Flows for Floodplain Forests: A Successful Riparian Restoration

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Throughout the 20th century, the Truckee River that flows from Lake Tahoe into the Nevada desert was progressively dammed and dewatered, which led to the collapse of its aquatic and riparian ecosystems. The federal designation of the endemic cui-ui sucker (Chasmistes cujus) *as endangered prompted a restoration program in the 1980s aimed at increasing spring flows to permit fish spawning. These flows did promote cui-ui reproduction, as well as an unanticipated benefit, the extensive seedling recruitment of Fremont cottonwood* (Populus fremontii) *and sandbar willow* (Salix exigua). *Recruitment was scattered in 1983 but extensive in 1987, when the hydrograph satisfied the riparian recruitment box model that had been developed for other rivers. That model was subsequently applied to develop flow prescriptions that were implemented from 1995 through 2000 and enabled further seedling establishment. The woodland recovery produced broad ecosystem benefits, as evidenced by the return by 1998 of 10 of 19 riparian bird species whose populations had been locally extirpated or had declined severely between 1868 and 1980. The dramatic partial recovery along this severely degraded desert river offers promise that the use of instream flow regulation can promote ecosystem restoration along other dammed rivers worldwide.*

Keywords: birds, cottonwoods, ecosystem restoration, river regulation

Throughout the world, rivers support particularly rich natural environments and provide centers for human activities. In addition to supporting fish and aquatic ecosystems, rivers sustain vegetation in riparian or floodplain ecosystems (Naiman and Décamps 1997). Riparian woodlands typically include abundant phreatophytic (water table–dependent) trees and shrubs, especially cottonwoods *(Populus* spp.) and willows *(Salix* spp.) along rivers throughout the Northern Hemisphere (Johnson 1994, Patten 1998). Particularly in arid and semiarid regions, these riparian woodlands provide biological oases and often support great richness and diversity of wildlife (Finch and Ruggiero 1993). The aquatic and riparian ecosystems are interacting components of the riverine landscape shaped by and dependent on the flowing river. However, rivers also provide water and energy resources, and consequently rivers around the world have been extensively dammed and diverted for agricultural irrigation, hydroelectric power generation, domestic and industrial water use, flood control, and other purposes (Dynesius and Nilsson 1994).

Following river damming and diversion, downstream aquatic and riparian ecosystems have collapsed along many streams (Nilsson and Berggren 2000). About three-quarters of the riparian woodlands in the southwestern United States have been lost during the past two centuries, with substantial losses resulting directly and indirectly from damming, dewatering, and the imposition of artificial patterns of instream flows (Johnson and Haight 1984). Aquatic ecosystems have also been degraded, and many fish and other aquatic organisms are now threatened or endangered, particularly because of river development projects and artificial patterns of flow regulation (Fausch et al. 2002). The complex interactions of physical and biological processes in riverine ecosystems can complicate restoration efforts.

Many stream restoration efforts have targeted the reconstruction of small reaches through artificial measures such as boulder placement, vegetation planting, and fish stocking (Malanson 1993, Alpert et al. 1999). These restoration

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strategies are very costly, may require perpetual effort, and often fail. An alternate approach is to restore more naturalized instream flow patterns to allow recovery through natural recruitment and growth processes (Molles et al. 1998, Richter and Richter 2000, Rood and Mahoney 2000). This systemic approach (Hughes and Rood 2001) has the potential to provide effective and widespread benefits, and consequently a number of conservation ecologists have concluded that the recovery of more natural flow patterns could provide an effective riverine restoration strategy (Stanford et al. 1996, Goodwin et al. 1997, Poff et al. 1997). Consistent with this view, we describe a promising multiple-year river restoration project involving instream flow management directed toward environmental restoration. This case study demonstrates that an endangered species restoration effort directed toward the recovery of the dominant underlying physical process in a river ecosystem can produce broad ecosystem benefits.

The Truckee River

The Truckee River in western Nevada has been severely altered over the past century (Strong 1984, Wheeler 1987, USACE 1995). The Truckee presents the types of impacts and management complexities that are relatively common for rivers worldwide, but the lower Truckee occurs in one of the driest regions of North America, with precipitation in the growing season (April to October) averaging only 7.3 centimeters (cm). Consequently, its water faces particular demand. Given the historical and contemporary challenges to the Truckee River, its partial restoration should provide optimism about many other rivers worldwide.

The Truckee River originates from snowmelt and rainfall in the Sierra Nevada, flowing into the exceptionally clear, deep, and scenic Lake Tahoe (figure 1). From Lake Tahoe, the Truckee River flows north and then east through Reno, Nevada (regional population 350,000). Finally, the lower Truckee River meanders to the north, across a floodplain valley cut into the bed of ancient Lake Lahontan, to the river's terminus in Pyramid Lake, from which evaporation provides an atmospheric outflow.

The Truckee River was first dammed in 1870 at Lake Tahoe (Strong 1984). Eight other dams have subsequently been constructed on the river and its tributaries. The greatest impact to the lower river ecosystem has been caused by Derby Dam, completed in 1905 as part of the first US Bureau of Reclamation project. Derby Dam diverts water for irrigation; about one-half of the annual flow of the Truckee was typically diverted in the early to mid-1900s (USACE 1995). The dam creates only a small reservoir with limited trapping of mineral sediments, and mobile sands and gravels remain abundant along the lower Truckee River.

The reduced river flows caused by damming have degraded aquatic conditions and disturbed the water balance of Pyramid Lake, which dropped by about 25 meters (m) in surface elevation by 1970 (Wheeler 1987, USACE 1995). The lowered water level exposed a large delta over which the river flowed in shallow, distributary channels that impeded fish passage. Upstream of this delta, the river eroded into the alluvial deposits and created a head-wall cut, an incised trench that migrated upstream (USACE 1995). The river reach was also channelized for flood control in the early 1960s. Stream flow patterns were further altered by mining and logging in the watershed and by partial drainage of Truckee Meadows, near Reno, through explosive excavation of bedrock sills.

