Timers mentioned they did not cause problems. McKee saw ringtail tracks at six sites between Bright Angel Creek (mile 87.8-R) and Diamond Creek (mile 225.8-L) in 1937, and Reilly also

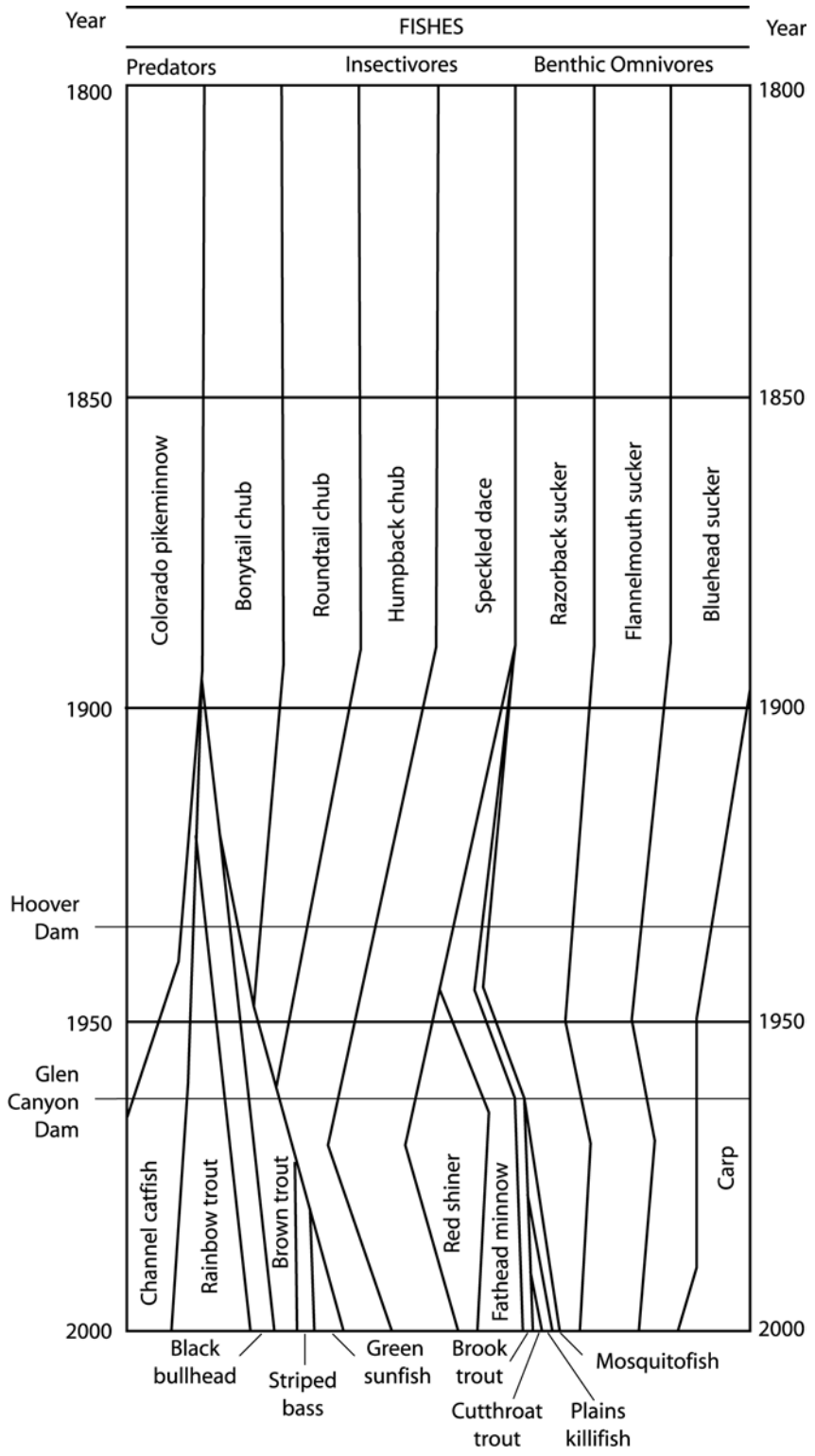

Figure 6. Historical changes in fish populations in the Colorado River in Grand Canyon.

The width of the columns reflects an approximate proportion of each fish species, although the initial 1800 population of native species is unknown and is depicted as evenly distributed (R.A. Valdez, unpublished data, 2002).

