Appendix J.

Fluvial Hydrology of Regulated Rivers in the Range of the Southwestern Willow Flycatcher

A. Purpose

Dams, large and small, are important components of the economic infrastructure of the American Southwest. They were constructed with specific purposes and objectives designed to foster economic development through flood reduction, irrigation supply, urban supply, hydroelectric power generation, and provision of recreation. Dam management and administration during most of the twentieth century viewed rivers simply as sources of commodity water and electrical power, but changing social values have now expanded the roles of dams and the rivers they control. Rivers are now viewed by decision-makers and the public as complex landscapes and ecosystems that, in addition to providing commodities, are also the habitats of endangered wild species that our culture deems worth preserving. Part of this new mission for water managers is a rethinking of the role of dams, not as sources of problems for endangered species, but as opportunities for recovery. To use dams effectively in this effort, decision-makers require an understanding of the effects that dams and their operations have had on rivers and the hydrology, geomorphology, and riparian habitats.

Water is a key component of the natural, social, economic, and cultural fabric of the American Southwest (Table 1). The availability of water is highly variable through time and across space, but the construction and maintenance of an engineered water delivery system has permitted extensive economic development in the region. Early uses of water as a commodity focused on mining and agriculture, but subsequent uses broadened to include industrial, commercial, and livestock purposes. Cities in the region have always depended on diverted water from rivers (and later, groundwater), but explosive urban growth in the region in the latter half of the twentieth century has brought about new pressures on water resources. At the end of the twentieth century, however, agriculture still withdraws several times more water from Southwestern streams and groundwater sources than any other sector of the economy (Table 1). Dams, a portion of the critical infrastructure that supports the region’s society and economy, store water, dispense it in economically useful patterns, and provide for flood suppression. More than 20 million people in the region depend directly on water from the system dams and delivery structures, and as many as 50 million enjoy at least indirect benefits such as electricity from the regional power grid and recreation opportunities afforded by the rivers and reservoirs.

When most of the dams in the region were built, water was viewed by the public and decision makers as a commodity, and rivers were simply conduits for the movement of that commodity from one place to another. By 1996, the major water resource regions that include the willow flycatcher range contain 4,659 dams of all sizes, and 173 dams with storage capacity of greater than 100,000 ac ft (Table 1). In recent decades, however, ecosystem perspectives, recognition of the loss of valued species, and a change in social values has brought new emphasis to the undesirable changes associated with dams. While the upstream implications of reservoir development have often been clear, the unintended downstream consequences of river regulation are only now becoming obvious and of general interest. General works reviewing the downstream impacts of dams include a general review by Petts (1984), and a more ecologically oriented review by Brown (1988). Williams and Wolman (1984) provided a comprehensive evaluation of hydrologic and geomorphic changes by dams on selected American rivers, including some in the southwestern willow flycatcher range. The following report is more specific, and shows that the regulation of Southwestern rivers has had a detrimental effect on southwestern willow flycatcher habitat by changing the water and sediment flows, river landforms, and their associated vegetation communities important for flycatcher use.

The purpose of this appendix is to report the hydrologic characteristics of regulated rivers in the range of the endangered southwestern willow flycatcher of the southwestern United States. This exploration focuses on the apparent effects of dams and their operations on several major rivers that support riparian habitat for the bird by comparing the hydrologic behavior of the rivers as affected by dams with their behavior before dams or on reaches unaffected by them. Because one of the primary threats to the viability of the species is the loss of riparian habitat by means of stream flow altered by dams, restoration of the habitat depends on a clear understanding of the natural flow characteristics that have been lost through impoundment and regulation.

