DECOMMISSIONING GLEN CANYON DAM: THE KEY TO COLORADO RIVER ECOSYSTEM RESTORATION AND RECOVERY OF ENDANGERED SPECIES?

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I. INTRODUCTION

Of all the major dams on the Colorado River system, advocates of dam decommissioning have focused their attention on Glen Canyon Dam. Among the arguments offered in support of this decomissioning is restoration of the Colorado River biological systems in Glen and Grand Canyons both upstream and downstream of the dam. Specific mention has been made of the benefits that theoretically would accrue to endangered species in and along the river, particularly native fish species. The purpose of this paper is to: (1) identify ecological components that likely would be affected by removing or bypassing Glen Canyon Dam; (2) speculate (given the sketchy nature of available data) on how such action might affect endangered species, particularly native fish; and (3) take a broader, albeit less visionary, look at managing a regulated Colorado River system for endangered species. We focus our discussion on endangered species because of the power of the Endangered Species Act of 1973 ("ESA")[1] to shape natural resource management actions.

Four primary difficulties complicate any attempt to determine the influence of reservoir drainage on biological systems upstream and downstream of Glen Canyon Dam. First, the terrestrial and aquatic ecosystems of Glen and Grand Canyons were only cursorily studied before the dam was built, rendering our

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1. Endangered Species Act of 1973, 16 U.S.C. §§ 1531–1544 (1994).

assessment of the dam's impacts somewhat speculative;[2] second, by the late 1800s the pre-dam river's ecosystem had already been altered by the introduction of non-native species, especially several fish species known to be competitors/predators of the native fish;[3] third, after almost forty years of dam operations, the dynamic nature of the post-dam river in Grand Canyon has not yet reached equilibrium;[4] and, fourth, in the absence of rigorous data collection and analysis, any assessment of how the floral and faunal elements would respond to a drained lake must be, by definition, speculative.

II. THE COLORADO RIVER SYSTEM

The Colorado River, together with its principal tributaries, the Green River and the San Juan River, drains 242,000 square miles of seven relatively arid states—Colorado, Wyoming, Utah, New Mexico, Arizona, Nevada, and California—as well as another 2000 square miles of northern Mexico.[5] The Colorado River Basin is legally divided into two sub-basins, the Upper Basin (Colorado, Wyoming, and Utah) and the Lower Basin (New Mexico, Arizona, Nevada, and California).[6] During the twentieth century, flow in the Colorado River has averaged about 15 million acre-feet ("maf") of water per year.[7] Humans have used this water as long as they have lived in the region, at least 13,000 years, but until the last century they caused little disruption to the complex communities of other organisms that rely on the river system for their existence.

The twentieth century, however, brought radical changes. These primarily resulted from two types of actions. The first, and most consequential, has been the modification of habitats by damming the Colorado River and its tributaries;

2. *See* STEVEN W. CAROTHERS & BRYAN T. BROWN, THE COLORADO RIVER THROUGH GRAND CANYON: NATURAL HISTORY AND HUMAN CHANGE 82 (1991).

3. *See* RICHARD A. VALDEZ & STEVEN W. CAROTHERS, THE AQUATIC ECOSYSTEM OF THE COLORADO RIVER IN GRAND CANYON: GRAND DATA INTEGRATION PROJECT, SYNTHESIS REPORT 48 (1998).

4. *See* John C. Schmidt et al., *Science and Values in River Restoration in the Grand Canyon*, 48 BIOSCIENCE 735, 735–47 (1998).

5. *See* Bill Plummer, *The Colorado, A River for Many People*, *in* AQUATIC RESOURCE MANAGEMENT OF THE COLORADO RIVER ECOSYSTEM 1, 3 (V. Dean Adams & Vincent A. Lamarra eds., 1983).

6. In 1922, Congress approved the Colorado River Compact, 43 U.S.C. § 617*l* (1994), which split the basin at a point near Lee's Ferry, Arizona, and allocated river flow between the Upper and Lower Basins. As a result of this compact, and subsequent treaty obligations with Mexico, the Upper Basin is required to deliver a minimum of 8.23 million acre feet ("maf") of water (as measured at Glen Canyon Dam) to the Lower Basin each year.

7. *See* Christopher S. Harris, Overview of the Law of the River: A Historical Perspective of the Legal and Physical Operations of the Colorado River 1 (unpublished paper, presented at Restoring Native Fish to the Lower Colorado River: Interactions of Native and Non-Native Fishes, A Symposium & Workshop, Las Vegas, Nevada, July 13–14, 1999) (on file with Author).

diverting water for agricultural, industrial, and municipal uses; and physically modifying stream channels. Structural modifications within the Colorado River system include six major dams in the Upper Basin[8] and six in the Lower Basin,[9] as well as numerous smaller impoundments. Water diversions[10] now siphon off all the river's flow before it reaches the Sea of Cortez in the Gulf of California. Between 1986 and 1990, average annual consumptive use of Colorado River water totaled about 3.7 maf in the Upper Basin and 6.9 maf in the Lower Basin.[11] About 1.7 maf was used in Mexico and another 1.7 maf was lost to evaporation.[12] Long reaches of what was once natural riverine habitat have been replaced by impoundments, regulated flow, reduced flow, and channelized flow.

The second development that radically changed the Colorado River Basin ecosystem is the sometimes intentional, sometimes accidental, introduction of non-native species into both aquatic and terrestrial habitats. Aquatic invaders include fish, of course, and numerous other organisms ranging from crayfish and molluscs to algae and microorganisms. Terrestrial non-natives include highly prolific tamarisk (salt cedar) and Russian thistle (tumbleweed).

Native fish in particular have been assaulted by unfamiliar competitors and predators that have been released into streams and ponds, rivers, and lakes—initially as potential food sources and later for sport fishing. These introductions began in the 1870s when the newly formed U.S. Fish Commission—precursor to the present-day U.S. Fish and Wildlife Service ("USFWS")—distributed large numbers of non-native fishes throughout the country.[13] Accounts of early explorers indicated that carp and catfish had become established throughout the Colorado River Basin by the late 1800s.[14] Other non-native species followed. Now, non-native fish far exceed native fish, both in terms of number of species[15]

8. *See id.* at 18–20 (listing Fontenelle Dam (1964, Green River), Flaming Gorge Dam (1962, Green River), Blue Mesa Dam (1962, Gunnison River), Morrow Dam (1968, Gunnison River), Crystal Dam (1976, Gunnison River), Navajo Dam (1963, San Juan River), and Glen Canyon Dam (1963, Colorado River)).

9. *See id.* (listing Hoover Dam (1935), Davis Dam (1953), Parker Dam (1938), Palo Verde Diversion Dam (1957), Imperial Dam (1938), and Laguna Dam (1909), all of which are on the Colorado River mainstem).

10. For descriptions of major water diversions from the Colorado River system, see *id.*

11. *See* U.S. BUREAU OF RECLAMATION, COLORADO RIVER SYSTEM CONSUMPTIVE USES AND LOSSES REPORT, 1986–1990, at iv (1998).

12. *See id.*

13. *See* Wendell L. Minckley & Michael E. Douglas, *Discovery and Extinction of Western Fishes: A Blink of the Eye in Geologic Time*, *in* BATTLE AGAINST EXTINCTION: NATIVE FISH MANAGEMENT IN THE AMERICAN WEST 7, 9–11 (Wendell L. Minckley & James E. Deacon eds., 1991) [hereinafter BATTLE AGAINST EXTINCTION].

14. *See* CAROTHERS & BROWN, *supra* note 2, at 83.