Table 7. Anecdotal accounts of native and non-native fishes in the Colorado River in Grand Canyon.

Date	Expedition (Diarist)	Notes
1869	J.W. Powell	No fishes noted.
1872	F.S. Dellenbaugh	No fishes noted.
1890	R.B. Stanton	Colorado pikeminnow caught in Cataract Canyon, none noted in Grand Canyon.
1896	G. Flavell	No fishes noted.
1909	J. Stone	No fishes noted.
1911	E. Kolb	Caught 14-16 “salmon” (Colorado pikeminnow) downstream from Lava Falls.
1912	Reilly (1999, p. 393)	Jerry Johnson dynamites fish in the eddy downstream from the Paria Riffle.
1923	USGS	No sign of fish in Tapeats Creek. Kolb caught a “bonytail fish” near Mohawk Canyon. Despite regular fishing, no catfish were caught.
1923	Eddy (1999, p. 302)	Flagstaff residents dynamite fish below Paria Riffle after USGS trip departs.
1927	C. Eddy	No fishes noted.
1936	Reilly (1999, p. 393)	Frank Dodge begins dynamiting fish at Lee’s Ferry. Fishermen use river at Lee’s Ferry.
1938	N. Nevills	No fishes noted.
1940	N. Nevills	“Large salmon (Colorado pikeminnow)” and catfish abound in Shinumo Creek.
	(B. Goldwater)	Catfish appeared to be spawning in Tapeats Creek.
1942	N. Nevills	They caught catfish at Shinumo Creek. The trout in Tapeats Creek were 10-14 in., and catfish were jumping in the mouth of Havasu Creek.
1942	N. Nevills (O. Marston)	Small fish observed in Hermit Creek. No fish were observed in Shinumo Creek above the waterfall, but he caught 15 channel catfish, a 2 lb. “humpbacked sucker,” and 2 Colorado pikeminnow below the waterfall. He caught 10 rainbow trout in Tapeats Creek. Catfish was observed 3/4 mile upstream in Diamond Creek. Near Gneiss Canyon Rapid, they caught “2 ft humpbacked suckers” with bare hands. The water was “alive with fish.”
1942	Reilly (1999, p. 419)	Frank Dodge dynamited fish below Paria Riffle that “provided many a meal for Flagstaff citizens.”
1942-1948	N. Nevills (G. Marston)	Trout appeared to grow 1 in. per year in Tapeats Creek.
1947	N. Nevills	They caught catfish at Lava Creek. No trout were seen in Shinumo Creek, but 4 in. “suckers” and 2 in. “minnows” were observed 2.5 miles up Shinumo Creek. A dozen trout were caught in Tapeats Creek.
1947	Reilly (1999, p. 428)	High sediment concentrations killed many fish in the Colorado River at Lee’s Ferry
1948	N. Nevills	They caught 11 rainbow trout in Tapeats Creek.
1948	N. Nevills (J. Doerr)	Colorado pikeminnow 9 in. long caught in Tapeats Creek with 6 rainbow trout. Catfish were seen in Havasu Creek.
1948	N. Nevills (O. Marston)	Carp and catfish were observed under the waterfall near the mouth of Shinumo Creek. Catfish were observed in the mouth of Havasu Creek.
1949	N. Nevills	No fishes noted.
	(F. Wright)	
1949	N. Nevills	Caught catfish at Elves Chasm and 12 in. trout in Tapeats Creek.
	(P.T. Reilly)	
1951	P.T. Reilly	Two catfish were caught at Vaseys Paradise.
	(S. Reilly)	
1954	O. Marston	Rainbow trout caught in Tapeats Creek.
1955	P.T. Reilly	Observed 2-3 in. fish in Nankoweap Creek and thought they were catfish. Shinumo Creek had 8 in. fish of an unknown species in its mouth. They caught trout in Tapeats Creek and saw 8 in. catfish in Diamond Creek 400 ft from the Colorado River. Bluegill and crappie were in Separation Creek in the mouth.
1956	P.T. Reilly	They caught catfish at President Harding Rapid.
1959	P.T. Reilly	Found rainbow trout on a rock at mile 38.5. These must have come from the Colorado River.

Table 7. Anecdotal accounts of native and non-native fishes in the Colorado River in Grand Canyon.

