External Threats: the Dilemma of Resource Management on the Colorado River in Grand Canyon National Park, USA

R. ROY JOHNSON*
STEVEN W. CAROTHERS
National Park Service/University of Arizona
Tucson, Arizona 85721, USA

ABSTRACT / The United States Congress established Grand Canyon National Park in 1919 to preserve for posterity the outstanding natural attributes of the canyon cut by the Colorado River. In some cases National Park Service attempts to maintain Grand Canyon's natural environment have been thwarted by activities outside the park. One of the most obvious external threats is Glen Canyon Dam, only 26 km upstream from the park boundary. Constructed in 1963, this gigantic dam has greatly altered the physicochemical and biological characteristics of 446 km of the Colorado River in Grand Canyon National Park. The river's aquatic ecosystem has been greatly modified through the loss of indigenous species and the addition of numerous exotics. We consider this an *exotic ecosystem.* The riparian ecosystem has been less modified, with addition of a few exotics and no loss of natives—this we consider a *naturalized ecosystem.*

The great dilemma now faced by park managers is that, after 20 years of managing resources along a river controlled by Glen Canyon Dam, the Bureau of Reclamation has proposed major changes in operational procedures for the dam. Scientists and managers from the National Park Service, Bureau of Reclamation, and cooperating federal and state resource management agencies are using a systems analysis approach to examine the impacts of various Colorado River flow regimes on aquatic, riparian, and recreational parameters in the park. This approach will help in the development of management alternatives designed to permit the most efficient use of that river's natural resources without their destruction.

A series of drastic changes in the nature of the Colorado River in Grand Canyon in the United States has occurred as a result of Glen Canyon Dam. Management of the environmental and recreational resources of the 446 km of the river in Grand Canyon National Park has become increasingly complicated since completion of the dam in 1963 (Figure 1). Important physicochemical and biological characteristics of the aquatic and riparian environments in this world-famous natural area have been affected by such modifications of the natural water regime as colder water year-round, lower sediment loads and nutrient transport, and daily, tidelike fluctuations in water levels (Dolan and others 1974 and 1977, Carothers and Johnson 1983).

Management of large complex systems such as watersheds, airsheds, and large rivers presents difficult problems. This is especially true for systems which have different segments managed by different individuals or agencies. In such systems, results of natural or man-caused activities extend across political/management boundaries, often affecting ecosystems as well as managers and users tens to thousands of kilometers downstream. Thus, interagency cooperation, communication, and systems analysis are imperative to prevent natural and cultural catastrophies and interagency strife.

Operation of Glen Canyon Dam most affects the Colorado River in Grand Canyon National Park. Since completion of the dam, its operational procedures have evolved through a series of interagency negotiations related not only to water storage, power production, and repayment schedules, but also to natural and recreational values immediately downstream in the park and resource values as far downstream as Mexico.

This article discusses the dilemma faced by agencies responsible for managing the Colorado River in the Grand Canyon, especially the National Park Service (NPS), which has a congressional mandate to protect and preserve the resources of Grand Canyon National Park. We also describe conflicting values in NPS management of designated natural areas in Grand Canyon National Park versus the adjacent national recreation areas of Glen Canyon (upstream) and Lake Mead (downstream).

KEY WORDS: National Park; Exotics; Riverine ecosystems; Southwest; Riparian; Aquatic

*Address communications to: Dr. R. Roy Johnson, Leader, Cooperative National Park Resources Studies Unit, 125 Biological Sciences East, Building 43, University of Arizona, Tucson, AZ 85721, USA.

Environmental Management Vol. 11, No. 1, pp. 99–107

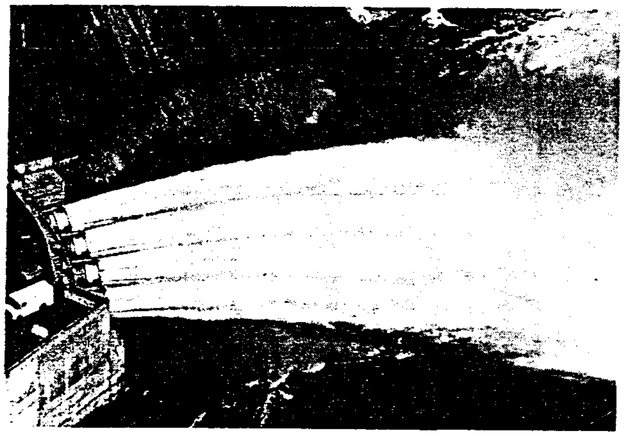

Figure 1. Water (83,000 cfs) being released through the turbine bypasses at Glen Canyon Dam, 26 June 1983 (note delivery truck in left foreground for size comparison). Bryan Brown photo.