15. *See* JOHN A. HAWKINS & THOMAS P. NESLER, NON-NATIVE FISHES OF THE UPPER COLORADO RIVER BASIN: AN ISSUE PAPER 1 (1991) (stating that 13 of the 55 species of fish known from the Upper Colorado River Basin are native and 42 are non-native).

and total biomass, and have been implicated in the decline of native species. As Minckley and Douglas wrote in 1991, "The presence of non-native fish may prove a far greater problem to native fish survival than all our other environmental abuses combined."[16]

A. Endangered Species

The ESA authorizes the USFWS to list endangered and threatened species, and section 9 of the ESA and implementing regulations restrict all persons from taking listed endangered fish and wildlife anywhere in the United States.[17] Compliance with the ESA is required for any action, public or private, large or small, that has the potential to impact listed species.[18] The broad jurisdiction of this law, coupled with its strict prohibitions and substantial civil and criminal penalties for noncompliance, make it a powerful piece of legislation,[19] and one that must be considered when contemplating any action as significant as decommissioning Glen Canyon Dam.

Draining Lake Powell and bypassing the dam could affect several species listed as threatened or endangered under the ESA. We focus our attention on four fish species, three bird species, and a snail. The fish species, all endangered, are the humpback chub (*Gila cypha*), bonytail (*G. elegans*), roundtail chub (*G. robusta*), Colorado pikeminnow (*Ptychocheilus lucius*), and razorback sucker (*Xyrauchen texanus*). The bird species are the southwestern willow flycatcher (*Empidonax traillii extimus*), which is endangered; the bald eagle (*Haliaeetus leucocephalus*), which has recently been proposed for delisting;[20] and the American peregrine falcon (*Falco peregrinus anatum*), which was recently delisted[21] but still is treated as a species of special concern by several state and federal agencies. The snail is the endangered Kanab ambersnail (*Oxyloma haydeni kanabensis*).

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16. Minckley & Douglas, *supra* note 13, at 17.

17. *See* 16 U.S.C. § 1532(19) (defining "take" as "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct").

18. *See* Endangered Species Act § 9, 16 U.S.C. § 1538.

19. *See generally* Symposium, *Endangered Species Act at Twenty-One: Issues of Reauthorization*, 24 ENVTL. L. 321 (1994) (discussing the effectiveness of the ESA).

20. *See* Proposed Rule to Remove the Bald Eagle in the Lower 48 States from the List of Endangered and Threatened Wildlife, 64 Fed. Reg. 36,454, 36,454–64 (1999).

21. *See* Final Rule to Remove the American Peregrine Falcon from the Federal List of Endangered and Threatened Wildlife, and to Remove the Similarity of Appearance Provision for Free-Flying Peregrines in the Conterminous United States, 64 Fed. Reg. 46,542, 46,452–58 (1999) (amending 50 C.F.R. §§ 17.11(h), 17.95(b)).

III. GLEN CANYON DAM

Located in northern Arizona, just south of the Utah border, Glen Canyon Dam stands near the Colorado River Compact point. Completed in 1963, the 710-foot-tall concrete structure was built primarily to store water and to serve as a spigot to control allocations of water from the Upper Colorado River Basin to the Lower Colorado River Basin.[22] Lesser purposes include hydroelectric power generation, sediment control, and recreation. Upstream, the dam backed up the Colorado River to create Lake Powell, the second largest reservoir in the United States. Approximately 155 miles of Glen Canyon and 30 miles of Cataract Canyon were flooded, along with about 75 miles of the San Juan River and scores of lesser tributaries.[23] Downstream, the Colorado River that flows through the remaining 15 miles of Glen Canyon and about 240 miles of Grand Canyon was transformed into a highly regulated stream profoundly different in terms of flow pattern, temperature, and turbidity from the one that existed before the dam. These physical differences, combined with human biological intervention (notably the introduction of non-native game, forage, and bait fish), have resulted in very different aquatic and terrestrial communities.

A. Lake Powell

The surface of Lake Powell at full-pool (3700 feet above sea level) covers approximately 160,800 acres.[24] Originally, the capacity of the reservoir was 27 maf, an amount equal to about two year's average river flow. Siltation, which began immediately after the dam's flood gates were closed in 1963, has reduced that capacity by about 37,000 acre-feet ("af") per year.[25] Current capacity is estimated at roughly 25.7 maf. Given this siltation rate, the reservoir would be completely filled in some 700 years;[26] however, the functional life of the dam as a

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22. Colorado River Storage Project Act of 1956 ("CRSP"), 43 U.S.C. § 620–620o (1994), authorized the Glen Canyon Dam and other projects,

> for the purposes, among others, of regulating the flow of the Colorado River, storing water for beneficial consumptive use, making it possible for the States of the Upper Basin to utilize, consistently with the provisions of the Colorado River Compact, the apportionments made to and among them in the Colorado River Compact and the Upper Colorado River Basin Compact, respectively, providing for reclamation of arid and semiarid land, for the control of floods, and for the generation of hydroelectric power, as an incident of the forgoing purposes.

MILTON NATHANSON, U.S. DEPARTMENT OF THE INTERIOR, UPDATING THE HOOVER DAM DOCUMENTS I-99 app. I (1978).

23. *See* RONALD L. FERRARI, U.S. BUREAU OF RECLAMATION, 1986 LAKE POWELL SURVEY 3 (1988).

24. *See id.* at 6.

25. *See id.*

26. *See id.*

water storage and hydropower-generating facility would be diminished much sooner as sediment deposits reached the dam's river outlet works (3374 feet above sea level), and then its powerplant penstocks (3470 feet above sea level).[27] Estimates of the effective life span of Lake Powell and Glen Canyon Dam vary radically, from as little as another 100 years to over 500.

Lake Powell retains water, but it also loses water through seepage (called bank storage) and evaporation. Between dam closure and 1976, water seeped into the surrounding rock formations, mostly the porous Navajo Sandstone that forms the bulk of reservoir walls, at an average rate of about 600,000 af per year.[28] Rate of water movement into bank storage decreases over time as rock becomes increasingly saturated. Currently, bank storage is estimated at 18.5 maf of water.[29]

B. Proposal to Decommission Glen Canyon Dam

Proposals to restore the Colorado River in Glen and Grand Canyons—that is, remove the influence of Glen Canyon Dam—would require either dismantling the dam or diverting the river around it. Both methods would drain Lake Powell and result in a free-flowing or minimally restricted river. The Glen Canyon Institute, a private, nonprofit organization based in Salt Lake City dedicated to the "reestablishment of a free-flowing Colorado River through a restored Glen Canyon,"[30] proposes to leave the dam in place but divert river flow through tunnels on both sides of the structure.[31] Under this scenario, the diversion tunnels would constitute a channel restriction, particularly at high flows.

Restoring the Colorado River would encompass two phases: a short-term phase, during which Lake Powell would be drained, and a long-term phase with a through-flowing river. The Glen Canyon Institute has suggested that the reservoir reasonably could be depleted in ten to fifteen years.[32] To assess possible downstream impacts of draining Lake Powell, we calculated how much water would have to be released from the dam on a constant basis for several depletion periods ranging from five to twenty-five years. These calculations assume an inflow of 13.6 maf per year, the average annual inflow into what is now Lake

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27. *See* U.S. BUREAU OF RECLAMATION, GLEN CANYON DAM AND POWERPLANT: TECHNICAL RECORD OF DESIGN AND CONSTRUCTION 10 fig.5 (1970) [hereinafter TECHNICAL RECORD OF DESIGN]. Releases through the four tubes of the river outlet works bypass the powerplant; the eight penstocks direct water to the powerplant's eight turbines. *See id.* at 9 fig.4.

28. *See* LOREN D. POTTER & CHARLES L. DRAKE, LAKE POWELL: VIRGIN FLOW TO DYNAMO 214 (1989).

29. *See* U.S. Bureau of Reclamation, *Lake Powell* (visited Mar. 26, 2000) <http://www.uc.usbr.gov/wrg/crsp/crsp_gc.txt>.

30. *Glen Canyon Institute* (visited Mar. 26, 2000) <http://www.glencanyon.org>.

31. *See* Telephone Interview with David Wegner, Science Director, Glen Canyon Institute (Aug. 16, 1999).