Date	Expedition (Diarist)	Notes
1962	P.T. Reilly	He observed trout in Lava Creek and caught catfish at Elves Chasm. He caught rainbow trout at Spencer Canyon.
1963	Reilly (1999, p. 445)	28,800 trout, 7-9 in. long, and one million bass were planted at Lee's Ferry.
1963	Reilly (1999, p. 446)	89,080 "catchable" rainbow trout were released between the dam and Lee's Ferry.
1964	Reilly (1999, p. 446)	88,200 rainbow trout were released at Lee's Ferry; 10,000 were 10 in. long
1965	Reilly (1999, p. 449)	9,500 rainbow trout were released at Lee's Ferry in the first three months of 1965.
1965	Reilly (1999, p. 450)	Parasitic cysts first observed in trout at Lee's Ferry.

recorded their presence in the 1950s. In 1937, Holmstrom repeatedly and humorously noted that "rats" ate his butter, indicating that consumption of unsecured food by rodents is not new in Grand Canyon.

Fishes

Eight species of native fish were found in the Colorado River in the 19th century (Fig. 6). Although none of these species is extinct within the Colorado River basin, four species -- Colorado pikeminnow (*Ptychocheilus lucius*), bonytail (*Gila elegans*), roundtail chub (*Gila robusta*), and razorback sucker (*Xyrauchen texanus*) -- have been extirpated from Grand Canyon (Minckley, 1991). The humpback chub (*Gila cypha*), flannelmouth sucker (*Catostomus latipinnis*), bluehead sucker (*C. discobolus*), and speckled dace (*Rhinichthys osculus*) all retain reproducing populations in Grand Canyon. Human modification of the riverine environment, and most notably the construction of Glen Canyon Dam and its regulated, cold-water releases, are generally blamed for declines in native species. Also, 24 species of non-native fishes have been introduced or escaped into Grand Canyon starting in the late 1800s (Fig. 6). Competition with and predation by these fishes is also a large factor in the decline of the native species (Valdez and Ryel, 1995).

Few of the currently listed endangered fish in the Colorado River were caught or seen by pre-dam river runners (Table 7). The Stanton expedition (1889-1890) caught Colorado pikeminnow, and in 1911 the Kolb brothers caught 23 "bony tail" chub and one pikeminnow (Fig. 7b; Kolb, 1914). In 1923, Emery Kolb caught a "boneytail fish" near Mohawk Canyon (mile 171.5-L). Photographs (Fig. 7) show that most of the fish referred to as bonytail probably were humpback chub, which was not described as a species until 1946 (Miller 1946). The holotype used by R.R. Miller to describe the humpback chub was taken by N. N. Dodge angling with hook and line near Phantom Ranch in 1942. In 1940, Goldwater mentions catching "salmon" (Colorado pikeminnow) in the mouth of Shinumo Creek (mile 108.6-R) in addition to catfish. Nevills observed 4-in. suckers and 2-in. minnows in Shinumo Creek, 2.5 miles upstream from the Colorado River. Humpback chub and razorback sucker were not specifically mentioned, but "humpbacked suckers" were caught in Shinumo Creek and near Gneiss Canyon Rapid (mile 236; see Table 7). Although most fishermen caught trout in Tapeats Creek (mile 133.8-R), John Doerr, the chief naturalist at Grand Canyon National Park, caught Colorado pikeminnow there in 1948.

Some Old Timers remember seeing fishermen along the river, particularly in the first 32 miles downstream of Lee's Ferry. Nevills observed a fishing boat pulled up on the bank at mile 187 in 1947. Many trips included fishermen, which led to many observations about the kinds of fish in the river. Dynamite was commonly used to kill fish at Lee's Ferry (Table 7), and Frank Dodge, a river runner and U.S. Geological Survey employee in the 1930s and 1940s, was one of its biggest users. Cross Sr. talked with Bert Loper about fishing in Glen Canyon in the 1940s; dynamiting earlier in the century yielded Colorado pikeminnow, whereas later dynamiting yielded only catfish. Nevills found a cache of dynamite at the mouth of Parashant Wash (mile 198.5-R) in 1942 that he thought was used for fishing. Rigg and Nichols saw dynamite being used to fish for catfish at Whitmore Wash (mile 188.1-R) in the 1950s.