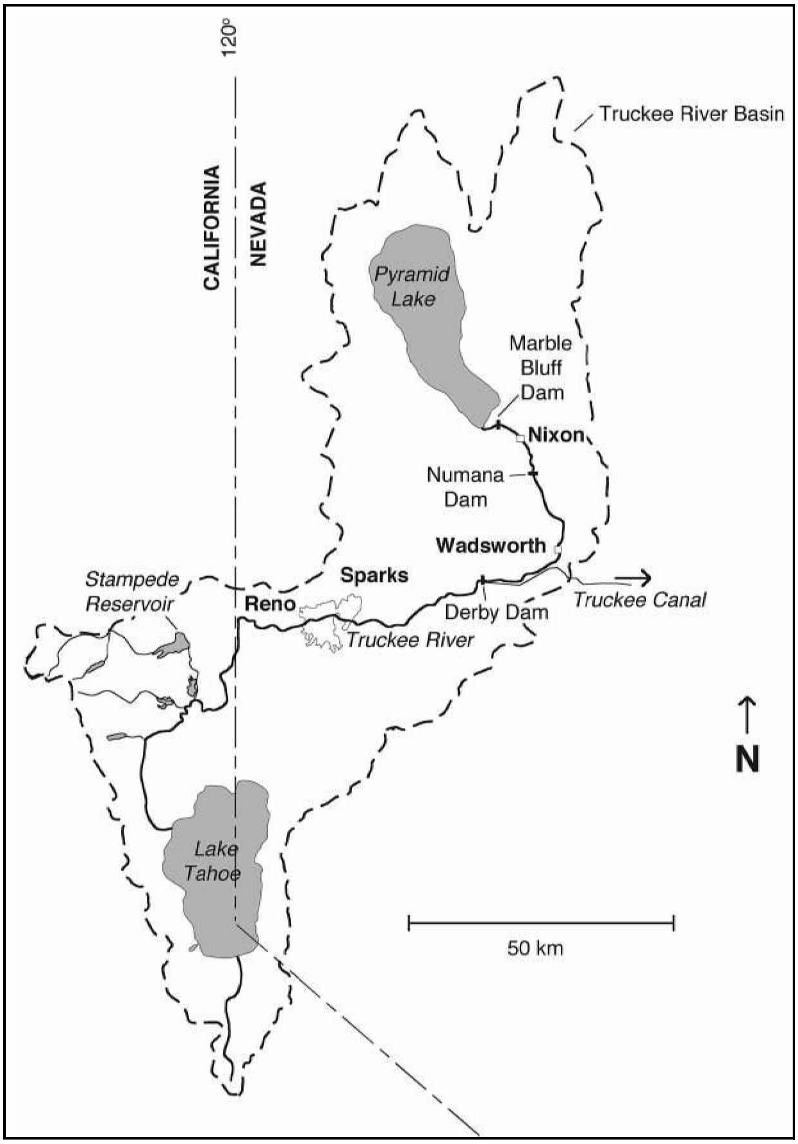

Figure 1. Map showing the Truckee River Basin, with the Truckee River flowing from Lake Tahoe to terminal Pyramid Lake. Major dams are indicated, and city or town names are in bold print.

Ecosystem collapse

The reduced river flows and the alterations to the river channel degraded the aquatic and riparian ecosystems. There were two prominent conservation concerns: fish and forests.

Failing fisheries. The lower Truckee River was once a prolific trout stream, but dewatering led to the extinction of the Pyramid Lake subspecies of Lahontan cutthroat trout *(Oncorhynchus clarki henshawi)* by the early 1940s (Wheeler 1987, USACE 1995). The river also supported the endemic cui-ui sucker, *Chasmistes cujus,* an obligate lake fish that spawned exclusively in the lower Truckee River. The lower Truckee is the only perennial stream flowing into Pyramid Lake (Scoppettone and Rissler 1995), and the cui-ui were once the staple food of the Paiute people in the region that became the Pyramid Lake Indian Reservation in 1874.

The cui-ui avoided extinction during the 1900s only through its longevity. Individual cui-ui survive for about a half-century, and the fish persisted through decades with minimal reproduction (Scoppettone et al. 2000). However, the cui-ui population plummeted, and the fish was designated as endangered in 1967.

Cottonwood decline. A lush riparian landscape along the lower Truckee River was described in 1844 by explorer John Fremont, for whom the local cottonwood, *Populus fremontii,* is named. Dense willows and extensive cottonwood groves were similarly described by biologist Robert Ridgway (1877). Insufficient instream flows degraded the riparian ecosystem, which is dependent on stream water for water table recharge and vegetation recruitment (Klotz 1997, Mahoney and Rood 1998). Riparian decline had probably occurred by 1938, when aerial photographs were first taken. Those photographs reveal extensive riparian woodlands ranging from 300 to 600 m in width, with about 50% vegetation canopy closure (Lang et al. 1990). In contrast, aerial photographs from 1976 and 1984 show reduced cottonwood abundance and an absence of young trees. Thus, by the 1970s, the riparian woodlands had dwindled to sparsely scattered relict trees (figure 2; USACE 1995).

Field surveys before 1989 confirmed the scarcity of riparian willows and the absence of young cottonwood, indicating that recruitment had failed through much of the 1900s (Lang et al. 1990). The riparian zone had been further degraded since an aggressive exotic plant, tall whitetop *(Lepidium latifolium),* invaded. Like the cui-ui, the cottonwood had undergone a prolonged period of reproductive failure after the stream dewatering, and it was only the plants' longevity that enabled their survival along the river reach.