32. *See id.*

Powell between 1914 and 1986,[33] and a full reservoir of 25.7 maf. Our calculations show that draining the reservoir over five, ten, fifteen, twenty, and twenty-five years could be accomplished by releasing a constant 20,213, 20,572, 21,152, 22,341, and 25,891 cubic feet per second ("cfs"), respectively. These figures are not extraordinarily high. The mean daily discharge for dam releases between July 1983 and April 1987 exceeded 22,000 cfs on every day but four,[34] and the operating criteria for Glen Canyon Dam currently caps the daily releases at 25,000 cfs.[35] The reservoir could be drained through the penstocks until the elevation of 3470 feet (230 feet below the top of the dam) was reached. Below that level, water could only be released through the river outlet works (326 feet below the top of the dam), which have a combined release capacity of only 15,000 cfs at a reservoir elevation of 3700 feet.[36] Releasing any water below the level of the outlet works would require either re-opening the two 41-foot-diameter diversion tunnels that were used during dam construction and subsequently plugged with concrete,[37] or excavating new ones. Once the reservoir drained, the river would flow through the diversion tunnels to bypass the dam. Several questions about how diversion tunnels would have to be designed leap to mind. For example, how would they be activated with the reservoir still in place; how would they be kept from being clogged by the huge amount of driftwood (including 50-foot-long cottonwood logs) and other debris[38] that would be carried down the undammed river; how would they be kept intact over decades of pounding flows; and how would they accommodate floods that could reach 300,000 cfs? Presumably, if diversion tunnels were used to drain the reservoir, some means would have to be installed to regulate flow. If not, *prolonged* releases in excess of 70,000 cfs (one tunnel) or 140,000 cfs (both tunnels) would cause irreparable damage to the environment downstream in Grand Canyon.

Assuming these impediments could be overcome and draining Lake Powell became a reality, the dam would still have to operate in compliance with the Endangered Species Act,[39] Clean Water Act,[40] National Environmental Policy

33. *See* FERRARI, *supra* note 23, at 12 tbl.2.

34. *See* United States Gaging Stations, *U.S. Geological Survey Historical Streamflow Daily Values for Colorado R At Lees Ferry, Az.* (visited Mar. 26, 2000) <http://waterdata.usgs.gov/nwis-w/AZ/data.components/hist.cgi?statnum=09380000> [hereinafter *Colorado River Streamflow Values*].

35. *See* U.S. BUREAU OF RECLAMATION, OPERATION OF GLEN CANYON DAM: FINAL ENVIRONMENTAL IMPACT STATEMENT SUMMARY 24–25 (1995).

36. *See id.* at 5 fig.2; TECHNICAL RECORD OF DESIGN, *supra* note 27, at 10 fig.5.

37. *See* TECHNICAL RECORD OF DESIGN, *supra* note 27, at 42 (stating that the original tunnels had a combined capacity of 143,000 cfs).

38. *See* Charles W. Ferguson, *Tree-ring Dating of Colorado River Driftwood in Grand Canyon*, *in* HYDROLOGY AND WATER RESOURCES IN ARIZONA AND THE SOUTHWEST 351–66 (1971) (stating that huge amounts of driftwood accumulated along the high water line in Glen and Grand Canyons before the dam).

39. 16 U.S.C. §§ 1531–1544 (1994).

40. 33 U.S.C. §§ 1251–1387 (1994 & Supp. III 1997).

Act,[41] Law of the River,[42] and other extant laws during the period of drawdown, unless Congress legislated otherwise. Environmental effects of the drawdown would have to be taken into account when designing the drawdown release regime. Effects of the program would have to be monitored.

IV. BEFORE AND AFTER THE DAM

The basic elements of the existing Colorado River aquatic and terrestrial ecosystems above and below Glen Canyon Dam would be altered dramatically should Lake Powell be drained. To understand the nature and significance of these changes it is necessary to briefly review the ecological status of the ecosystems before the dam and how these systems were changed by the dam.

Within recorded history, the unregulated Colorado River in Glen and Grand Canyons was characterized by dramatically variable seasonal river flows, heavy sediment loads and very muddy water, especially during peak discharges, a wide range of dissolved solids concentrations, and water temperatures varying by as much as 50°F between winter and summer.[43] Once the flood gates of Glen Canyon Dam closed in March of 1963, the characteristics of the river changed sharply. Above the dam, of course, the river became Lake Powell. Below the dam, the wildly variable seasonal flow was stabilized, the high sediment loads were trapped behind the dam, the once muddy flows became clear, and, by the early 1970s, the water temperatures discharging from the dam became cold, averaging 48°F and varying no more than 4°F between winter and summer. These changes led to profound differences in the pre- and post-dam ecological systems.

A. Aquatic Components

The aquatic organisms that lived within the pre-dam environment had to be able to deal with river flows ranging from a trickle to raging spring/summer floods (from about 700 cfs in December 1924 to an estimated peak of more than 300,000 cfs during the spring of 1884).[44] The sediment concentrations were no less variable, with an annual average of 85.9 million tons,[45] but variable enough that in one record breaking day in 1927 a storm sent 27 million tons past the Phantom Ranch gauging station in twenty-four hours.[46] The pre-dam temperature of the

41. 42 U.S.C. §§ 4321–4370d (1994 & Supp. III 1997).

42. The Law of the River is an informal designation for the body of laws, court decrees, treaty obligations, and contracts that govern water rights and uses of the Colorado River. *See* WILLIAM L. GRAF, THE COLORADO RIVER: INSTABILITY AND BASIN MANAGEMENT 8–9 (1985).

43. *See* CAROTHERS & BROWN, *supra* note 2, at 21–23, 48–55, 67.

44. *See id.* at 22.

45. *See* Edmund D. Andrews, *Sediment Transport in the Colorado River Basin*, *in* COLORADO RIVER ECOLOGY AND DAM MANAGEMENT: PROCEEDINGS OF A SYMPOSIUM 54, 63 (1991) (reporting the average during the period from 1941 to 1957).

46. *See* CAROTHERS & BROWN, *supra* note 2, at 52.

river was related to the ambient temperatures, with winter lows ranging from freezing to 40°F, gradually warming in spring from 60 to 70°F, and reaching peak highs sometimes approaching 85°F in summer.[47]

Primary Productivity and Food Base in the Pre-Dam River. Although never directly measured within Glen and Grand Canyons before the dam, primary productivity originating within the river (autochthonous) was limited due to the absence of a stable river bottom (massive quantities of fine sediments and sand moved along the river bottom), and the inability of solar radiation to penetrate the usually muddy water. Opportunity for growth of algae was limited, and few macroinvertebrates or aquatic insects were produced in the river itself. Thus, the food base upon which the fishes lived is thought to have been relatively depauperate and mostly originating from outside the aquatic system (allochthonous), typically in the form of terrestrial insects.[48]

Fish in the Pre-Dam River. Few fish species evolved in this system. In the Grand and Glen Canyon reaches of the Colorado River mainstem, the native assemblage was limited to two families, six genera, and eight species.[49] Notwithstanding the relatively inhospitable habitat the pre-dam river presented to fish, several species of warmwater non-native species had come to occupy the San Juan and Colorado Rivers in abundance long before Glen Canyon Dam was even conceptualized. Most of these fishes derived from distant introductions; however, with the creation of Grand Canyon National Park in 1919, non-native trout (primarily rainbow, brook, brown, and cutthroat) were introduced into the cold-water tributaries of Grand Canyon itself.[50] And after Hoover Dam was finished in 1935, state and federal resource agencies launched a vigorous program to introduce non-native fishes for sport fishing, forage, and bait into the reservoir forming behind the dam.[51] Some of these fishes inevitably traveled upstream, contributing to the non-native species load in Grand Canyon.

By the time Glen Canyon Dam was completed in 1963, fourteen species of non-native fish had already been reported in a system that once held only eight native species.[52] The first ichthyological surveys in the area were conducted in Glen Canyon as part of pre-impoundment studies for the dam. Surveys led by A.M. Woodbury in 1957 and 1958[53] and by McDonald and Dotson in 1960[54]

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47. *See id.* at 67.