Catfish were extremely common and are mentioned in every fishing reference after 1938, except most years at Tapeats Creek (mile 133.8-R). Before 1938, no fisherman reported catching catfish despite

Figure 7. Photographs showing Examples of native fishes caught in Grand Canyon.

A. (left). Early 1900s. Two unidentified men with a canvas boat holding a large stringer of humpback chub, probably near the mouth of Bright Angel Creek (mile 87.5) (no photographer or number, courtesy of the David Rust Photograph Collection, Church of Jesus Christ of Latter Day Saints, Salt Lake City, Utah). B. (right) November 1911. Emery Kolb holding a stringer of 14 humpback chub near the mouth of the Little Colorado River (mile 61.5) (Kolb photograph 954, courtesy of Special Collections, the Cline Library, Northern Arizona University, Flagstaff, Arizona).

occasionally intensive efforts. In 1938, Johnson reports "thousands of fish" in Lake Mead where the water turned blue; these likely were catfish and/or carp. Nevills observed catfish jumping in the mouth of Havasu Creek (mile 157) in 1942. Goldwater observed catfish in Tapeats Creek, and speculated they spawned in the side canyons. In 1955, Reilly observed 3-in. fish he thought were catfish in Nankoweap Creek (mile 52.2-R). Carp were commonly observed in Shinumo Creek (mile 108.6-R) near its waterfall, and large individuals were caught in the river near its mouth.

Rainbow trout were commonly caught in Tapeats Creek. Garth Marston remembered that they increased in size about 1 in./yr in the 1940s. Reilly notes that trout were caught and left by a river party at mile 38.5-L in 1959; these could have only come from the Colorado River. On two consecutive days in 1962, Reilly observed trout in Lava Canyon (mile 65.5-R); trout were never planted in Lava Canyon. Reilly also observed bluegill and crappie in the backwaters of Separation Canyon (mile 239.5-R) in 1955 and rainbow trout at Spencer Canyon (mile 246.0-L) in 1962. Cross Sr. remembers catching bluegill in tributaries of Glen Canyon in the 1950s.

Most tributaries had water backed up into their mouths during high water. Reilly, who took many high-water trips, saw water backed up into Rider Canyon (mile 16.8-R), South Canyon (mile 31.6-R), Nankoweap Creek (mile 52.2-R), the Little Colorado River (mile 61), Shinumo Creek (mile 108.6-R), Kanab Creek (mile 143.5-R), and Havasu Creek (mile 157). Fish occasionally were observed in these pools. In the dry years of the 1950s, Reilly recorded the width and depth of perennial streams. Nankoweap Creek (mile 52.2-R) dried up a half mile from the river, stranding fish in the channel upstream; flow in Nankoweap Creek apparently decreased between 1949 and 1955, or the early period of the mid-century drought on the Colorado Plateau.

CONCLUSIONS

The strongest conclusion we can make from the Old Timers Trip is that people who traveled the pre-dam river have vivid, and typically accurate, memories of the environment of Grand Canyon. Few early river runners observed or remembered all aspects of the environment; most noted or remembered specific details about certain changes, such as the distribution

of sand bars, while not noticing other aspects, such as changes in wildlife populations. These observations must be taken in aggregate to provide an accurate accounting of environmental changes in Grand Canyon.

Much has changed along the Colorado River since most of the Old Timers and other historic river runners were in Grand Canyon. The following changes, many of which are supported using photographic or other evidence, are probably significant:

- The low water temperature, increase in riparian vegetation, lack of substantial sediment in the river, noise from aircraft, and deteriorated air quality are considered the largest changes in Grand Canyon.
- The largest changes in the river corridor, other than rapids, were observed just downstream from Nankoweap Creek (mile 52.2-R), and at the mouth of the Little Colorado River (mile 61-L), Elves Chasm (mile 116.5-L), and Tapeats Creek (mile 133.8-R).
- The Old Timers saw little evidence of debris flows before closure of Glen Canyon Dam. The frequency of debris flows may have increased after the early 1960s, as speculated by Melis and others (1994) and Webb (1996). Certain rapids -- such as Crystal (mile 98.3), Bedrock (mile 130.5), and House Rock (mile 16.9) -- are now more difficult than in the pre-dam era. Lava Falls Rapid (mile 179.5), which was always large, also was discussed as having changed. Other rapids are unchanged or are less difficult.
- Erosion of camping beaches used by pre-dam river runners is severe. Now, some formerly popular camping sites are not easily used for camping.
- Fires had a significant impact on the amount of driftwood along the river corridor. Fires were set randomly and specifically at certain popular places, particularly the mouth of Nankoweap Creek (mile 52.2-R) and Tanner Canyon (mile 68.5-L).
- Riparian vegetation, mostly tamarisk, is much denser along the river, whereas cottonwoods and tree-form willows decreased in the post-dam era. Tamarisk slowly increased, particularly in the 1940s and 1950s, but accelerated after 1963.
- Perennial marsh vegetation was not observed or photographed along the pre-dam river except near springs.
- Catfish were the most common fish caught in the pre-dam river, although rainbow trout were also present. Some of the Old Timers caught native fish, mostly before about 1950, and the species they observed could not be accurately determined unless the catch was photographed.
- Ducks and other water birds were commonly observed along the unregulated river, but they were not as abundant as they are now, in accord with the findings of Stevens and others (1997).