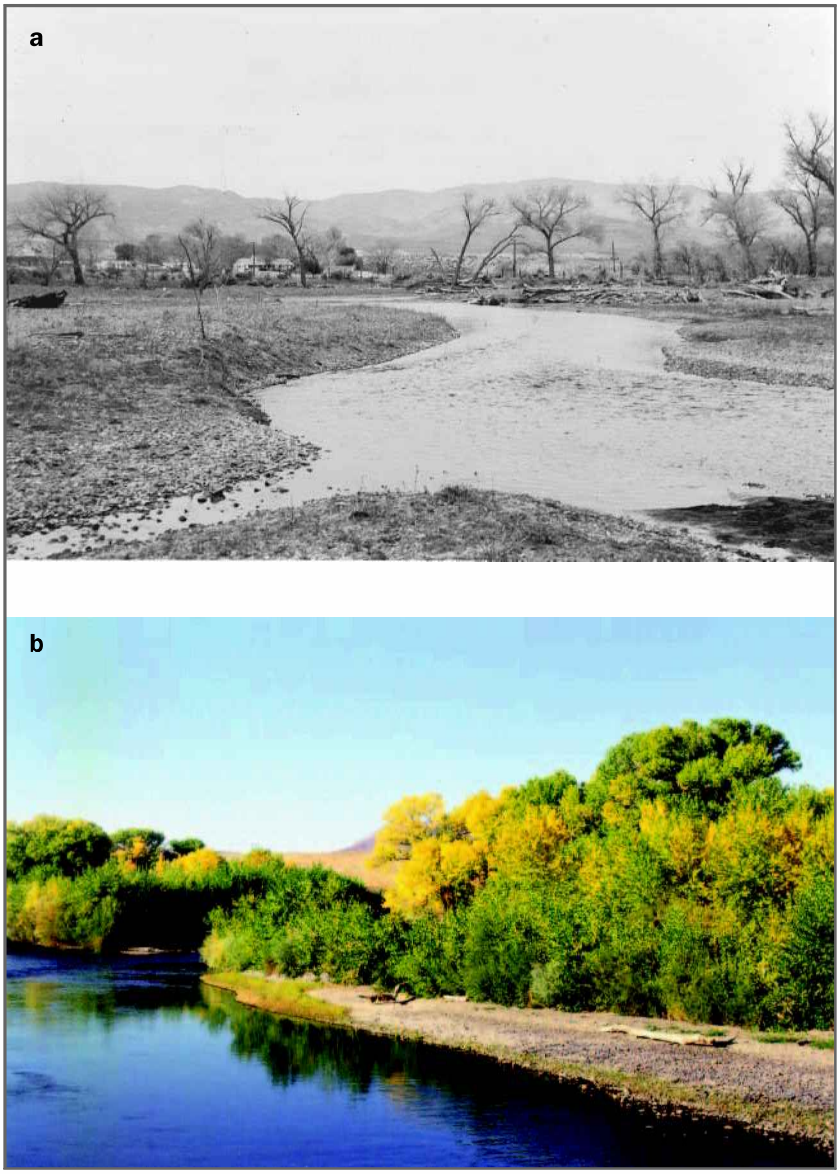

Figure 2. Photographs of the same reach of Truckee River, below Wadsworth, in 1977 (top) and 1997 (bottom). The 1977 photograph was taken in winter when leaves were absent; the 1997 photograph was taken in October. Both views are about the same distance downstream of the town, but the river channel had moved substantially over the two-decade interval. Photographs: top, Donald A. Klebenow; bottom, Stewart B. Rood.

Instream flows for restoration: Conserving cui-ui

Following the directive of the 1973 Endangered Species Act, US federal agencies commenced programs to conserve the cui-ui (USACE 1995, Scoppettone et al. 2000). Marble Bluff Dam was constructed in 1975 to stabilize channel erosion and was equipped with an elevator for upstream fish passage. The Stampede Reservoir, which had been constructed on the

Little Truckee River in 1970, was partly regulated for cui-ui conservation. Spring flows were increased to attract cui-ui and facilitate their migration upstream for spawning. Flushing flows followed to assist larval migration downstream to Pyramid Lake. Increased spring and summer flows, delivered in the 1980s (figure 3), produced a 10-fold increase in the adult cui-ui population between 1983 and 1993 (Scoppettone and Rissler 1995).

Collateral cottonwood recruitment

Efforts to restore the riparian ecosystem along the lower Truckee River commenced in the 1980s. Initial efforts involved cottonwood plantings, but it soon became clear that such expensive and labor-intensive efforts would be insufficient to restore the tens of kilometers (km) of degraded woodland. Surprisingly, field surveys in the early 1990s revealed extensive sapling bands that lined the river. The narrow bands (typically 3 to 6 m wide) consisted primarily of Fremont cottonwood saplings (> 80% of sapling stems at six sites studied in 1994), with some sandbar and black willows *(Salix exigua, Salix laevigata)* and the exotic Russian olive *(Elaeagnus angustifolia)* at some sites. Tamarisk *(Tamarix ramosissima)* occurred rarely.

The sapling bands were unusual, being particularly narrow and very dense, and sometimes flanking both sides of the stream (table 1) rather than exhibiting the more typical arcuate banding (curved bands of trees following the point bars of meander lobes). The cottonwood bands were quite complete along the reach, occurring along 67.1% of the 30.9 km reach. The saplings were relatively uniform in size (in April 1995, diameter = 4.11 ± 1.18 cm [standard deviation]; height = 4.20 ± 0.84 m), indicating common age.

Float trips and field visits over a range of flows confirmed that the sapling bands along the river reach were wetted by a common discharge of slightly below 30 cubic meters (m^3) per second. This uniform elevational position further suggests an individual recruitment event. The bands occurred 40 to 70 cm above the elevation at base flow (the typical low flow at the end of the growing season) of 1.5 m^3 per second. This elevation is consistent with the lower limit of the riparian "recruitment box," a position defined in space (elevation) and time (relative to the period of seed release) as potentially suitable for successful seedling establishment (Mahoney and Rood 1998). The riparian recruitment box model integrates aspects of seedling physiology and riparian hydrology and recognizes the water pattern requirements for seedling recruitment of cottonwoods (Mahoney and Rood 1998) and willows (Amlin and Rood 2002).

We sectioned the sapling trunks at the substrate surface and counted the annual rings. Fifty percent indicated stem establishment in 1987, while 36% and 16% had one or two fewer rings, respectively (*n* = 180 at eight sites over 30 km). As a result of browsing, flood training, and sediment deposition, surface stem ages of some saplings underrepresent the establishment age, and consequently this analysis indicated establishment of the cottonwood bands in 1987.

The recruitment of Fremont cottonwoods is primarily through seedlings that are episodically established during years with favorable flow patterns (Mahoney and Rood 1998, Shafroth et al. 1998). The prolific small seeds are released in late spring and remain viable for only about a month. The seeds are transported by wind and water, and germination is rapid if they land on suitably moist sites. The seedlings are small, and the vast majority die during the first summer as a result of drought stress. The few successful seedlings are generally established in narrow bands above the stream at elevations that provide sufficient access to moisture through the summer (Mahoney and Rood 1998).