While it would be informative to review all the dams with reservoirs larger than some minimum threshold capacity (perhaps 100,000 ac ft) within the range of the southwestern willow flycatcher, the following detailed analysis is limited to the main stem of the Gila River, Verde River, Middle Rio Grande, and Lower Colorado River. These rivers and their dams receive emphasis here for three reasons. First, large amounts of stream flow data are readily available for them, while records for other streams with dams are less useful because they are discontinuous, or the measurement sites do not provide for highly informative comparisons between regulated and unregulated portions of the rivers. Second, general conclusions and lessons about the effects of dams on river hydrology are likely to emerge from these data rich sources that are widely applicable to other rivers in the American Southwest. Finally, these four main rivers are the region’s largest, and they host important flycatcher nesting sites. California coastal rivers with dams that provide occupied habitat for the southwestern willow flycatcher and that offer restoration and population recovery potential include the San Luis Rey and Santa Clara systems, as well as the Santa Ynez downstream from Bradbury Dam. These regulated rivers have sediment and terrain characteristics that are somewhat different from the interior streams, but their hydrologic responses to dams and the consequences of those responses are similar to those of the inland rivers. Figure 1 shows the approximate location of the dams mentioned in the text below.

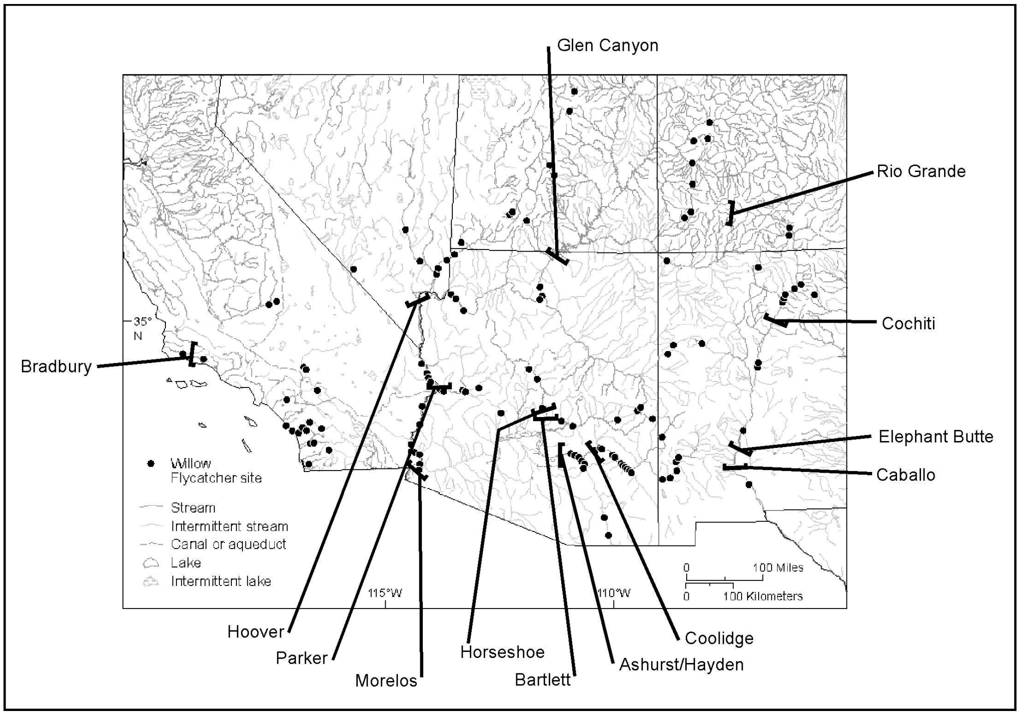

Figure 1. Approximate location of dams discussed in this appendix.

Extensive studies of the impacts of one dam on one river within the southwestern willow flycatcher range are available, and have resulted in changes in dam operations (National Research Council 1991). For over a decade, the Bureau of Reclamation, Glen Canyon Environmental Studies Program, analyzed the downstream effects of the operation of Glen Canyon Dam on the Colorado River (U.S. Bureau of Reclamation 1995). This effort, the most extensive ever undertaken for a regulated river, produced large amounts of data, information, and generalizations about the effects of the dam on the river (Carothers and Brown 1991), and resulted in a series of adjustments in the operation of the dam to partially reverse downstream changes brought about by the structure. Adjustments included the introduction of occasional moderate peak flows, maintenance of low flows that are larger than those released previously, and reduced ramping rates (that is, slowing the rate of change from one discharge level to another). Outside the range of the southwestern willow flycatcher, operators have adjusted the operations of many dams to mitigate downstream damages sustained through regulation (Collier et al. 1996).