Other changes may or may not be significant, if in fact changes even occurred: (1) Bats and some species of birds may have decreased along the river, whereas swallows may have increased. (2) Bighorn sheep possibly are more numerous; they certainly are observed more often now. No changes can be inferred in the population of deer or other large mammals along the river. (3) It is uncertain whether the population of beavers has changed, and otters remain an uncommon sighting. (4) Bothersome insects were common before Glen Canyon Dam, although it is unknown if species or abundances may have changed.

Some of the issues raised in this report have significant implications for dam management. The increase in frequency of debris flows will hasten a long-postulated change in the longitudinal profile of the river; without dam releases significantly higher than power plant capacity, the river will eventually attain an exaggerated pool-drop configuration. Implications of such a trend might be that navigation of rapids becomes generally more difficult, and in some cases, the river may become impassable. Continued aggradation of the river channel by coarse sediment delivered during debris flows will likely fill-in deeper pools above and below rapids, while also enhancing the size of eddies. On the basis of photographic evidence and sediment-transport studies, bars are predicted to continue decreasing in size (Laursen and others, 1976). Tamarisk was increasing despite pre-dam flooding. Although dam releases could be used to thin some of the population, tamarisk would have become a common, although exotic, resident of Grand Canyon even if the dam had not been built. Marshes are an artifact of flow regulation, not a natural feature of the pre-dam environment (Webb, 1996). Native fish may

have declined precipitously before Glen Canyon Dam was built possibly owing to invasion by predatory non-native species such as catfish, carp, and trout.

Much remains unknown about the pre-dam river and its environment. Ultimately, we may never determine whether changes reported in wildlife populations are in fact significant or merely the result of limited observation. The observations of the Old Timers suggest that future monitoring of bighorn sheep and bat populations may be warranted. Regardless of whether hard, scientific conclusions can be reached on all of their observations, one thing is certain: we should listen to the historical experiences of the Old Timers and attempt to independently and scientifically test their ideas about the timing and causes of change along the Colorado River in Grand Canyon.

REFERENCES CITED

Beer, W., 1988, We swam the Grand Canyon: Seattle, Washington, The Mountaineers, 171 p.

Bowers, J.E., Webb, R.H., and Rondeau, R.J., 1995, Longevity, recruitment, and mortality of desert plants in Grand Canyon, Arizona, U.S.A.: Journal of Vegetation Science, v. 6, p. 551-564.

Carothers, S.W., and Brown, B.T., 1991, The Colorado River through Grand Canyon: Tucson, University of ARizona Press, 235 p.

Clover, E.U., and Jotter, L., 1944, Floristic studies in the canyon of the Colorado and tributaries: American Midland Naturalist, v. 32, p. 591-642.

Cook, W., 1987, The Wen, the Botany, and the Mexican Hat: Orangevale, California, Callisto Books, 151 p.

Cooley, J., 1988, The great unknown: Flagstaff, Arizona, Northland Publishing, 207 p.

Dellenbaugh, F.S., 1908, A canyon voyage: New Haven, Connecticut, Yale University Press, 277 p.

Eddy, C., 1929, Down the worlds most dangerous river: New York, F.A. Stokes Company, 293 p.

Ferguson, C.W., 1971, Tree-ring dating of Colorado River driftwood in the Grand Canyon, *in* Hydrology and Water Resources in Arizona and the Southwest: Tempe, Arizona, Proceedings of the 1971 meetings of the Arizona Section C American Water Resources Association and the Hydrology Section C Arizona Academy of Sciences, p. 351-366.