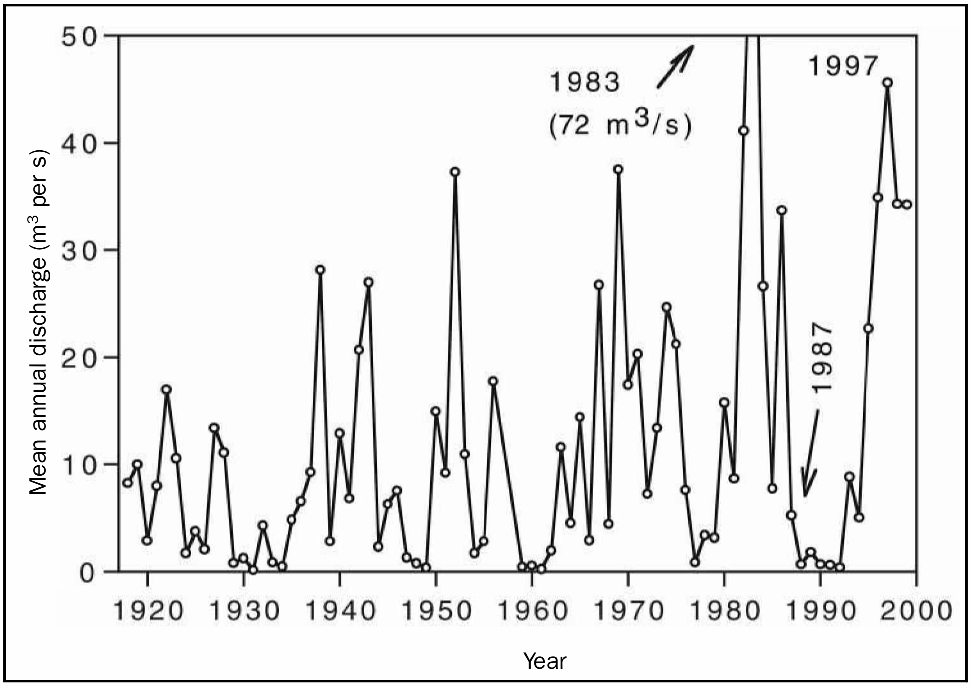

Figure 3. Mean annual discharge, in cubic meters per second, of the Truckee River at Wadsworth for the period 1918–2000. The hydrometric gauge was installed after extensive damming, and thus the early values do not reflect free-flow conditions.

We analyzed historical hydrographs to determine the flow pattern that permitted seedling success in 1987. Hydrographs of 1987 and adjacent years were converted from discharge to stage (water surface elevation), because it is the water level rather than the flow that is relevant for most riparian processes such as seedling recruitment. The 1987 hydrograph

Table 1. Lineal extent of the cottonwood sapling bands that originated in 1987 along the lower Truckee River from Wadsworth to Nixon, Nevada.

River segment	Start location	Length (km)	Sapling bands along banks (% occurrence) Right bank	 Left bank	 Either bank[a]
I	Wadsworth	8.4	32	41	60
II	Bluff	8.6	57	51	87
III	Dead Ox[b]	5.8	28	20	45
IV	Numana	8.1	42	45	69

Note: Occurrence was determined from 1:6000-scale black-and-white aerial photographs taken in July 1995. A lineal ticking method was applied in which stereoscopic photograph pairs were aligned, the stream channel was traced on a transparency overlay, and the stream was broken into 0.5-centimeter segments from which sapling occurrence was evaluated along each stream bank as absent, partial (occurrence = 0.5), or present.

a. Values for either bank are less than the combined values for the right and left banks because some locations had cottonwoods along both banks.

b. Excluding 1.4 kilometers of reservoir upstream from Numana Dam.

indicated that the stream reached the observed cottonwood recruitment zone during the seed dispersal period and then gradually receded through the summer at about 2.5 cm per day. The rate seldom exceeded 5 cm per day (figure 4). Such gradual recession is essential for cottonwood seedling survival, because the roots must elongate to maintain contact with the receding moisture zone. This zone involves the capillary fringe above the saturated water table that extends almost horizontally from the stream (Klotz 1997, Mahoney and Rood 1998). Field observations and experimental studies in which rates of water table decline were manipulated have been consistent in revealing that recession rates of 2.5 cm per day are favorable, whereas 5 cm per day is stressful and 10 cm per day is lethal to cottonwood seedlings. The 1987 hydrograph thus ideally satisfied the recruitment box model that had been developed based on observations and studies of cottonwoods across western North American (Mahoney and Rood 1998).

Hydrographs for the 5 years after 1987 revealed low-flow years in which stages during the seed dispersal period were substantially below the observed recruitment zone. Moisture to support seedling growth and survival was provided through capillary rise. The low flows for 5 years after 1987 (figure 3) were probably very important for the survival of the 1987 seedlings, because higher flows would have increased flood scouring of the vulnerable low-elevational seedlings. The year 1986 was high flow but did not provide a hydrograph pattern that would have exposed the low-elevation recruitment band in which the saplings were observed. Thus, 1986 could have contributed to the production of the barren recruitment sites that were colonized by the 1987 seedlings.

Field and aerial surveys in the early 1990s revealed a few isolated clumps and small bands of cottonwoods that were intermediate in size between the 1987 saplings and the older, relict trees (1994 diameter = 14.3 ± 4.8 cm; height = 7.69 ± 1.42 m; figure 5). Ring counts from basal cross-sections and increment cores of the intermediate trees indicated establishment in 1983, although some samples produced one or two fewer rings. Hydrologic analyses revealed that prolonged high flows had occurred in 1983, the highest-flow year of record (figure 3). The stage pattern of 1983 was favorable for seedling establishment through June, but flow abruptly declined in late July. The hydrograph analysis and pattern of distribution suggest that the few seedling patches were produced in locations with favorable sediment features that produced localized water retention. The years 1984 and 1985 did not provide sufficiently high stream stages during seed dispersal, and it is thus likely that the clumps and bands of intermediate trees had established solely in 1983. The 1983 recruitment complemented the