Background

The Colorado is the largest and most important river in the southwestern United States and one of eight ninth-order rivers in the country. The Colorado originates high in Rocky Mountain National Park, Colorado, flows southwesterly for 2350 km to the Gulf of California, and drains 634,000 km^2 in parts of seven western states. It is one of the longest rivers in the United States, and crosses dozens of boundaries—local, regional, national, and international. For political and management reasons, the Colorado drainage has been divided into the Lower Basin and the Upper Basin near Lees Ferry, at the northeastern boundary of Grand Canyon National Park, and 1108 km upstream from Mexico. The Upper Basin drains about 285,000 km^2 of Wyoming, Utah, Colorado, New Mexico, and Arizona. The Lower Basin drains about 349,000 km^2 including most of Arizona and minor segments of Utah, California, Nevada, and New Mexico as well as the Mexican states of Sonora and Baja California.

The Colorado River is known as the most highly used and modified river in the United States. NPS areas along the river include three national parks—Arches, Canyonlands, and Grand Canyon—and two national recreation areas—Glen Canyon and Lake Mead. Thus, the NPS has partial administrative responsibility for almost 970 of the 1450 km of the lower Colorado River in the United States, including Arches, Canyonlands, and Glen Canyon in the Upper Basin and Grand Canyon and Lake Mead in the Lower Basin (Johnson 1978).

Prior to construction of a series of immense dams and storage reservoirs on the Colorado River, an average of about 1.77 million ha-m of water annually flowed across a broad delta into the Gulf of California. Completion of the first dam (Hoover) in 1935 formed 185-km-long Lake Mead, which initially could store more than 3.54 million ha-m. Completion of the last of these large dams (Glen Canyon) in 1963 formed 290-km-long Lake Powell, which could hold 3.41 million ha-m of water. The combined capacity of the two reservoirs equaled four years of the river's average flow. The capacity of both reservoirs has been greatly reduced by the deposition of sediments which were formerly carried into the Gulf of California. Sediment loads for the predam river averaged 127 million metric tons annually, hence the name *Rio Colorado* (Red River) or Colorado River. Water temperatures fluctuated from more than 21°C (70°C) during summer to nearly freezing in winter, when large blocks of ice sometimes floated through the Grand Canyon. Postdam sediment loads average 18 million metric tons annually ($\frac{1}{7}$ of the load of predam waters) and are little more than double that measured by the US Geological Survey for a single day (8.6 million metric tons) in 1948 (Dolan and others 1974, Carothers and Dolan 1982). Water temperatures in the Grand Canyon now remain at about 10°C (50°F) all year, since most releases at Glen Canyon Dam are drawn from a depth of about 65 m in Lake Powell.

Before Glen Canyon Dam, flows of the Colorado River in the Grand Canyon ranged from 19.8 m^3/s in December 1924 to about 8400 m^3/s in 1884 (Dolan and others 1974). Today the Colorado is a tidal river in the Grand Canyon with its daily ebb and flow varying monotonously from less than 283 m^3/ to more than 566 m^3/s (unusual extremes of less than 28 m^3/s in 1976 to 2637 m^3/s in June 1983). These fluctuating water releases, resulting from changing demands for power production at Glen Canyon Dam, often produce variations in river levels throughout the canyon of 1.5 to 3.0 m or more.

Problems

Originally dams along the Colorado were promoted, in part, for flood control of this "dangerous river," but the major purposes for the dams were water storage and power production, since loss of life and property from flooding along the sparsely settled lower Colorado was negligible. Water in the West has always had premium value for irrigation and for municipal and industrial use. Water supplies, power production, and recreation are facilitated by full reservoirs; flood control requires empty reservoirs. Thus, suggesting that a single reservoir can simultaneously provide both flood control and water storage results in contradictory management strategies and goals. In addition, attempting to manage a river for "multiple uses" often results in conflicts between uses and leads to complex management dilemmas.

NPS areas have been established by Congress "to conserve the scenery and the natural and historic objects and the wildlife therein and to provide for the enjoyment of the same . . . leave them unimpaired for the enjoyment of future generations." (Quotations are from NPS enabling legislation and policy documents.) Management of different types of NPS areas varies greatly. For example, exotic organisms are de facto viewed very differently in natural areas and in recreational areas. In natural areas management is "directed toward maintaining, and where necessary, reestablishing indigenous plant and animal life. . . ." The emphasis is on exclusion and elimination of exotic species while perpetuating the native biota and allowing continuation of natural processes. In contrast, recreational areas have been primarily established "to assure adequate outdoor recreation resources for all our citizens." Exotic species of plants or animals "may be introduced into recreation areas as part of various management programs for the purposes of public recreational use and enjoyment . . ." (USDI 1968). The problems in managing the Colorado River in Grand Canyon National Park, a natural area between two recreation areas, provide an interesting study of the dilemmas faced by one agency (NPS) in managing a continuous river under what have been different management policies. Management dilemmas become even more complex when the jurisdictional practices of other agencies are added, such as the Bureau of Reclamation's operation of Glen Canyon Dam for water storage and power production, the US Fish and Wildlife Service's responsibility for endangered species, the Bureau of Land Management's administration of livestock grazing, the wildlife management interests of Arizona and Utah, and the activities of several Indian tribes and the Bureau of Indian Affairs, all vying for the use of a single river for multiple purposes.