48. *See* VALDEZ & CAROTHERS, *supra* note 3, at 35.

49. *See id.* at 47.

50. *See* ARIZONA DEPARTMENT OF GAME AND FISH, FISH PLANTING: GRAND CANYON NATIONAL PARK 1920 (1950).

51. *See* Carl L. Hubbs, *Establishment of a Forage Fish, the Red Shiner* (Notropis lutrensis) *in the Lower Colorado River System*, 40 CAL. FISH & GAME 287 (1954).

52. *See* VALDEZ & CAROTHERS, *supra* note 3, at 48–52.

53. *See* Angus M. Woodbury, *An Ecological Study of the Colorado River in Glen Canyon*, *in* ECOLOGICAL STUDIES OF THE FLORA AND FAUNA IN GLEN CANYON 149–76 (Angus M. Woodbury ed., 1959) [hereinafter GLEN CANYON ECOLOGICAL STUDIES].

reported that channel catfish, a non-native, represented over ninety percent of fish captured in the Glen Canyon area. Little work was done in the Grand Canyon during those days due to logistical difficulties in sampling the area, but early river runner's recorded observations indicate a preponderance of non-natives (carp, catfish, and trout) in that reach as well.[55]

1. The Lake Above the Dam

As soon as Glen Canyon Dam's flood gates were closed, the environment above the dam began to change from a lotic (river) ecosystem to a lentic (lake) ecosystem. Lake Powell took seventeen years to fill, from 1963 to 1980.[56] As it deepened it took on characteristics of a large body of water, including thermal stratification into an upper stratum of warmer, circulating water called the *epilimnion*, and a deep, cold, and relatively undisturbed stratum called the *hypolimnion*. An intermediate region, called the *metalimnion*, separates the two.[57] Lake Powell is also chemically stratified, with a large body of saline water accumulating on the bottom. Under normal dam operations, this region of high salinity stagnates over time, becoming increasingly anaerobic as levels of dissolved oxygen decrease. Eventually the only life forms that can survive at depth are anaerobic bacteria that produce such toxic products as hydrogen sulfide and ammonia.[58] Some mixing of layers, which is necessary for the biological health of the reservoir, has taken place when large volumes of water have been released through the dam,[59] but stagnation does cause water quality problems in Lake Powell. Additional water quality concerns stem from concentrations of heavy metals, particularly selenium and mercury, in reservoir sediments and from petroleum products, human waste, and other types of pollution associated with heavy recreational use of the reservoir.

The Fish of Lake Powell. The fish assemblage in Lake Powell is almost exclusively non-native. Stocking of non-native species to create a sport fishery

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54. *See* DONALD B. MCDONALD & PHIL A. DOTSON, STATE OF UTAH DEPARTMENT OF FISH AND GAME, FEDERAL AID IN FISH RESTORATION: INVESTIGATIONS OF SPECIFIC PROBLEMS IN UTAH'S FISHERY 8–9 (1960).

55. *See* ROBERT H. WEBB & THEODORE S. MELIS, GLEN CANYON ENVIRONMENTAL STUDIES, OBSERVATIONS OF ENVIRONMENTAL CHANGE IN GRAND CANYON 15–18 (1994).

56. *See* U.S. BUREAU OF RECLAMATION, OPERATION OF GLEN CANYON DAM, FINAL ENVIRONMENTAL IMPACT STATEMENT 79 (1995) [hereinafter GLEN CANYON DAM FEIS].

57. *See* ROBERT G. WETZEL, LIMNOLOGY 70 (1975).

58. *See* POTTER & DRAKE, *supra* note 28, at 191.

59. *See* WILLIAM J. VERNIEU & SUSAN S. HUEFTLE, EXECUTIVE SUMMARY OF LAKE POWELL ASSESSMENT 3 (1999) (noting Grand Canyon Monitoring and Research Center observation that mixing at depth took place as a result of prolonged high releases in 1983 and 1984 that peaked at 92,000 cfs, and again after an experimental seven-day release of 45,000 cfs in 1996). For flow data, see *Colorado River Streamflow Values*, *supra* note 34.

began immediately after the flood gates were closed and continued until 1992.[60] Roughly a dozen or more non-native fish species constitute the bulk of the fish biomass in Lake Powell, the most abundant being threadfin shad, smallmouth bass, striped bass, bluegill, green sunfish, channel catfish, carp, and walleye.[61] The fish most commonly caught, smallmouth bass and striped bass, as well as channel catfish, walleye, and largemouth bass, are piscivorous (fish eaters). Few native fish remain. Occasionally flannelmouth suckers are taken in the extreme upper ends of the reservoir near the Colorado River and San Juan River inflows; razorback sucker and Colorado pikeminnow have been caught in the same areas, but very rarely.

Recent estimates, using hydroacoustic techniques, of the actual numbers and types of fishes living in Lake Powell have been completed by the Bureau of Reclamation.[62] The highest estimates indicate that as many as 276,000,000 fish are occupying reservoir habitats in the pelagic zone (below the 60-foot level).[63] Estimates for the shallower zones of the reservoir (above the 60-foot level), which are generally more productive than deeper water, likely equal the density estimated for the pelagic zone. It would not be outrageous to estimate upwards of one-half billion non-native fishes living in the waters of Lake Powell.

2. The River Below the Dam

Since the dam became operational, river flow has been characterized by significant reductions in annual and seasonal variations. During the seventeen year period of time the reservoir was filling, normal low discharge was in the 3000 cfs range, and peak flows, with few exceptions, remained below 31,500 cfs.[64] The normal hydrography of high peak spring/summer flows in excess of 90,000 cfs were not seen again until the flood of 1983.[65] Beginning in 1991 and continuing to the present, discharge has been stabilized even further. Today, due to the findings of the Glen Canyon Dam Environmental Impact Statement[66] discharge remains within the limits of 8000 to 25,000 cfs for normal operations. Sediment loads from above the dam have virtually disappeared and water releases, drawn from the reservoir's cold hypolimnion layer, hover near 48°F through winter and summer.

Primary Productivity and Food Base in the Post-Dam River. Clear water releases from the dam have resulted in greater light penetration than during the

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60. *See* GEORG L. BLOMMER & A. WAYNE GUSTAVESON, SMALLMOUTH BASS IN LAKE POWELL, 1982–1996, at 3 tbl.1 (1997). *See also* A. WAYNE GUSTAVESON ET AL., LAKE POWELL FISHERIES INVESTIGATIONS 40 tbl.14 (1990).

61. *See* Telephone Interview with A. Wayne Gustaveson, Utah Division of Wildlife Resources (Dec. 7, 1999).

62. *See, e.g.*, GORDON MUELLER & MICHAEL J. HORN, DESCRIPTION OF THE PELAGIC ZOOPLANKTON AND FISH COMMUNITIES OF LAKES POWELL AND MEAD (1999).

63. *See id.* at viii.

64. *See Colorado River Streamflow Values*, *supra* note 34.

65. *See id.*

66. GLEN CANYON DAM FEIS, *supra* note 56, at 27–28.

pre-dam flows, and primary productivity has significantly increased as a result.[67] Where algae was once virtually absent from the pre-dam river, now the green alga *Cladophora* dominates the system. In association with this alga are nutrient-rich epiphytic diatoms and dozens of species of invertebrates that constitute a greatly enhanced food base for fish. The upper seventy-five mile reach of the river, from the dam to the Little Colorado River confluence, is characterized by this very high productivity. Below the confluence, where the often sediment-laden waters of the Little Colorado River mix with the mainstem, the productivity falls off but still is much higher than during the pre-dam days.

Fish in the Post-Dam River. The change in primary productivity and the cold water flows have combined to impact profoundly the type and density of fish that currently inhabit the river. Once the river temperatures stabilized in the early 1970s, both native and non-native warmwater fishes in the mainstem suffered an overall decline, while coldwater and coolwater species, specifically rainbow and brown trout, showed a concomitant increase.[68] The success of rainbow trout was aided greatly by human intervention; immediately after completion of the dam, the Arizona Game and Fish Department began stocking trout in the dam's cold tailwaters. Today, a world-class rainbow trout fishery extends for tens of miles below the dam.