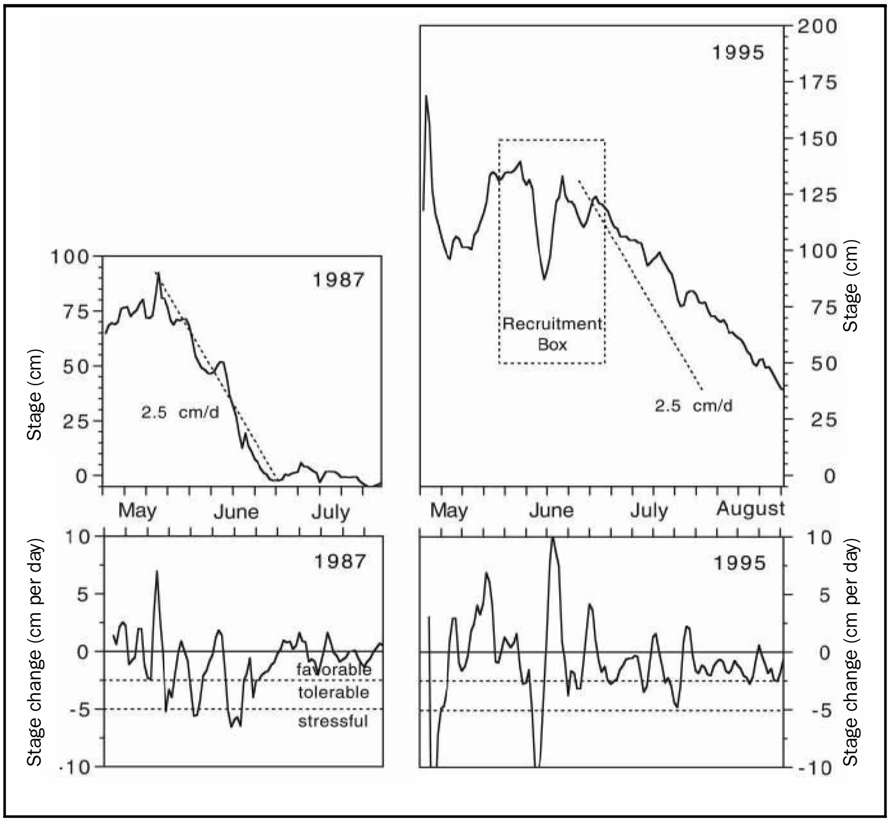

Figure 4. Stage hydrographs (top) and moving three-point-average daily stage changes (bottom) for the lower Truckee River for May to July 1987 (left) and May to August 1995 (right). Note the different y*-axis scales for the hydrographs.*

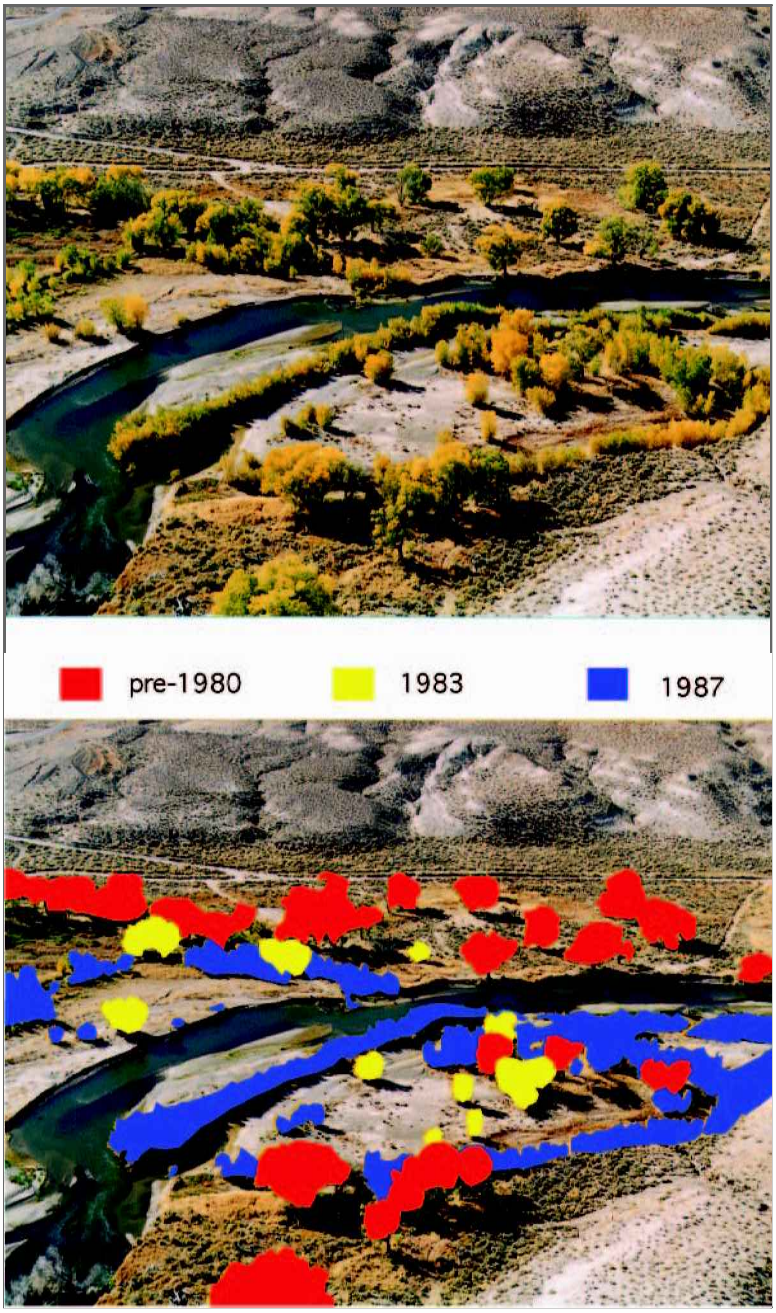

Figure 5. Top: Aerial view of the lower Truckee River, October 1997. Bottom: Same view with age groupings of riparian cottonwoods indicated. Photographs: Stewart B. Rood.

interpretations based on the 1987 saplings. In addition, the trees established in 1983 were important for subsequent cottonwood recruitment efforts, because they were reproductively mature by the mid-1990s and thus provided pollen and seed to complement that from the sparsely distributed older trees.

The analyses of these new sapling bands provided optimism for the deliberate instream flow management of cottonwoods along the Truckee River. First, the 1983 and especially the 1987 bands demonstrated that cottonwood recruitment could occur along the dammed and severely altered stream. Second, these sapling bands provided specific recruitment events that confirmed the applicability of the recruitment box model, which had been developed as a tool to understand and promote cottonwood seedling replenishment (Rood et al. 1998, Shafroth et al. 1998, Rood and Mahoney 2000).