A few examples of typical recreational and natural resource management problems follow. The 25 km of the river in Glen Canyon National Recreation Area between Glen Canyon Dam and Grand Canyon National Park now support one of the finest rainbow trout fisheries in North America. Trophy trout in excess of 4.5 kg are common, with a record of 8.6 kg. The consistently cold water of the postdam period has improved food furnished by the introduced crustacean, *Gammarus* sp., and increased algal production has provided an ideal condition for the introduced rainbows. Thus, the Arizona Department of Game and Fish is enthusiastic about this outstanding recreational resource. NPS managers at Glen Canyon are also interested in this exotic fishery and the recreational opportunities it provides. However, NPS managers at Grand Canyon National Park are not equally enthusiastic about trout, since their mandate is to maintain indigenous populations and prevent invasion by exotics. Grand Canyon's managers are equally or more concerned with a small breeding population of the endangered humpback chub (for scientific names, see Tables 1 and 2) at the confluence of the Colorado and Little Colorado rivers in the park. This warm water refugium is the only known breeding locality for this species in Grand Canyon. The postdam, cold, clear water which has insured the vigor of rainbow trout has apparently extirpated the humpback chub as a breeding resident in the Colorado River mainstream. This unusual species is one of eight fishes originally native to the Grand Canyon (Table 1). The humpback chub is so highly adapted to the Colorado's swift currents and remote tributaries that it was unknown to science less than 40 years ago (Miller 1946). This species and the razorback sucker, although in different families, are specialists, uniquely adapted to the Colorado's swift currents through the development of a pronounced dorsal hump. Today, only three of these fishes are breeding residents of the Colorado's mainstream (Carothers and Minckley 1981). The Colorado squawfish, bonytail chub, Colorado River chub, and razorback sucker have been extirpated, and the humpback chub is a breeding resident of a single tributary. In addition, NPS and US Fish and Wildlife Service scientists are concerned about rainbow trout and several other game fish among the 19 introduced fishes recorded for Grand Canyon (Table 1) since some of these large game fish are potential predators on the smaller native fishes.

The release of clear, cold water from Lake Powell has made the Colorado suitable for exotics such as rainbow trout but unsuitable for several native fishes. Increasing the water temperature by placing intakes for Glen Canyon Dam's generators near the surface of Lake Powell rather than 65 m below has been considered. Unfortunately, several other exotics in the Grand Canyon, such as carp and striped bass, are well adapted to warm water. Thus, one common predator (and threat to the few remaining native fishes) such as the rainbow trout could be replaced by another, exotic predator such as the striped bass, possibly with disastrous results. Research by NPS, Bureau of Reclamation, and US Fish and Wildlife Service scientists should result in a better understanding of the environmental parameters conducive to the survival and reproduc-

Table 1. Current status of the fishes of the Colorado River in Grand Canyon National Park (after Carothers and Minkley 1981).

Species	Status
Native species	
Bonytail chub (*Gila elegans*)[a]	Extinct
Humpback chub (*Gila cypha*)[a]	Small breeding population at mouth of Little Colorado River
Colorado River (roundtail) chub (*Gila robusta*)[a]	Extinct
Colorado squawfish (*Ptychocheilus lucius*)[a]	Extinct
Speckled dace (*Rhinichthys osculus*)	Common
Razorback sucker (*Xyrauchen texanus*)	Extinct
Flannelmouth sucker (*Catostomus latipinnis*)	Common
Bluehead sucker (*Pantosteus* (*Catostomus*) *discobolus*)	Common
Introduced species	
Coho salmon (*Oncorhynchus kisutch*)	Accidental, extinct
Rainbow trout (*Salmo gairdneri*)	Abundant
Cutthroat trout (*S. clarki*)	Abundant
Brown trout (*S. trutta*)	Fairly common
Brook trout (*Salvelinus fontinalis*)	Fairly common
Carp (*Cyprinus carpio*)	Abundant
Golden shiner (*Notemigonus crysoleucus*)	Accidental
Virgin River spinedace (*Lepidomeda mollispinis*)	Accidental, extinct
Woundfin (*Plagopterus argentissimus*)	Accidental, extinct
Red shiner (*Notropis lutrensis*)	Accidental, extinct
Fathead minnow (*Pimephales promelas*)	Locally common
Channel catfish (*Ictalurus punctatus*)	Locally common
Black bullhead (*Ictalurus melas*)	Accidental
Rio Grande killifish (*Fundulus zerbrinus*)	Locally common
Striped bass (*Morone saxatilis*)	Locally common
Largemouth bass (*Micropterus salmoides*)	Accidental
Green sunfish (*Chaenobryttus cyanellus*)	Accidental
Bluegill sunfish (*Lipomis macrochirus*)	Accidental
Walleye (*Stizostedion vitreum*)	Accidental

Abundant—easily captured, always present in large numbers.