Cold mainstem temperatures allow trout to flourish, but they prevent reproduction of warmwater species. Cold temperatures also kill newly hatched warmwater fish moving out of tributaries, which, with a few significant exceptions, have become a spawning refugia for the remaining native species. This is especially true of the Little Colorado River, which joins the Colorado River about seventy-five miles below the dam and provides spawning habitat for the largest remaining breeding population of endangered humpback chub.[69] One study estimates this population at approximately 7500 adult fish.[70]

While relative abundances of fish species have changed since the early 1970s, species composition has changed little.[71] Four species of native fish (humpback chub, specked dace, flannelmouth sucker, and bluehead sucker) have maintained recruiting populations and are still common in Grand Canyon. Two other native species were present in small numbers when the dam became operational, but one, the endangered Colorado pikeminnow, was extirpated by the early 1970s, probably because of the cold water discharges and interruptions to their migratory behavior. The other, the endangered razorback sucker, is virtually

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67. See Lawrence E. Stevens et al., *Colorado River Benthic Ecology in Grand Canyon, Arizona, USA: Dam, Tributary, and Geomorphological Influences*, 13 REGULATED RIVERS: RESEARCH & MGMT. 129–49 (1997).

68. *See* CAROTHERS & BROWN, *supra* note 2, at 82–99.

69. *See* Lynn R. Kaeding & Marian A. Zimmerman, *Life History and Ecology of the Humpback Chub in the Little Colorado and Colorado Rivers of the Grand Canyon*, 112 TRANSACTIONS OF THE AM. FISHERIES SOC'Y 577, 577–94 (1983).

70. *See* VALDEZ & CAROTHERS, *supra* note 3, at 57.

71. *Id.* at 48–52.

gone from Grand Canyon but persists, albeit in low numbers, downstream in Lake Mead, where researchers have found evidence of minimal recruitment.[72]

Interestingly, the ratio of native to non-native fishes in the Grand Canyon below the Glen Canyon Dam is significantly higher (about twenty percent natives) than in the reaches of the Colorado, Green, and San Juan Rivers above Lake Powell (about ten percent natives). Below Lake Mead, the natives are almost completely extirpated, constituting less than one percent of the fish assemblage.[73] Throughout the Colorado River system, both above and below Grand Canyon, the decline in the native fishery first documented nearly forty years ago continues unabated, and this despite millions of dollars of mitigation monies pumped into research and reintroduction efforts.[74] The relatively high percentage of native fishes consistently found in Grand Canyon since the early 1970s may be related to the increased primary productivity and overall food base,[75] but it may also be related to the cold water flows that suppressed populations of warmwater non-native fishes, notably channel catfish, which prey on other fish, and carp, which eat fish eggs and compete with native species for habitat. In short, the cold water may have prevented non-native warmwater fishes from gaining the upper hand in the mainstem, forming a sort of barrier of relatively inhospitable habitat that precluded the proliferation of warmwater lake species.

B. Terrestrial Components

1. Above the Dam

Before Glen Canyon Dam was built, the free-flowing Colorado River reaches through Glen and Grand Canyons and the San Juan River all were similar in terms of extreme variations in discharge and heavy sediment loads. Geomorphological differences existed, however, and these differences were reflected in the resulting vegetation patterns.

Before inundation, Glen Canyon was characterized by a less constricted river channel than Grand Canyon, a relatively low gradient (two feet per mile[76]

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72. *See* Wendell L. Minckley et al., *Management Toward Recovery of the Razorback Sucker*, *in* BATTLE AGAINST EXTINCTION, *supra* note 13, at 303, 311.

73. William C. Leibfried, Presentation at Restoring Native Fish to the Lower Colorado River: Interaction of Native and Non-Native Fishes, A Symposium & Workshop (July 13–14, 1999) (discussing future implications of historical native/non-native fish interactions in the Grand Canyon).

74. For example, the Upper Basin Recovery Implementation Program alone spent over $59 million between 1988 and 1999. *See* John Shields, *Upper Colorado River Endangered Fish Recovery Program*, *in* CLE INTERNATIONAL, LAW OF THE COLORADO RIVER H-1, H-10 (1999) [hereinafter CLE SYMPOSIUM] (reporting proceedings of a symposium sponsored by CLE International in Tucson, Arizona, May 20–21, 1999).

75. *See* VALDEZ & CAROTHERS, *supra* note 3, at 35–44.

76. *See* Woodbury, *supra* note 53, at 155.

compared to eight feet per mile in Grand Canyon[77]), and far fewer and less severe rapids. These differences, mostly attributable to softer rock formations in the Glen Canyon reach, resulted in more channel margin deposits and multilevel river terraces, which, in turn, supported more abundant riparian habitats than those found in Grand Canyon or along the San Juan River. The dominant parent rock in Glen Canyon, Navajo Sandstone, generated vast amounts of sand that, in many places, buttressed cliff faces in massive, fan-shaped dunes. Erosion continually swept sand into the river and its tributaries. Sand formed broad deltas at tributary mouths and accumulated inside curves along the river's serpentine course.

In Glen Canyon, an often continuous narrow belt of tall shrubs and small trees lined the riverbank in dense masses.[78] Belt width usually varied from ten to sixty feet but could balloon to as much as 600 feet at tributary mouths. Major species included sandbar willow, baccharis, and arrowweed, all native species, and tamarisk, an invasive, exotic species. Larger trees included occasional hackberrys, Gambel oaks, and, less frequently, Fremont cottonwoods. Spring flood waters would inundate the lower reaches of these riparian belts, saturating soils, but a swath of vegetation generally survived. Terraces above the flood water level supported a second belt of vegetation that was dominated by more xeric (drought-tolerant), long-rooted shrubs and a few trees, while even higher, talus slopes and plateau landforms supported low desertscrub.

In larger side canyons with intermittent or perennial water, widely spaced cottonwood trees, sometimes in small groves, joined willow, baccharis, and tamarisk along stream courses. Small, shady, wet canyons provided habitat for these species as well as boxelder, chokecherry, redbud, and single-leaf ash.[79] Throughout Glen Canyon, in both the mainstem and tributary canyons, seeps and springs sustained small, lush growths of maidenhair fern, columbine, monkey flower, grasses, and mosses.[80]

The relatively abundant riparian vegetation in Glen Canyon either directly or indirectly provided sustenance for most terrestrial animals along the canyon corridor. It supported a rich avifauna; pre-dam studies documented the presence of 96 species, but as many as 197 species are likely to have used the canyon's varied habitat.[81] Several species of small mammals depended on riparian habitat for their existence, although annual spring floods were a destabilizing

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77. *See* Susan W. Kieffer, *Hydraulics and Geomorphology of the Colorado River in the Grand Canyon, in* GRAND CANYON GEOLOGY 333, 334 (Stanley S. Beus & Michael Morales eds., 1990).

78. *See* Seville Flowers, *Vegetation of Glen Canyon, in* GLEN CANYON ECOLOGICAL STUDIES, *supra* note 53, at 21, 31–37.

79. *See id.* at 44–50.

80. *See id.* at 59–61.

81. *See* William H. Behle & Harold G. Higgins, *The Birds of Glen Canyon, in* GLEN CANYON ECOLOGICAL STUDIES, *supra* note 53, at 107, 110.

influence and probably limited their distribution and abundance.[82] Beavers occupied the banks of Colorado River and perennial tributaries, using riparian vegetation (primarily willow) for food and to construct their dens.[83]

Rising waters behind the dam inundated all riparian vegetation in the main and side canyons up to the reservoir surface level. Now, for the most part, reservoir waters abut barren rock or desert shore. When the reservoir is drawn down,[84] wet sandy areas are quickly colonized by two exotic species: tamarisk and Russian thistle.[85] Native grasses and forbs (such as sand verbena, evening primrose, and sacred datura) take root as well, only to be drowned when the reservoir level comes back up. The terrestrial animal species that once depended on riparian habitat for shelter and food have been either extirpated or radically reduced in number. Conversely, water fowl have increased both in species diversity and abundance, and they, in turn, provide a plentiful prey base for resident peregrine falcons. Bald eagles, which rely heavily on fish in their diet, also benefit from the reservoir's presence.