Deliberate cottonwood recruitment flows

On the basis of the recruitment box model, we developed instream flow prescriptions for deliberate cottonwood seedling establishment. The recruitment phase commenced with stream stages from 60 to 150 cm above base flow during the period of seed dispersal. Initial flow recession would expose suitably barren and moist seedling nursery sites, and subsequent gradual stage decline of 2.5 cm per day would permit seedlings to maintain contact with the receding moisture zone (figure 4). These stage patterns were converted into discharge patterns and communicated to the agencies operating dams and diversions along the Truckee River. A project partnership between The Nature Conservancy, the US Fish and Wildlife Service, and the US Army Corps of Engineers provided a strategic foundation for the negotiations.

Abundant Sierra Nevada winter snowpack in 1994–1995 indicated sufficient water for other commitments. The Stampede Reservoir provided water storage that was supplemented with water authorized under licenses held by the Pyramid Lake Paiute Tribe. These water sources enabled the first implementation of deliberate cottonwood recruitment flows in the spring of 1995 (figure 4). The implementation required daily coordination of streamflow patterns and planning for diversions and for transit times of water passage. The water abundance permitted (or demanded) refinement of the recession rate to a more gradual 1 cm per day, which we anticipated would favor seedling survival. The recruitment flow pattern was delivered throughout the summer of 1995, and the implemented decline closely approximated the target "ramping" of 1 cm per day (figure 4).

In 1995 and in subsequent years, the stream stage pattern did result in the establishment of extensive patches and arcuate bands of cottonwood seedlings at expected elevations (figure 6a; Klotz 1997, Christensen 2000). Initial seedling densities often exceeded 500 per square meter (m^2), and recruitment particularly occurred in elevationally consistent bands. However, the summer of 1995 was exceptionally hot and dry, and substantial seedling mortality occurred. Many seedlings did survive through 1995, as observed in quadrats along 18 cross-sectional belt transects on 6 meander lobes (Klotz 1997). Across the sampling quadrats, seedling densities at the end of the 1995 growing season were often about 10 per m^2, and heights averaged 33 ± 7 cm.

Abundant snowpack in 1995–1996 permitted implementation of ramping flows in 1996. Initial stream stages during the period of seed dispersal in 1996 were slightly lower than those of 1995, and seedling elevations were correspondingly lower (Klotz 1997). Summer weather in 1996 was more typical, without the unusual heat and dryness of the previous year; the milder conditions favored seedling survival. Numerous seedlings established in 1996 survived and additional distribution patterns emerged, including the influence of proximity to the 1987 sapling bands, which slowed stream velocities and trapped fine sediments to increase moisture retention.

An exceptionally heavy winter rain event produced the highest flows of record on 3 January 1997. The cottonwoods that had been established in 1987 largely withstood the flood, and many 1995 and 1996 seedlings also survived, although others were scoured away or lethally buried. Recruitment flow patterns were implemented again in 1997, 1998, and 1999, and in each case various seedlings survived through the vulnerable period of their first summer (figure 6a). The seedlings grew slowly in their first two years but accelerated in the third or fourth year, and by 1999 many of the seedlings established in 1995 and 1996 had reached heights of 2 to 3 m (figure 6b).

While the cottonwood seedlings were vastly denser than the initial willow seedlings in the seedling recruitment bands, the willow saplings displayed vigorous clonal suckering and became dominant in some of the lower-elevation streamside zones by 1998 through 2001 (figure 6c). Following this successional pattern, some riparian zones began to resemble the original historical descriptions of the area, with dense willow bands lining the stream and cottonwoods set slightly back (figure 6c).

It is not yet possible to fully determine the quantitative extent of recruitment following the regulated flows of 1995 through 1999. By about 2005, we expect that field-verified aerial photograph interpretation, as conducted for the 1987 trees, will enable us to assess the contribution of the seedlings established in 1995 through 1999. The transect and quadrat monitoring reveal extensive recruitment of seedlings following the recruitment flows of 1995 through 1999 and support the interpretations based on the 1987 recruitment event.

Figure 6. Photographs showing newly recruited vegetation along the lower Truckee River. (a) Bands of first-year cottonwood (left of center) and willow (right) seedlings, September 1998. (b) Two- to three-meter-tall cottonwoods established in 1995 and photographed in September 1998. (c) Dense bands of willows lining the stream, July 2001. Photographs: Stewart B. Rood.

Riparian habitat

Cottonwoods not only have intrinsic environmental and aesthetic value, they also provide the foundation for the riparian forest ecosystem. Groves of riparian cottonwood and willows provide especially rich habitat for many wildlife species, and populations of those riparian animals are predicted to vary with the condition of the woodlands. Consistent with this interpretation, a semiquantitative bird inventory was conducted along the lower Truckee River, commencing in 1868 (Ridgway 1877, Klebenow and Oakleaf 1984, Lynn et al. 1998). That assessment revealed 107 bird species, including 21 obligate riparian (and wetland) species that can be used as indicators of the condition of riparian vegetation. By the early 1970s, 18 of the 21 riparian birds were substantially less common or absent, and by 1981, only 1 of the 21 riparian and wetland bird species had not strongly declined since 1868.

Following the establishment of the 1983 and 1987 cottonwoods, bird surveys in 1993 revealed that 7 of the 21 riparian and wetland species had recovered to approach their original abundances in 1868. Subsequent surveys in 1998 revealed continuing recovery; 21 of 72 birds, including 10 of the 19 riparian species that had been become rare or locally extirpated, had substantially increased in abundance (table 2). Thus, the avifauna patterns reflected woodland conditions, with evidence of rapid recovery following recruitment of the riparian cottonwoods and willows. The presence of these species during spring and summer also suggests that breeding occurs within the restored riparian woodlands.

As the riparian landscape has substantially changed along the Truckee River since 1983, the woodland now provides a broader range of environments with more diverse and complex vertical and horizontal vegetation structure. The cottonwoods and willows provide some of the necessary habitat for additional birds and presumably for other wildlife. This woodland restoration is still incomplete, and it is anticipated that as the riparian woodlands further develop, the extent and diversity of wildlife habitats will increase.

The band of cottonwoods and willows established in 1987 has also produced changes to the channel and floodplain morphology. Sediment scour and deposition have been altered, and depositional features of 1 m or more are common along and behind the vegetation bands. The shrubs and trees have defined and confined the channel, which has responded by becoming narrower and deeper. These changes, combined with shading by riparian vegetation, have improved aquatic conditions. For example, in 1999, in contrast to prior years, trout were observed in the river reach throughout the summer.