Common—easily captured, although not present in large numbers.

Fairly common—occasionally captured, but not unexpected.

Locally common—captured easily in specific areas, often present in numbers.

Accidental—one or two specimen records, isolated incidences of bait bucket releases, relatively unsuccessful transplants or individual dispersing from Lake Mead.

[a] Listed in the *Federal Register* as an endangered species.

tion of various aquatic species, as well as a better understanding of the interactions between predacious exotics and endangered and rare natives.

While the fishery immediately downstream from the dam is exceptionally productive, fisheries further downstream are exceptionally poor. Nutrients which were previously carried downstream are now trapped in Lake Powell along with sediments. This reduces the production of biomass and greatly affects the large sport fishery in Lake Mead about 483 km downstream (Paulson and others 1983, Adams and Lamarra 1983). The recent decline of commercial fishing in the Gulf of California, more than 1200 km below Glen Canyon Dam, may also be largely attributable to a decrease in fresh water and nutrients entering the gulf from the Colorado River.

Another problem concerns introduced plants. Saltcedar (*Tamarix chinensis*) was not reported from the Colorado until the 1920s, but by 1930 it had "become a nuisance plant" in the West (Christensen 1962). Although NPS managers and scientists are concerned about saltcedar, eradication of this exotic in the Grand Canyon would be extremely difficult if not impossible. A complicating factor is saltcedar's value as a bank stabilizer and as shade and camp shelter for river recreationists. In addition, it increases the suitability of the riparian community for native birds and insects (Brown and others 1983). Thus, even though NPS policy calls for the removal or control of exotics in natural areas when feasible, logistical, financial, wildlife, and recreational considerations make removal of saltcedar from Grand Canyon highly unlikely.

Table 2. Birds and mammals which have changed noticeably in the Grand Canyon region during historic times (mammals after Ruffner and others 1978).

Common name (scientific name)	Records from along the Colorado River	Status on the river	Predicted changes in population size with higher flows
Birds			
1) Western Grebe (*Aechmophorus occidentalis*)	x	Colonizing	None
2) Green-backed Heron (*Butorides striatus*)	x	Nonbreeding	None
3) Black-crowned Night Heron (*Nycticorax nicticorax*)	x	Colonizing	None
4) California Condor (*Gymnogyps californianus*)	x	Extinct	
5) Gambel's Quail (*Lophortyx gambelii*)	x	Extinct	
6) Chukar (*Alectoris chukar*)			
7) Wild Turkey (*Meleagris gallopavo*)			
8) Rock Dove (*Columba fasciata*)			
9) Burrowing Owl (*Athene cunicularia*)			
10) Black-chinned Hummingbird (*Archilochus alexandri*)	x	Colonizing	Reduced
11) Magnificent (Rivoli's) Hummingbird (*Eugenes fulgens*)			
12) Willow Flycatcher (*Empidonax traillii*)	x	Colonizing	Reduced
13) Vermilion Flycatcher (*Pyrocephalus rubinus*)	x	Range expansion	None
14) Bewick's Wren (*Thryomanes bewickii*)	x		
15) European Starling (*Sturnus vulgaris*)	x	Nonbreeding, exotic	
16) Bell's Vireo (*Vireo bellii*)	x	Range expansion	Reduced
17) Lucy's Warbler (*Vermivora luciae*)	x	Colonizing	Reduced
18) Yellow Warbler	x	Colonizing	Reduced
19) Common Yellowthroat (*Geothlypis trichas*)	x	Colonizing	Reduced
20) Yellow-breasted chat (*Icteria virens*)	x	Colonizing	Reduced
21) Red-faced Warbler (*Cardellina rubifrons*)			
22) Summer Tanager (*Piranga rubra*)	x	Range expansion	None
23) Blue Grosbeak (*Guiraca caerulea*)	x	Colonizing	Reduced
24) Indigo Bunting (*Passerina cyanea*)	x	Range expansion	Reduced
25) Lazuli Bunting (*Passerina amoena*)	x	Colonizing	Reduced
26) Red-winged Blackbird (*Agelaius phoeniceus*)	x	Colonizing	Reduced
27) Great-tailed Grackle (*Quiscalus mexicanus*)	x	Range expansion	None
28) Hooded Oriole (*Icterus cucullatus*)	x	Range expansion	Reduced
29) Northern Oriole (*Icterus galbula*)	x	Colonizing	Reduced
30) Brown-headed Cowbird (*Molothrus ater*)	x	Colonizing	Reduced
31) Lesser Goldfinch (*Carduelis psaltria*)	x	Colonizing	Reduced
32) House Sparrow (*Passer domesticus*)	x	Nonbreeding, exotic	None
Mammals			
1) Beaver (*Castor canadensis*)	x	Colonizing	Reduced
2) Brush mouse (*Peromyscus boylei*)	x	Colonizing	Reduced
3) Deer mouse (*Peromyscus maniculatus*)	x	Colonizing	Reduced
4) River otter (*Lutra canadensis*)	x	?	?