2. Below the Dam

Pre-dam vegetation in Grand Canyon differed in that the scouring action of late spring floods kept the willow/baccharis/tamarisk assemblage from becoming established along the river's edge. Water level fluctuations between low winter flows and high spring/summer flows resulted in river level fluctuations of as much as thirty feet.[86] This scour zone, which was occupied primarily by non-woody ephemeral grasses and low growing herbaceous vegetation,[87] most likely was utilized by a few small mammals, reptiles and amphibians, and invertebrates, but without trees, it could not have supported much of a bird population. Upslope of the scour zone (above the 100,000 cfs waterline) was a narrow band of vegetation, often referred to as the old high water line, where acacia, mesquite, redbud, hackberry, and Apache plume were found.[88] Upslope of this band, on steep talus grades, vegetation was, and continues to be, desert scrub.

Once Glen Canyon Dam began to regulate flow, and huge spring floods no longer scoured the bankline, a new high-water-line of riparian plants took hold.

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82. *See* Stephen D. Durrant & Nowlan K. Dean, *Mammals of Glen Canyon*, *in* GLEN CANYON ECOLOGICAL STUDIES, *supra* note 53, at 73, 100–01.

83. *See id.* at 87–88.

84. Typically, to accommodate spring runoff the reservoir is drawn down beginning in July or August of the preceding year and continuing until February or March. Spring inflow then raises the water surface level to reach a maximum in June or July. The pattern is then repeated, creating a drawdown zone at the reservoir's edge. *See* GLEN CANYON DAM FEIS, *supra* note 56, at 83.

85. *See* POTTER & DRAKE, *supra* note 28, at 163.

86. *See* CAROTHERS & BROWN, *supra* note 2, at 117.

87. *See* Elzada U. Clover & Lois Jotter, *Floristic Studies in the Canyon of the Colorado and Tributaries*, 32 AM. MIDLAND NATURALIST 591, 600–16 (1944).

88. *See* CAROTHERS & BROWN, *supra* note 2, at 119.

Now, downslope from the old high-water-line growth (which is dying out), a thin belt of vegetation dominated by tamarisk, willow, baccharis, and arrowweed lines the river's edge, and dense stands of these riparian species crowd the larger sandbars. Some marsh habitat has developed in eddy-return channels (backwaters). This new growth provides much more habitat for small mammals, reptiles and amphibians, and invertebrates than existed in Grand Canyon before the dam. At least twenty-five species of birds have either expanded their range into the new habitat or increased in abundance.[89] A vastly increased biomass of flying insects emanating from the new vegetation and the newly productive river support a burgeoning population of violet-green swallows and white-throated swifts.[90] More swallows and swifts, in turn, provide abundant food for a growing population of peregrine falcons. The bald eagle has benefited from the dam's downstream influence as well. Colder river water allows rainbow trout to survive and reproduce in tributaries, and large spawning runs into these tributaries provide nourishment each winter for migrating bald eagles.[91] One last apparent beneficiary of regulated flows is the endangered Kanab ambersnail, which lives in a spring-fed habitat at Vasey's Paradise, about forty-seven miles downstream from Glen Canyon Dam. This population of the snail would be inundated and probably washed away by the high flows of pre-dam days. How it survived then is unknown—perhaps it became established at Vasey's Paradise after dam construction.

V. ECOLOGICAL CONSEQUENCES OF DECOMMISSIONING GLEN CANYON DAM

It is a well-recognized tenet of riparian ecology that long-term sustainability of the natural ecosystem is dependent upon protecting or restoring a natural hydrograph, where seasonal low and high discharges are a functional necessity.[92] The primary question we pursue here, however, is whether the Glen Canyon Institute's proposal to drain Lake Powell and bypass the dam would accomplish its objective of restoring natural ecosystems and preserving endangered fish species.[93] Our tentative conclusion is mixed. Given enough time, aquatic and terrestrial habitats above and below the dam would likely be restored to a semblance of pre-dam conditions, but we have to ask a second question—is the pre-dam condition the desired condition? From the standpoint of the native fishery, the answer is probably "no," because these fish were in significant decline long before Glen Canyon Dam became a reality, and in a perverse way, the dam may have helped the native fish even as it degraded their habitat. But the benefits

89. *See id.* at 150, 165–67.

90. *See id.* at 152.

91. *See id.* at 146–48.

92. *See* N. LeRoy Poff et al., *The Natural Flow Regime: A Paradigm for River Conservation and Restoration*, 47 BIOSCIENCE 769, 769–81 (1997).

93. *See Glen Canyon Institute* (visited Mar. 26, 2000) <http://www.glencanyon.org>.

and risks of returning the river to its pre-dam condition over the long-term may be moot for the endangered humpback chub and other native fish in Grand Canyon; the act of draining Lake Powell could wipe them out long before any natural hydrograph is restored. Consequences for endangered birds would likely be a trade-off, with some advantages gained, others lost. We present these conclusions with the caveat that they are somewhat conjectural.

A. Aquatic Ecosystem

1. Above the Dam

If Lake Powell were drained, reducing water volume could lead to water quality problems with increasing concentrations of contaminants. High dam releases, however, could reduce problems associated with saline and anaerobic conditions at depth. At low reservoir volumes, summer water temperatures would significantly increase. Fishes in the reservoir would suffer from a degrading habitat and increased competition over diminishing resources (less habitat and reduced food base), which could result in significant die offs.

Over the long term,, through-flowing Colorado and San Juan Rivers would return to near pre-dam conditions, but with even heavier sediment loads as lake deposits worked their way into the system. Primary and secondary productivity and fish populations eventually would stabilize at low levels as the lake species died out. Because of the abundance of non-native fish in the reservoir and the near absence of native species, the relative proportion of non-native fish species to natives almost certainly would be higher than before the dam, with catfish and carp once again predominating. Barring human intervention, native species would have to recolonize from upstream into niches probably already filled by non-natives.

2. Below the Dam

Initially, releases would remain cold, but would warm as the reservoir level dropped and water was drawn from nearer the surface. At some point, the location of withdrawal would have to shift to the bottom of the reservoir and release temperatures would abruptly decrease, only to gradually warm again. For most of the depletion period, releases would remain sediment-free, but toward the end suspended sediments would appear. Poor water quality could become an issue for downstream aquatic organisms. The major consequence of the depletion period, however, would be an enormous infusion of non-native, largely piscivorous fish and other non-native organisms (like crayfish) into the Colorado River below the dam. The potential impact of that infusion on Grand Canyon's fish assemblage would be difficult to exaggerate.

Over the long term, physical properties of the through-flowing river in Grand Canyon would closely resemble those of the pre-dam river: highly variable flow, highly variable temperatures, and high sediment loads (probably significantly higher than pre-dam levels as lake deposits moved downstream). As a result, the post-dam food base would virtually collapse, with a substantial reduction in primary and secondary productivity. The trophy trout fishery in the tailwaters would vanish. Warmwater fish species would predominate over remnant populations of cool and cold water species. Glen Canyon Dam no longer would be a barrier to the downstream passage of migrating fish like Colorado pikeminnow, but high-velocity flow through the diversion tunnels may preclude upstream passage.