Implications for river restoration

The 1987 cottonwood recruitment event was an unplanned consequence of deliberate instream flow regulation directed toward the spawning needs of the cui-ui sucker. It is logical that the native fish and trees of a common stream system are

Table 2. Historic changes in wetland- and riparian-dependent bird species along the lower Truckee River.

		Bird abundance			
Common name	**Species name**	**1868**	**1972 to 1976**	**1980 to 1981**	**1998**
American avocet	*Recurvirostra americana*	C	—	—	—
American bittern	*Botaurus lentiginosus*	C	—	—	—
Black-chinned hummingbird	*Archilochus alexandri*	A	—	—	R
Black-headed grosbeak	*Pheucticus melanocephalus*	C	—	R	C
Black-necked stilt	*Himantopus mexicanus*	C	—	—	—
Common yellowthroat	*Geothlypis trichas*	C	—	—	C
Long-billed curlew	*Numenius americanus*	C	—	—	—
MacGillivray's warbler	*Oporornis tolmiei*	—	R	R	R
Marsh wren	*Cistothorus palustris*	A	—	—	—
Northern harrier	*Circus cyaneus*	A	—	—	R
Song sparrow	*Melospiza melodia*	A	—	R	C
Sora	*Porzana carolina*	C	—	R	—
Spotted sandpiper	*Actitis macularia*	C	R	C	C
Willow flycatcher	*Empidonax traillii*	A	—	—	—
Warbling vireo	*Vireo gilvus*	A	R	—	C
Western wood-pewee	*Contopus sordidulus*	A	R	R	C
Willet	*Catoptrophorus semipalmatus*	R	—	—	—
Wilson's warbler	*Wilsonia pusilla*	R	C	R	C
Yellow warbler	*Dendroica petechia*	A	C	R	C
Yellow-billed cuckoo	*Coccyzus americanus*	R	—	—	—
Yellow-breasted chat	*Icteria virens*	C	—	—	C
	Totals	A = 8 C = 9 R = 3	A = 0 C = 2 R = 4	A = 0 C = 1 R = 7	A = 0 C = 9 R = 3
	Total number of species	20	6	8	12

Source: Data were obtained from Ridgway (1877), Klebenow and Oakleaf (1984), and this study.
Note: Bird abundance ranks: —, no sightings; R, rare (1 to 3 sightings); C, common (4 to 79 sightings); A, abundant (> 80 sightings).

similarly dependent on naturally dynamic patterns of instream flow. However, the Truckee River case study provided a number of surprises, most notably the speed of the favorable responses. The most prominent changes in the riparian landscape are linked to the band of cottonwoods that was established in 1987, only a decade and a half ago. After a century of neglect and decline, the provision of suitable instream flow patterns led to measurable improvement in the riverine and riparian ecosystems in a decade.

This case study should provide optimism for the conservation and restoration of other dammed rivers across North America and elsewhere in the world. The delivery of vegetation recruitment flow patterns may be achieved without sacrificing other water commitments, because the restoration efforts associated with vegetation population recruitment are particularly targeted toward high-flow years. During these wet years, sufficient water would generally be available for other commitments. The competition for water allocation in dry years will remain a problem for riverine ecosystem management, but the ecosystem benefits of managed flows during wet years may offset problems during dry years. Streamflow management objectives should be different in dry and wet years: For example, cottonwood recruitment is naturally episodic, occurring in only about 1 year of every 3 to 10, with medium or high spring flows (Scott et al. 1996, Cordes et al. 1997, Mahoney and Rood 1998). In low-flow years, water should not be directed toward population recruitment but should instead be allocated for the maintenance of riparian plants and other components of the riverine ecosystems.

The importance of streamflow pattern rather than quantity was also demonstrated to be critical. The extensive cottonwood recruitment of 1987, for example, occurred in a year in which the overall flow was below average, but the flow pattern ideally satisfied seedling requirements. The recruitment event probably benefited from a sequence of low-flow years, and thus the riparian recruitment was successful despite a partial drought cycle. This result is somewhat contrary to current perceptions of riparian processes, in which the quantity of flow is often believed to be of primary importance. The extensive establishment in a moderate-flow year (1987) also suggests that, while flood flows are essential to drive the geomorphological processes required to create riparian nursery sites (Friedman et al. 1996, Scott et al. 1996, Auble and Scott 1998, Rood et al. 1998), flood flows may not be directly required for vegetation recruitment. This point has considerable importance for riparian management now that cities have encroached into river floodplains, and deliberate flood flows are likely to be discouraged because of their considerable economic and social costs.

In the present case, the Truckee River experienced a series of high-flow years that permitted deliberate implementation of the cottonwood flows commencing in 1995, when local support existed for this restoration initiative. The decision was made to implement the cottonwood recruitment flows whenever possible, even though this introduced an artificially frequent occurrence of recruitment events. This management strategy was determined as a response to the deficiency of cottonwood recruitment over the previous century.

The Truckee River case study demonstrates that the legislated potency of endangered-species status can be used as a tool for ecosystem restoration. In the present case, the endangered cui-ui provided the impetus for recovery of the fundamental physical process of instream flow. In turn, the improved flow pattern directly and indirectly benefited a broad range of ecosystem processes. However, the ecosystem restoration in and around the Truckee River is ongoing and incomplete. Cottonwoods often live for more than a century, while cui-ui can live for a half-century. It will thus be important to continue these restoration efforts and studies.

The successful partial restoration of the lower Truckee River was achieved by altering the patterns of instream flow regulation. This mitigation measure is less extreme than the dam decommissioning (removal) that is proposed to protect or restore some threatened and endangered fish populations. Dam removal will impose challenges for riparian restoration (Shafroth et al. 2002) and will not always be effective or practical (Kareiva et al. 2000). By contrast, refinements to dam operations and instream flow regulation should be environmentally favorable for virtually all dammed streams around the world.

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References cited

Alpert P, Griggs FT, Peterson DR. 1999. Riparian forest restoration along large rivers: Initial results from the Sacramento River Project. Restoration Ecology 7: 360–368.

Amlin NM, Rood SB. 2002. Comparative tolerances of riparian willows and cottonwoods to water-table decline. Wetlands 22: 38–346.

Auble GT, Scott ML. 1998. Fluvial disturbance patches and cottonwood recruitment along the upper Missouri River, Montana. Wetlands 18: 546–556.

Christensen TJ. 2000. Flood impact on the morphology and riparian vegetation of the lower Truckee River. Master's thesis. University of Nevada, Reno.