Another exotic of concern, Russian olive (*Elaeagnus angustifolia*), was first discovered in the Grand Canyon in the early 1970s by these authors. This spiny tree has formed large, impenetrable thickets along numerous streams in similar areas throughout the region and constitutes a new treat to the riparian community in the Grand Canyon. Several Russian olive trees on the park boundary at the confluence of the Paria River with the Colorado are a seed source for areas downriver. Although NPS policy calls for preventing the introduction of exotics into natural areas, this is not so for recreation areas. Thus, NPS managers and scientists in Grand Canyon National Park continue to be concerned about the increasing spread of Russian olive as a nuisance plant, while NPS managers at Glen Canyon National Recreation Area plant and nurture this species as the major shade tree in a campground only a few hundred meters from the park boundary.

Our third and final example of management dilemmas in the Grand Canyon requires description of the complex interactions between beaches (alluvial terraces), water flows, power production, and whitewater recreation. No other problem so thoroughly affects the status and management of riparian and recreational resources on the Colorado River in Grand Canyon National Park.

The Colorado River in the park is known as one of the world's prime whitewater rivers. More than 150 rapids occur in the park, including Lava Falls and Crystal Rapids, two of the world's most difficult, navigable rapids. Construction of Glen Canyon Dam was a mixed blessing for river recreationists. Between Major John Wesley Powell's first trip through the canyon in 1869 and the 1940s, only a few dozen people ran the Colorado. During the early 1950s fewer than 100 people ran the river annually. River runners increased gradually until 1965, when Glen Canyon Dam's operation became relatively stabilized, then their numbers increased dramatically from 547 in 1965 to 16,432 in 1972 (Nash 1977). By 1972 public concern over the rapid growth of river running in the park caused the NPS to establish an allotment system for the multimillion-dollar concession industry (21 concessioners) supporting this recreational activity. Establishment of predictable water releases made river running relatively safe, but also created environmental problems which threatened to negate what had seemed to be a stabilized recreational resource.

Releases from Glen Canyon Dam are used to produce electrical power on a daily cycle which is influenced largely by the 8-to-5 workday and corresponding increases and decreases in power consumption. Prior to construction of the dam, river flow increased with the spring snowmelt in the Rockies and decreased during dry summer months. During flood stage, old beach sediments were washed downstream and new sediments from upstream renewed the beaches periodically, often annually. Daily "tidal" fluctuations since the dam have gradually eroded away these beaches and reduced camping, picnicking, and other recreational sites, particularly at the upper end of the canyon where the river carries less silt. In addition, trash and debris left on beaches by recreationists accumulate indefinitely, as in a child's sandbox (Johnson and others 1977). Gradual erosion of camping beaches has been increased by recreationists' footsteps (Valentine and Dolan 1979).

Rapids are usually created when rubble and large boulders are washed into the river from side streams. Predam rapids were often cleared out or at least made more easily navigable by periodic floods which flushed much of the rapids-forming rubble downstream. Without this periodic flooding and flushing, eventually one or more of the Colorado's rapids probably will form an impassable barrier to boats. The possibility of flushing out rapids with high water releases that simulate predam floods has been suggested. This, however, has the disadvantage of increasing erosion of beaches through the process described earlier.

Discussion and Conclusions

These examples illustrate some of the dilemmas inherent in managing natural and recreational resources by two or more agencies with conflicting mandates or by one agency which has different management strategies for different kinds of areas under its jurisdiction (for example, parks vs recreation areas). These management problems are particularly severe when managers are working with linear resources which cross different management units and political boundaries.

Attempts to retain natural resource values along the Colorado River in Grand Canyon National Park and the recreational activities which largely depend on these resources have been complicated by the construction and operation of Glen Canyon Dam.

Power production and water storage objectives of the Bureau of Reclamation have dictated downstream water regimes in the park, thereby affecting the aquatic and riparian ecosystems. These resources have been modified so much as to preclude considering them natural, indigenous systems. They are best considered *exotic ecosystems.* Not only are most of the fish species introduced, but the physicochemical nature of the aquatic ecosystem (such as clear, cold water) has also been introduced from elsewhere (the depths of Lake Powell). Even native species such as *Cladophora* sp. have had drastic changes in their populations, and ecological processes (such as reproduction and growth) have often been modified or halted.