B. Terrestrial Ecosystem

1. Above the Dam

Draining Lake Powell would have monumental consequences for Glen Canyon and its tributaries. As reservoir levels drop, massive sediment deposits would be exposed. In 1986, the total volume of sediment accumulation in the reservoir was calculated to at 868,231 af.[94] At an annual accumulation rate of nearly 37,000 af, that sediment volume is now approaching 1.4 maf.[95] The thickness of sediment deposits in 1986 averaged 127 feet in the upper end of the Colorado River arm of the reservoir and 56 feet in the San Juan arm.[96] Erosion would begin immediately as the Colorado and San Juan Rivers, their tributaries, and overland runoff from rainstorms washed sediment into the shrinking reservoir. Some terraces would endure, however, as have Pleistocene-aged terraces at several places along the Colorado River,[97] which would permanently change the topography of Glen Canyon.

Plants would begin to colonize the exposed deposits immediately, partially stabilizing them and retarding erosion. Experience with plant succession in moist habitats throughout the Southwest, most notably in the fluctuation zone of Lake Powell,[98] indicate that non-native species with relatively low wildlife value would dominate the new habitat. Tamarisk in particular is likely to grow in dense stands wherever its roots can reach water. Eventually, through plant succession, native plant species would take hold. Over the long-term, several thousand acres of riparian habitat would line the restored river. This growth would provide vastly more habitat for riparian birds and other terrestrial life forms that inhabit the area now. With the loss of Lake Powell, however, waterfowl populations would be greatly reduced. Habitats and species associated with seeps and springs would thrive as the massive quantities of water stored in Glen Canyon's walls flowed to the surface.

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94. *See* FERRARI, *supra* note 23, at 6.
95. *See id.*
96. *See id.* at 29.
97. *See* W. Kenneth Hamblin, *Late Cenozoic Lava Dams in the Western Grand Canyon*, *in* GRAND CANYON GEOLOGY, *supra* note 77, at 385, 395, 405, 415.
98. *See* POTTER & DRAKE, *supra* note 28, at 163.

One of the ecological concerns that would accompany the draining of Lake Powell is the possibility of heavy metal, hydrocarbon, and even radioactive contaminants in exposed sediments. The magnitude of the problem is unknown and, given the complete lack of data, cannot be predicted.

2. Below the Dam

Downstream of the dam, the ten to fifteen year period that has been suggested for depleting Lake Powell would see high (in excess of 20,000 cfs on the average) and probably steady flows. This would be a period of accelerated erosion of existing riverbed deposits and sandbars (beaches), which provide substrate for riparian vegetation and campsites for river runners. Once the natural hydrograph returns, high spring flows would be accompanied by the loss of the naturalized[99] (new high water line) vegetative community that now occupies the pre-dam scour zone. This would be offset to a degree by the reinvigoration of the less productive old high-water-line community that has been perched high and dry since the pre-dam floods were curtailed. Loss of riparian vegetation would entail a concomitant decrease in the numbers of organisms that depend on that habitat.

C. Endangered Species' Responses to the "Restored" River

While it is speculative at best to predict species' responses to draining Lake Powell, especially since nothing of this magnitude has ever been attempted, we can draw some conclusions regarding the most likely outcome. We look first at the legislatively protected aquatic species, then at the terrestrial.

1. Aquatic Species

Draining Lake Powell could be the death knell for the most significant remaining recruiting population of humpback chub in existence. While six population segments of the species still exist throughout its range in Colorado, Utah, and Arizona, the Grand Canyon group (estimated at fewer than 10,000 individuals) is by far the most secure and numerous.[100] Draining Lake Powell would entrain the non-native fishery of the reservoir into the river below. During certain stages of reservoir depletion, upwards of 250,000 non-native fishes could

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99. Use of the term "naturalized" here follows the use in CAROTHERS & BROWN, *supra* note 2, at 188, meaning a mixture of native and non-native plants in apparent equilibrium.

100. *See* U.S. FISH & WILDLIFE SERVICE, HUMPBACK CHUB RECOVERY PLAN 3–8 (2d revised ed., 1990) (discussing basinwide distribution of this species); RICHARD A. VALDEZ & RONALD J. RYEL, LIFE HISTORY AND ECOLOGY OF THE HUMPBACK CHUB (*GILA CYPHA*) IN THE COLORADO RIVER, GRAND CANYON, ARIZONA: FINAL REPORT TO THE BUREAU OF RECLAMATION, at 6-24 to 6-30 (1995) (providing estimates of the Grand Canyon population). *See also generally* Michael E. Douglas & Paul C. Marsh, *Population Estimates/Population Movements of* Gila Cypha, *an Endangered Cyprinid Fish in the Grand Canyon Region of Arizona*, 1996 COPEIA 15.

enter Grand Canyon from the reservoir each week.[101] Such an onslaught would overwhelm downstream habitats and organisms, including humpback chub and the resources essential for its survival.

The three other Colorado River fishes protected with endangered status, razorback sucker, Colorado pikeminnow, and bonytail, would not be directly affected by draining the reservoir. All three species have been extirpated or nearly extirpated from the Grand Canyon and probably never were common there anyway.[102] They may have been common once in the river above the dam, but evidence is lacking. Currently, the numbers of razorback sucker and Colorado pikeminnow in the Colorado and San Juan Rivers above Lake Powell are small, and the bonytail is virtually nonexistent.[103] With the restoration of a free-flowing river, habitats that once supported these species might be re-created in Glen and even Grand Canyon, but reestablishment of these species would necessitate intensive stocking efforts—and, because of the presence of non-native competitors and predators, all restocking efforts of these species attempted to date have met with failure.[104]

2. Terrestrial Species

The bald eagle and American peregrine falcon, two protected species that have increased dramatically in regional density at least in part as a result of Glen Canyon Dam,[105] would suffer a reduction in habitat and prey base should the reservoir be drained. Bald eagles no longer would be able to feed on fish in Lake Powell, and far fewer spawning trout would be available in Grand Canyon. Reductions of water fowl in Glen Canyon and possibly swifts and swallows in Grand Canyon likely would affect peregrine falcons. While draining Lake Powell could reduce numbers of bald eagles and peregrine falcons locally, neither species as a whole would be affected. Both of these species have rebounded from threatened extinction in the last thirty to forty years, primarily as a result of pesticide control; the peregrine falcon has been removed from the federal endangered species list but is protected under other statutes,[106] and the bald eagle

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101. *See* MUELLER & HORN, *supra* note 62, at 57.

102. *See* VALDEZ & CAROTHERS, *supra* note 3, at 62.

103. With only a few debated exceptions, bonytails are known today only from remnant populations in the reservoirs below Hoover Dam. *See* Determination That the Bonytail Chub (Gila elegans) Is an Endangered Species, Final Rule, 45 Fed. Reg. 27,710 (April 23, 1980) (codified at 50 C.F.R. §17.11 (1999)).

104. *See* Harold M. Tyus, *Ecology and Management of Colorado Squawfish*, *in* BATTLE AGAINST EXTINCTION, *supra* note 13, at 379, 379–402.

105. *See* CAROTHERS & BROWN, *supra* note 2, at 146–48, 165–67.

106. Although the peregrine falcon officially was delisted, *see* Final Rule to Remove the American Peregrine Falcon from the Federal List of Endangered and Threatened Wildlife, and to Remove the Similarity of Appearance Provision for Free-Flying Peregrines in the Conterminous United States, 64 Fed. Reg. 46,542, 46,542–58 (August 25, 1999) (amending 50 C.F.R. §§ 17.11(h), 17.95(b)), the species is still protected

has been downlisted from endangered to threatened and has been proposed for delisting altogether.[107]

The southwestern willow flycatcher, once a common summer resident along the river in Glen Canyon[108] but now experiencing continual declines in numbers throughout its range, may reoccupy Glen Canyon restored habitats once riparian vegetation becomes established. Its reoccupation and success in the area would be contingent upon the existence of a source population to support the recolonization, the appropriate habitat developing, and low levels of cowbird parasitism.[109] The existing population of willow flycatchers in the Grand Canyon (above Diamond Creek) has declined from a high of eleven in 1986 to a single pair in 1999.[110] As much suitable but unoccupied habitat exists throughout the flycatcher range, it is doubtful that the addition of new habitat in Glen Canyon would have much effect on the species in general.