Flavell, G.F., 1987, The log of the Panthon (edited by N.B. Carmony and D.E. Brown): Boulder, Colorado, Pruett Publishing, 109 p.

Fowler, D.D. (editor), 1972, "Photographed all the best scenery," Jack Hillers's diary of the Powell Expeditions, 1871-1875: Salt Lake City, Utah, University of Utah Press, 225 p.

Graf, W.L., 1978, Fluvial adjustments to the spread of tamarisk in the Colorado Plateau region: Geological Society of America Bulletin, v. 89, p. 1491-1501.

Goldwater, B.M., 1940, A journey down the Green and Colorado Rivers: Phoenix, Arizona, privately published by H. Walker Publishing, 80 p.

Griffiths, P.G., Webb, R.H., and Melis, T.S., 1996, Initiation and frequency of debris flows in Grand Canyon, Arizona: U.S. Geological Survey Open-File Report 96-491, 35 p.

Johnson, R.R., 1991, Historic changes in vegetation along the Colorado River in the Grand Canyon, *in* Marzolf, G.R. (Editor), Colorado River ecology and dam management: Washington, D.C., National Academy Press, p. 178-206.

Jones, L., 1962, Colorado River Runner's Scroll Map: Midway, Utah, Western Whitewater, 1 sheet.

Kolb, E.L., 1914, Through the Grand Canyon from Wyoming to Mexico: Tucson, Arizona, University of Arizona Press, 344 p.

Lavender, D., 1985, River runners of the Grand Canyon: Grand Canyon Natural History Association, 147 p.

Leydet, F., 1968, Time and the river flowing, Grand Canyon: New York, Sierra Club - Ballantine Book, 160 p.

Martin, P.S., 1971, Trees and shrubs of the Grand Canyon, Lees Ferry to Diamond Creek: Tucson, University of Arizona, Desert Laboratory, unpublished manuscript, 16 p.

Masland, F.E., Jr., 1948, By the rim of time: Carlisle, Pennsylvania, C.H. Masland and Sons, 44 p.

Melis, T.S., 1997, Geomorphology of debris flows and alluvial fans in Grand Canyon National Park and their influences on the Colorado River below Glen Canyon Dam, Arizona [Ph.D. Dissertation]: Tucson, University of Arizona, 490 p.

Melis, T.S., Webb, R.H., Griffiths, P.G, and Wise, T.J., 1994, Magnitude and frequency data for historic debris flows in Grand Canyon National Park and vicinity, Arizona: U.S. Geological Survey Water Resources Investigations Report 94-4214, 285 p.

Melis, T.S., Phillips, W.M., Webb, R.H., and Bills, D.J., 1996, When the blue-green waters turn red: Historical flooding in Havasu Creek, Arizona: U.S. Geological Survey Water-Resources Investigations Report 96-4059, 136 p.

Melis, T.S., Webb, R.H., and Griffiths, P.G., 1997, Debris flows in Grand Canyon National Park: Peak discharges, flow transformations, and hydrographs: Debris-Flow Hazards Mitigation: Prediction and Assessment: New York, American Society of Civil Engineers, p. 727-736.

Miller, R.R., 1946. *Gila cypha*, a remarkable new species of cyprinid fish from the Colorado River in Grand Canyon, Arizona: Journal of the Washington Academy of Sciences, v. 36, p. 409-415.

Minckley, W.L., 1991, Native fishes of the Grand Canyon region B An obituary? *in* Marzolf, G.R. (editor), Colorado River ecology and dam management: Washington, D.C., National Academy Press, p. 124-177.

Reilly, P.T., 1999, Lee's Ferry, from Mormon Crossing to National Park (edited by R.H. Webb): Logan, Utah State University Press, 542 p.

Schmidt, J.C., and Graf, J.B., 1990, Aggradation and degradation of alluvial sand deposits, 1965 to 1986, Colorado River, Grand Canyon National Park, Arizona: U.S. Geological Survey Professional Paper 1493, 74 p.

Schmidt, J.C., Grams, P.E., and Webb, R.H., 1995, Comparison of the magnitude of erosion along two large regulated rivers: Water Resources Bulletin, v. 31, p. 617-631.