Riparian resources have been modified, but not as severely as aquatic resources. Aquatic modifications have included numerous deleterious impacts, while many of the riparian modifications have been additive in relation to colonization of this new habitat by native species and/or increasing population numbers. Although the physicochemical regime (for example, alluvial terraces) has been modified, we know of no native riparian organisms which have been extirpated in the Grand Canyon following construction of Glen Canyon Dam. However, several exotic species have been added. Newly established riparian communities contain indigenous coyote (sandbar) willow (*Salix exigua*), arrowweed (*Tessaria sericea*), seepwillow (*Baccharis* spp.), Goodding willow (*S. gooddingii*), and exotic saltcedar. This new riparian vegetation supports healthy populations of indigenous vertebrates (Johnson and Carothers 1982). In addition, ecological processes have not been as severely impacted as in the aquatic system. Many processes have not been noticeably modified. This development of new riparian habitat with its healthy populations of native riparian birds is unique in the Southwest. All other large riparian systems with which we have worked in the Colorado River and Rio Grande drainages have been sensecent, decadent, native communities, or exotic, scrubby communities (especially saltcedar) with low bird populations; original communities have been extirpated, leaving dry, channelized, rivers. In addition to an increase in populations of native riparian birds in the Grand Canyon, several native riparian species (such as Bell's Vireo and the Willow Flycatcher) have expanded their distribution into areas of the canyon where they had not previously occurred. Still others (such as the Northern Oriole, Hooded Oriole, and Summer Tanager) have moved into this new habitat from other sections of the Colorado River system (Carothers and Johnson 1975 and 1983; Table 2).

Thus the riparian ecosystem has been modified considerably. It now supports more terrestrial species and individuals, including woody vegetation, birds, mammals (Table 2), and probably reptiles, amphibians, and insects. Even though the riparian ecosystem contains a few exotic species, their impact seems to be negligible. In contrast to the highly modified aquatic ecosystem, which we label an *exotic ecosystem,* we suggest calling the new, less modified riparian ecosystem a *naturalized ecosystem* defined as follows: a *naturalized ecosystem* contains biotic communities with both indigenous and exotic plants and/or animals. In these communities dominance or predominance is not a function of species origin (that is, native or non-native), and the indigenous biota is not threatened either in species richness or population sizes by exotic species. In naturalized ecosystems biotic and abiotic processes have either reached or are evolving toward an equilibrium in which exotics do not restrict or interfere with native organisms or ecological processes, rather than evolving toward the destruction of components and processes of the original, natural ecosystem. If native species are extirpated or their populations greatly reduced, the ecosystem cannot be considered naturalized. In Grand Canyon new postdam riparian vegetation has led to larger populations of native species and generally has been beneficial to wildlife as well as recreationists.

Since the National Park Service has a congressional mandate to maintain areas such as Grand Canyon in a natural state, NPS managers and scientists are frustrated by the fact that the natural aquatic and riparian ecosystems have been irreparably changed by external forces over which they have little or no control. Paradoxically, however, the major changes in the riparian community consist of increases in populations and distribution of native species, some of which (certain birds and insects) largely depend on the exotic saltcedar. This increase in native species may be considered a plus in the arid Southwest, where riparian populations have been widely reduced to a small fraction of their pre-European-settler numbers. Nevertheless, the change is a modification of the Grand Canyon's natural environment as it existed before Glen Canyon Dam, and therefore may be considered at variance with the congressional intent for the preservation and management of the park's resources. Thus, the NPS has been faced with the dilemma of managing an ecosystem which has been converted from a natural to a naturalized state.

For 20 years, from 1963 to 1983, the NPS sought the best methods for managing this new legacy of Glen Canyon Dam to maximize preservation of biological and recreational resources in the Grand Canyon. During the spring and summer of 1983 an unusually heavy snowmelt in the Rockies allowed more than 2850 m^3/s to flow into upper Lake Powell, already near capacity as the Upper Basin states attempted to store their allocation of Colorado River water. In June 1983 unprecedented postdam flows of up to 2645 m^3/s were released from Glen Canyon Dam, flooding much of the new Grand Canyon riparian zone. For several weeks water flowed over shrubs and terraces, destroying nest sites and wildlife habitat, and inundating recreational and camp sites (Figure 2a and b).

The long-term implications of the 1983 flood are far-reaching. Prior to 1983, postdam flows in Grand Canyon ranged from approximately 28 m^3/s to 850 m^3/s, the amount that could be passed through the generators at Glen Canyon Dam. It was this 1963–1982 flow regime that created the new riparian zone discussed here and which left the old high-water riparian zone high and dry. Much of this old high-water riparian zone is now apparently senescent, consisting of species such as mesquite (*Prosopis glandulosa*), Gregg catclaw (*Acacia greggii*), redbud (*Cercis occidentalis*), and netleaf hackberry (*Celtis reticulata*), which are no longer being nourished by spring floods.