Cordes LD, Hughes FMR, Getty M. 1997. Factors affecting the regeneration and distribution of riparian woodlands along a northern prairie river: The Red Deer River, Alberta, Canada. Journal of Biogeography 24: 675–695.

Dynesius M, Nilsson C. 1994. Fragmentation and flow regulation of river systems in the northern third of the world. Science 266: 753–762.

Fausch KD, Torgersen CE, Baxter CV, Li HW. 2002. Landscapes to riverscapes: Bridging the gap between research and conservation of stream fishes. BioScience 52: 483–498.

Finch DM, Ruggiero LF. 1993. Wildlife habitats and biological diversity in the Rocky Mountains and northern Great Plains. Natural Areas Journal 13: 191–203.

Friedman JM, Osterkamp WR, Lewis WM Jr. 1996. Channel narrowing and vegetation development following a Great Plains flood. Ecology 77: 2167–2181.

Goodwin CN, Hawkins CP, Kershner JL. 1997. Riparian restoration in the western United States: Overview and perspective. Restoration Ecology 5: 4–14.

Hughes FMR, Rood SB. 2001. Floodplains. Pages 105–121 in Warren A, French JR, eds. Habitat Conservation: Managing the Physical Environment. New York: Wiley.

Johnson RR, Haight LT. 1984. Riparian problems and initiatives in the American Southwest: A regional perspective. Pages 404–412 in Warner RE, Hendrix KM, eds. California Riparian Systems: Ecology, Conservation and Productive Management. Berkeley: University of Calfornia Press.

Johnson WC. 1994. Woodland expansion in the Platte River, Nebraska: Patterns and causes. Ecological Monographs 64: 45–84.

Kareiva P, Marvier M, McLure M. 2000. Recovery and management options for spring/summer Chinook salmon in the Columbia River Basin. Science 290: 977–979.

Klebenow DA, Oakleaf RJ. 1984. Historical avifaunal changes in the riparian zone of the Truckee River, Nevada. Pages 203–209 in Warner RE, Hendrix KM, eds. California Riparian Systems: Ecology, Conservation and Productive Management. Berkeley: University of Calfornia Press.

Klotz JR. 1997. Riparian hydrology and establishment of woody riparian vegetation. Master's thesis. University of Nevada, Reno.

Lang J, Chainey S, O'Leary B, Shaul W, Rucker A. 1990. Channel Stabilization and Riparian Restoration Plan for the Lower 23 Miles of the Truckee River, Nevada. San Francisco: US Environmental Protection Agency.

Lynn S, Morrison ML, Kuenzi AJ, Neale JCC, Sacks BN, Hamlin R, Hall LS. 1998. Bird use of riparian vegetation along the Truckee River, California and Nevada. Great Basin Naturalist 58: 328–343.

Mahoney JM, Rood SB. 1998. Streamflow requirements for cottonwood seedling recruitment: An integrative model. Wetlands 18: 634–645.

Malanson JP. 1993. Riparian Landscapes. Cambridge (United Kingdom): Cambridge University Press.

Molles MC Jr, Crawford CS, Ellis LM, Valett HM, Dahm CN. 1998. Managed flooding for riparian ecosystem restoration. BioScience 48: 749–756.

Naiman RJ, Décamps H. 1997. The ecology of interfaces: Riparian zones. Annual Review of Ecology and Systematics 28: 621–658.

Nilsson C, Berggren K. 2000. Alterations of riparian ecosystems caused by river regulation. BioScience 50: 783–792.

Patten DT. 1998. Riparian ecosystems of semi-arid North America: Diversity and human impacts. Wetlands 18: 498–512.

Poff NL, Allan JD, Bain MB, Karr JR, Prestegaard KL, Richter BD, Sparks RE, Stromberg JC. 1997. The natural flow regime: A paradigm for river conservation and restoration. BioScience 47: 769–784.

Richter BD, Richter HE. 2000. Prescribing flood regimes to sustain riparian ecosystems along meandering rivers. Conservation Biology 14: 1467–1478.

Ridgway R. 1877. Ornithology. Pages 303–669 in King C, ed. Ornithology and Paleontology. US Geological Explorations 40th Parallel, Vol. 4. Washington (DC): US Government Printing Office.

Rood SB, Mahoney JM. 2000. Revised instream flow regulation enables cottonwood recruitment along the St. Mary River, Alberta, Canada. Rivers 7: 109–125.

Rood SB, Kalischuk AR, Mahoney JM. 1998. Initial cottonwood seedling recruitment following the flood of the century of the Oldman River, Alberta, Canada. Wetlands 18: 557–570.

Scoppettone GG, Rissler PH. 1995. Endangered cui-ui of Pyramid Lake, Nevada. Pages 323–324 in LaRoe ET, Farris GS, Puckett CE, Doran PD, Mac MJ, eds. Our Living Resources: A Report to the Nation on the Distribution, Abundance, and Health of U.S. Plants, Animals, and Ecosystems. Washington (DC): US Department of the Interior, National Biological Service.

Scoppettone GG, Rissler PH, Buettner ME. 2000. Reproductive longevity and fecundity associated with nonannual spawning in cui-ui. Transactions of the American Fisheries Society 129: 658–669.

Scott ML, Auble GT, Friedman JM. 1996. Fluvial process and the establishment of bottomland trees. Geomorphology 14: 327–339.

Shafroth PB, Auble GT, Stromberg JC, Patten DT. 1998. Establishment of woody riparian vegetation in relation to annual patterns of streamflow, Bill Williams River, Arizona. Wetlands 18: 577–590.

Shafroth PB, Friedman JM, Auble GT, Scott ML, Braatne JH. 2002. Potential responses of riparian vegetation to dam removal. BioScience 52: 703–712.

Stanford JA, Ward JV, Liss WJ, Frissell CA, Williams RN, Lichatowich JA, Coutant CC. 1996. A general protocol for restoration of regulated rivers. Regulated Rivers: Research and Management 12: 391–414.

Strong DH. 1984. Tahoe: An Environmental History. Lincoln: University of Nebraska Press.

[USACE] US Army Corps of Engineers. 1995. Lower Truckee River Reconnaissance Report. Sacramento (CA): USACE Sacramento District.

Wheeler SS. 1987. The Desert Lake: The Story of Nevada's Pyramid Lake. Caldwell (ID): Caxton Press.