Smith, D.L., (editor), 1965, Down the Colorado: Norman, Oklahoma, University of Oklahoma Press, 237 p.

Smith, D.L., and Crampton, C.G., (editors), 1987, The Colorado River survey: Salt Lake City, Utah, Howe Brothers Books, 305 p.

Stephens, H.G., and Shoemaker, E.M., 1987, In the footsteps of John Wesley Powell: Boulder, Colorado, Johnson Books, 286 p.

Stevens, L.E., 1989, Mechanisms of riparian plant community organization and succession in the Grand Canyon, Arizona: Flagstaff, Northern Arizona University, unpublished Ph.D. dissertation, 115 p.

Stevens, L.E., Buck, K.A., Brown, B.T., and Kline, N., 1997, Dam and geomorphic influences on Colorado River water bird distribution, Grand Canyon, Arizona, USA: Regulated Rivers, Research & Management, v. 13, p. 151-169.

Stockwell, C.A., 1989, The behavior of desert bighorn at Grand Canyon National Park: Implications for conservation: Flagstaff, Northern Arizona University, unpublished M.S. thesis, 67 p.

Stone, J.F., 1932, Canyon country: New York, G.P. Putnam's Sons, 442 p.

Turner, R.M., and Karpiscak, M.M., 1980, Recent vegetation changes along the Colorado River between Glen Canyon Dam and Lake Mead, Arizona: U.S. Geological Survey Professional Paper 1132, 125 p.

U.S. Department of the Interior, 1989, Glen Canyon Environmental Studies, Executive Summaries of technical reports: Flagstaff, Arizona, Bureau of Reclamation, Glen Canyon Environmental Studies Program, 411 p.

U.S. Department of the Interior, 1995, Operation of Glen Canyon Dam, Final Environmental Impact Statement: Salt Lake City, Bureau of Reclamation, Colorado River Storage Project, 337 p.

Valdez, R.A. and R.J. Ryel, 1995, Life history and ecology of the humpback chub (*Gila cypha*) in the Colorado River, Grand Canyon, Arizona, Glen Canyon Environmental Studies Technical Report, 282 p.

Webb, R.H., 1996, Grand Canyon, a century of change: Tucson, University of Arizona Press, 290 p.

Webb, R.H., and Bowers, J.E., 1992, Plant demography and burro grazing in Grand Canyon, *in* Young, D.D., (editor), Vegetation management of hot desert rangeland ecosystems: Tucson, Arizona, University of Arizona, School of Renewable Natural Resources, p. 210-222.

Webb, R.H., and Bowers, J.E., 1993, Changes in frost frequency and desert vegetation assemblages in Grand Canyon, Arizona, *in* Redmond, K.T., (editor), Proceedings of the Ninth Annual Pacific Climate (PACLIM) Workshop, April 21-24, 1992: California Department of Water Resources, Interagency Ecological Studies Program Technical Report 34, p. 71-82.

Webb, R.H., Pringle, P.T., and Rink, G.R., 1989, Debris flows in tributaries of the Colorado River in Grand Canyon National Park, Arizona: U.S. Geological Survey Professional Paper 1492, 39 p.

Webb, R.H., Smith, S.S., and McCord, V.A.S., 1991, Historic channel change of Kanab Creek, southern Utah and northern Arizona: Grand Canyon Natural History Association Monograph Number 9, 91 p.

Webb, R.H., Schmidt, J.C., Marzolf, G.R., and Valdez, R.A. (editors), 1999a, The controlled flood in Grand Canyon: Geophysical Monograph 110, American Geophysical Union, Washington, DC, 367 p.

Webb, R.H., Melis, T.S., Griffiths, P.G., Elliott, J.G., Cerling, T.E., Poreda, R.J, Wise, T.W, and Pizzuto, J.E., 1999b, Lava Falls Rapid in Grand Canyon, Effects of late Holocene debris flows on the Colorado River: U.S. Geological Survey Professional Paper 1591, 90 p.

Webb, R.H., Griffiths, P.G., Melis, T.S., and Hartley, D.R., 2000, Sediment delivery by ungaged tributaries of the Colorado River in Grand Canyon: U.S. Geological Survey Water Resources Investigations Report 00-4055, 67 p.

Woodbury, A.M., and Russell, H.N., 1945, Birds of the Navajo Country: Bulletin of the University of Utah Biological Service, v. 9, 160 p.