The filling of Lake Powell and the likelihood of periodic heavy snow packs in the Rockies, with consequent releases of up to 2850 m^3/s through the dam, have increased the complexity of managing the Colorado River in Grand Canyon. Although we do not project appreciable changes to the already highly modified aquatic ecosystem, the future of the riparian ecosystem and whitewater recreation is unclear. With these higher flows, the new riparian zone could be largely eliminated and many recreational beaches rendered unusable by erosion or flooding. On the other hand, these higher flows may reestablish the now senescent predam riparian zone. Much of this old zone

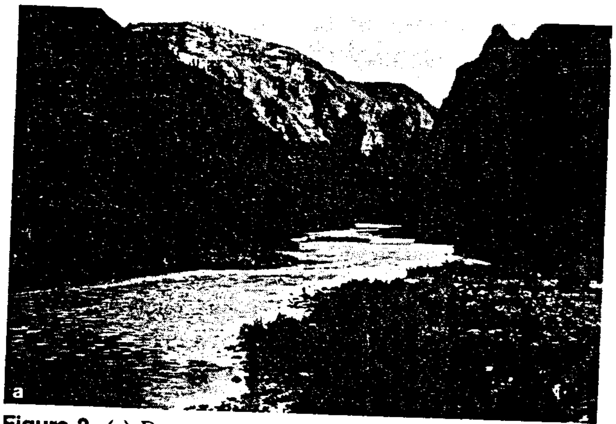
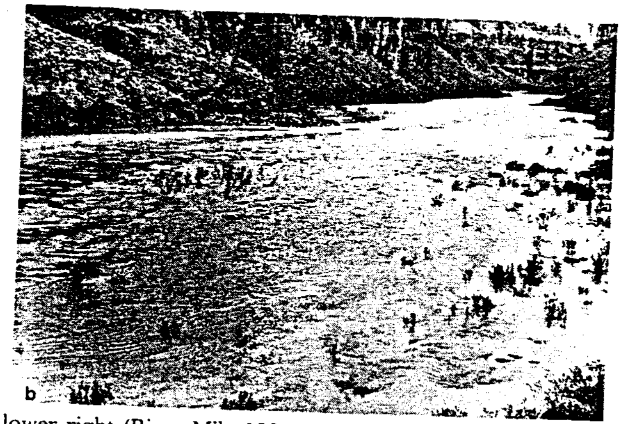

Figure 2. (a) Downstream view across Parashant Wash delta at lower right (River Mile 198.5R), 25 April 1983 at a flow of 28,000 cfs. The Colorado is still within its channel at this "normal" high, postdam flow. Most of the vegetation is saltcedar scrub 2–4 m high. Bryan Brown photo. (b) A view similar to **a** on 21 June 1983, with Parashant Wash delta occupying the bottom two-thirds of the photo. At approximately 62,000 cfs much of the vegetation in **a** has been eroded away and all but the tops of the highest shrubs have been inundated. Vegetation of the gravel bar (downstream in **a**) is gone. Bryan Brown photo.

is on rocky and gravelly talus slopes, where recreational values are not as high as in the new, postdam, sandy, riparian zone.

In summary, the Colorado River in Grand Canyon has progressed through the following three distinct regimes during historic times:

1) Predam flows of silt-laden water varied in volume and temperature throughout the year.
   a) Spring and early summer floods of about 2850 m^3/s were common. [Flow volumes are approximate in the summary. For more accurate levels, see Dolan and others (1974) and Carothers and Dolan (1983).]
   b) Later summer flows diminished in volume to approximately 1/10 flood level or lower and the water was warm and muddy into autumn.
   c) Winter flows were low and the water was cold until the spring snowmelt in the Rockies.
2) From the completion of Glen Canyon Dam through 1982, daily "tidal" flows of constantly cold, clear water ranged from somewhat in excess of 710 m^3/s to less than 140 m^3/s in response to hourly needs for power production. Releases usually were lower at night and higher during the day, especially in summer at the peak of the river-running season.
3) Finally, in the summer of 1983 the Bureau of Reclamation was forced to release a record volume of water to prevent the overflow of Glen Canyon Dam. In contrast to predam floods, the 1983 Grand Canyon flood consisted of clear, erosive water and was not followed by greatly diminished flows for most of the rest of the year. The Bureau of Reclamation continued to release over 850 m^3/s of water and/or the usual daily "tidal" rhythm of flow was lacking through the rest of 1983 in order to reduce excess water storage in Lake Powell.