The Kanab ambersnail population at Vasey's Paradise in Grand Canyon likely would be extirpated from that location should natural high spring flows be restored.

VI. LIVING WITH DAMS

We enthusiastically support the concept of river restoration throughout the Upper and Lower Basins of the Colorado River. However, even if the substantial, but limited, financial resources currently available for endangered species management and river restoration were to be increased greatly, draining Lake Powell would not be an economically or ecologically sound priority. Draining Lake Powell, with all its attendant economic, political, and recreational costs, without first addressing the crushing problem of non-native competitors/ predators, would be folly. It is folly, too, to allow the growing furor over the proposal to decommission Glen Canyon Dam to serve as a rallying point for political opposition to conservation efforts in general and to divert attention and resources away from real progress being made on the frontier of river restoration.

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under the Migratory Bird Treaty Act of 1916, 16 U.S.C. §§ 703–715s (1994 & Supp. IV 1998), and is managed as a species of special concern by many federal agencies.

107. *See* Final Rule to Reclassify the Bald Eagle from Endangered to Threatened in All of the Lower 48 States, 60 Fed. Reg. 36,000, 36,000–10 (July 12, 1995) (amending 50 C.F.R. § 17.11(h) (1999)); Proposed Rule to Remove the Bald Eagle in the Lower 48 States from the List of Endangered and Threatened Wildlife, 64 Fed. Reg. 36,454, 36,454–64 (July 6, 1999).

108. *See* Behle & Higgins, *supra* note 81, at 107–33.

109. *See* U.S. Bureau of Reclamation, *Long Term Restoration Program for the Historical Southwestern Willow Flycatcher (*Empidonax trailli extimus*) Habitat Along the Lower Colorado River* (visited Apr. 11, 2000) <www.lc.usbr.gov/~g2000/rpa11.html> [hereinafter BOR Restoration Program].

110. *See* C.E. PARADZICK ET AL., ARIZONA GAME AND FISH DEPARTMENT, DRAFT SOUTHWESTERN WILLOW FLYCATCHER 1999 SURVEY AND NEST MONITORING REPORT 66 (2000).

At present, major efforts are being directed toward effecting river restoration in both basins. If our society truly believes that preservation of unique genomes and native riparian systems is a component of the human species' own survival, then we should focus now on the need to control non-native organisms and to implement realistic proposals to reestablish riparian systems.

A. Invasive Species: The Key to Native Fish Restoration

One of the unintended and certainly serendipitous consequences of Glen Canyon Dam appears to have been a delay in the overwhelming and irreversible dominance of non-native fishes in Grand Canyon. Throughout the Upper and Lower Basins, non-native fishes are slowly gaining the upper hand. Unless something is done within the next several decades to reverse the trend, the native fish species of the region may be driven to extinction, to be represented only as curiosities in zoos and aquaria. Taking down dams will not remove this threat. Eliminating Glen Canyon Dam and returning the system to its "natural" hydrograph may, in fact, accelerate the loss of native species, and should not be seriously considered until the means are in place to drastically reduce the masses of non-native species in reservoirs upstream and downstream of Grand Canyon.

In our opinion, initiation of a basinwide long-term conservation strategy for dealing with non-native fishes, including the effect of sport fishing on endangered and other native species, is of the highest priority. The negative influence of non-native fish on endangered species recovery is common knowledge among the fisheries biologists of the world, but even to think about developing a program of non-native fish control and dedicating a section of river exclusively to native fish has, until recently, been considered heresy in fishery management circles.[111] This attitude is rooted in (1) the popularity of sport fishing, which in the Colorado River Basin is almost exclusively focused on non-native species; (2) the reliance of state wildlife agencies on support from anglers and angling fees; (3) the technical difficulties associated with suppressing or eradicating unwanted aquatic species; and (4) a lingering sense among anglers and some agency personnel that native species are "trash" fish. The concept of removing or controlling non-native fishes is so huge, so complicated, and so overwhelming to most fisheries biologists that research into its efficacy barely has

111. This attitude is reflected in negotiations among agencies regarding the ongoing development of a multi-species conservation plan ("MSCP") for the Lower Colorado River. The Arizona Game and Fish Department, the California Fish and Game Department, and the Nevada Division of Wildlife strongly expressed the view that the economic and social values associated with recreation and sport fishing, and agencies' responsibilities for these resources, mandated that the MSCP incorporate these values into the plan alongside those associated with conservation of endangered species and water and power resource management, and that the Steering Committee agree to adopt a policy of no net loss in recreational opportunities through implementation of the MSCP. Telephone Interview with Martin Meisler, Metropolitan Water District of Southern California (Jan. 20, 2000).

begun. Today we know that channel catfish and carp are two of the most damaging species to natives, but basic research into finding these species' "Achilles heels" has not even been conceptualized. Attitudes are beginning to change, however. The key may be to shift interest in sport fishing in the Colorado River Basin away from non-native to native species. Some anglers have already expressed interest in developing the native fishery as a sport fishery, promoting the idea that such species as Colorado pikeminnow, if recovered, would make excellent game fish.

B. Riparian Habitat Restoration: Alternatives to Dam Removal

While eliminating dams is one way to restore riverine habitats, that approach is not always feasible or practical. For example, a promising program, the Lower Colorado River Multi-Species Conservation Plan ("MSCP"),[112] is now in the development stages. This effort is being driven by the needs of endangered species recovery and the understanding that riparian habitats of the southwestern streams and rivers support wildlife species in disproportionally diverse ways.[113] Few North American habitats rival the cottonwood gallery forests and mesquite bosques of the Southwest in density and diversity of wildlife. Few habitats have been destroyed by the actions of human development more than riparian ecosystems. Then again, few habitats are as easy to reconstruct as the riparian. Ongoing efforts of federal and state wildlife and water management agencies are demonstrating that opportunities exist to recreate riparian vegetation,[114] without recreating natural hydrography through dam removal. These opportunities focus on replacing agricultural crops with native riparian vegetation. While most of the Lower Colorado Basin river margins are no longer suitable substrates for revegetation (due to downcutting of the river, saline soils, riprapped banks), the old alluvial terraces that now support the majority of river valley agriculture remain suitable for habitat restoration. Current efforts of the Lower Colorado River MSCP are targeting thousands of acres of agriculture for riparian restoration.

C. Decommissioning Dams Within the Basin: A Place to Start

This is not to say that the long-term restoration of riparian ecosystems does not demand some kind of return to the cycles of flooding and drying, with all of the cycle's attendant infusions of nutrients. Recognizing that the restoration of riverine ecosystems through dam removal is a beneficial ecological practice when feasible, we offer the suggestion that two dams, one on each end of the Colorado River drainage basin, Fontenelle Dam on the Green River and Laguna Dam on the

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112. *See* Christopher S. Harris, *The Multi-Species Conservation Plan in the Lower Colorado*, *in* CLE SYMPOSIUM, *supra* note 74, at I-1, I-7.

113. *See generally* U.S. FOREST SERVICE, IMPORTANCE, PRESERVATION AND MANAGEMENT OF RIPARIAN HABITAT: A SYMPOSIUM (1977).

114. *See, e.g.*, BOR Restoration Program, *supra* note 109.

Colorado River, are more reasonable candidates for decommissioning than Glen Canyon Dam.

Removal of the 139-foot-high, 40-year-old Fontenelle Dam would immediately reduce a sink of non-native fish species and reopen habitats for the endangered humpback chub. Fontenelle, high in the forested headwaters of the Green River drainage, does not have a large accumulation of sediment, and the area would return, both from an aquatic and terrestrial perspective, to what it once was. Laguna Dam on the Lower Colorado River largely has filled with sediment. Removing this dam and returning the river here to a more free-flowing character would provide an invaluable and relatively low-cost (compared to eliminating Glen Canyon Dam) research opportunity to explore the effects of dam decommissioning. Removing this dam would also be a first step in allowing future discharges into the Colorado River delta where many species, some endangered, many not, would benefit from the return of a free-flowing Colorado River.