Aquatic and riparian organisms of the Grand Canyon had adapted to the seemingly harsh environment of the predam Colorado. Natural ecological processes of the biotic and abiotic environment were largely driven by seasonal variations in flow levels, temperature, and sediment loads. The postdam changes in these factors created a new ecosystem. Studies of the effects of changes in these factors are being conducted by scientists and cooperators from the National Park Service, Bureau of Reclamation, US Geological Survey, US Fish and Wildlife Service, and other agencies. Models are being developed to predict the results of varying flow levels over varying time intervals. This and other information is being analyzed in the light of agency mandates (which often conflict), user needs, and the socioeconomic and ecological implications of various alternatives. Results of these studies will, it is hoped, aid in the adoption of a suitable management plan, but for now, future management strategies for the Colorado riverine resources in Grand Canyon are uncertain.

Literature Cited

Adams, V. D., and V. A. Lamarra (eds.). 1983. Aquatic resources management of the Colorado River ecosystem. Proceedings of the 1981 symposium on the aquatic resources management of the Colorado River Ecosystem, 16–18 November 1981, Las Vegas. Ann Arbor Science, Ann Arbor, Michigan, 697 pp.

Brown, B. T., S. W. Carothers, and R. R. Johnson. 1983. Breeding range expansion of Bell's Vireo in Grand Canyon, Arizona. *Condor* 85:499–500.

Carothers, S. W., and R. Dolan. 1982. Dam changes on the Colorado River. *Natural History* 91:74–83.

Carothers, S. W., and R. R. Johnson. 1975. Recent observations on the status and distribution of some birds of the Grand Canyon region. *Plateau* 47:140–153.

Carothers, S. W., and R. R. Johnson. 1983. Status of the Colorado River ecosystem in Grand Canyon National Park and Glen Canyon National Recreation Area. Pages 139–160 *in* V. D. Adams and V. A. Lamarra (eds.), Aquatic resources management of the Colorado River ecosystem. Proceedings of the 1981 symposium on the aquatic resources management of the Colorado River ecosystem, 16–18 November 1981, Las Vegas. Ann Arbor Science, Ann Arbor, Michigan, 697 pp.

Carothers, S. W., and C. O. Minckley. 1981. A survey of the aquatic flora and fauna of the Grand Canyon. USDI Bureau of Reclamation, Lower Colorado Region, Boulder City, Nevada, 401 pp.

Christensen, E. M. 1962. The rate of naturalization of tamarix in Utah. *American Midland Naturalist* 68:51–57.

Dolan, R., B. Hayden, A. Howard, and R. Johnson. 1977. Environmental management of the Colorado River within the Grand Canyon. *Environmental Management* 1:391–400.

Dolan, R., A. Howard, and A. Gallenson. 1974. Man's impact on the Colorado River in the Grand Canyon. *American Scientist* 62:392–401.

Johnson, R. R. 1978. The Lower Colorado River: a western system. Pages 41–55 *in* R. R. Johnson and J. F. McCormick (tech. coords.), Strategies for protection and management of floodplain wetlands and other riparian ecosystems. Proceedings of the Symposium. USDA Forest Service General Technical Report WO-12, Washington, DC, 410 pp.

Johnson, R. R., and S. W. Carothers. 1982. Riparian habitats and recreation: interrelationships and impacts in the Southwest and Rocky Mountain region. Eisenhower Consortium Bull. 12. Rocky Mountain Forest and Range Experiment Station, USDA Forest Service, Fort Collins, Colorado 31 pp.

Johnson, R., S. Carothers, R. Dolan, B. Hayden, and A. Howard. 1977. Man's impact on the Colorado River in the Grand Canyon. *National Parks and Conservation Magazine* (March):13–16.

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 Science* 36:409–415.

Nash, R. 1977. River recreation: history and future. Pages 2–7 *in* D. W. Lime and C. A. Fasick (tech. coords.), Proceedings: river recreation management and research symposium. Forest Service General Technical Report NC-28, North Central Forest Experiment Station, St. Paul, Minnesota.

Paulson, L. J., and others. 1983. The influence of Lake Powell on the suspended sediment–phosphorus dynamics of the Colorado River inflow to Lake Mead. Pages 57–70 (plus six additional papers) *in* V. D. Adams and V. A. Lamarra (eds.), Aquatic resources management of the Colorado River ecosystem. Proceedings of the 1981 symposium on the aquatic resources management of the Colorado River ecosystem, 16–18 November 1981, Las Vegas. Ann Arbor Science, Ann Arbor, Michigan, 697 pp.

Ruffner, G. A., N. J. Czaplewski, and S. W. Carothers. 1978. Distribution and natural history of some mammals from the Inner Gorge of the Grand Canyon, Arizona. *Journal of the Arizona–Nevada Academy of Science* 13:85–91.

USDI Bureau of Reclamation. 1946. The Colorado River: a nautral menace becomes a national resource. Washington DC, 295 pp. + 11 maps.

USDI National Park Service. 1968. Administrative policies for recreational areas of the National Park System. National Park Service, USDI, Washington, DC, 108 pp.

Valentine, S., and R. Dolan. 1979. Footstep-induced sediment displacement in the Grand Canyon. *Environmental Management* 3:531–533.