The following paragraphs outline the parameters that describe important characteristics of river flows in the region, identify the sources of data, and report on the effects of dams on the Gila, Verde, Rio Grande, and Lower Colorado rivers. This appendix concludes by using these demonstrated effects of dams to make general recommendations for the recovery of the southwestern willow flycatcher population, generally by restoring a portion of the pre-dam flow characteristics of the rivers to support appropriate flycatcher habitat.

B. Flow Parameters

The construction and operation of dams have dramatically changed downstream flows, the channels they create and maintain, and the riparian vegetation that provides habitat for the southwestern willow flycatcher. Although a complete hydrologic analysis would include a myriad of flow parameters, the following investigation focuses on only a few measure that describe stream flow in simple terms:

- *Annual peak flow*: the largest daily flows found in each year of record for stream gages (the technical spelling for gauges); there is one annual peak flow for each year representing the largest flow for that particular year.
- *Mean annual peak flow*: the average annual peak flow for all the years of record; the average of the individual values for each year; there is one mean annual peak flow for each gage representing its entire record.
- *Annual mean flow*: the average of each of the mean daily flows for each year of record; the average of all the 365 (or 366 for leap years) single days of record for the year; there is one annual mean flow for each year.
- *Mean annual mean flow*: the average mean daily flow for all the years of record; the average of means for each year; there is one mean annual mean flow for each gage representing its entire record.
- *Annual low flow*: the lowest daily flow found in each year of the record; there is one annual low flow of each year, representing the lowest flow for that particular year; in the cases where the lowest flow is zero, the lowest flow may occur on more than one day.
- *Mean annual low flow*: the average annual low flow for all the years of record; the average of the individual values for each year; there is one mean annual low flow for each gage representing its entire record.

There are three reasons to emphasize investigation of the annual peak flows. First, the annual peak flows are the most important channel forming and maintaining flows because they shape channel and near-channel landforms, transport much of the sediment in the system, and directly influence biotic processes in the channel and on nearby flood plains. Second, data for annual peak flows are readily available in published records and are easily analyzed. Third, annual peak flows represent a parameter of the river discharge below dams that can be controlled through operating rules for the dams, and they are therefore subject to direct management.

There are three reasons to emphasize investigation of the annual mean flows. First, although the annual mean flow is not geomorphologically significant, it indicates the amount of water generally available for biotic systems in the river. Fluctuations from year to year give indications of drought or moist conditions. Second, the variability of the mean annual flows provides indications of the influence of dam operations which tend to dampen the variability. Third, the annual mean flow provides a method of standardizing the annual maximum flow when comparing one stream system with another of a different size. The annual maximum flow divided by the annual mean flow is a scale-free value that permits comparison among rivers.

There are two reasons for investigating annual low flows. The magnitude of these flows show the range of hydrologic conditions when they are compared to the mean and high flows, thus indicating the range of flow conditions to which the riparian vegetation must adjust. The mean annual low flows generally do not perform geomorphological work, but their magnitude also is significant for groundwater recharge and the maintenance of near-channel vegetation dependent on shallow groundwater. Streams with zero low flow conditions cease contributions to the groundwater system and contribute to falling water tables.

C. Sources of Data

The analysis of annual peak, mean, and low flows in the following paragraphs is simple and straightforward. Although more sophisticated statistical analysis is possible, a fundamental and basic approach is best because the trends are most obvious. The major parameter not included in this analysis is the low flow information, which is more difficult to measure and analyze. The raw data for the annual peak flows are available from the U.S. Geological Survey in that agency's *Water-Supply Papers*, in its *Water Resource Investigation Reports*, or at its web site (http://water.usgs.gov). The analysis of data for stream gages in this investigation includes investigation of pairs, with one gage upstream and one downstream from a major dam on a single stream. Other analyses are of two sets of stream gages, with one set drawn from dammed rivers and the other drawn from free flowing streams.

Information on dams is from data bases collated by the U.S. Army Corps of Engineers and the Federal Emergency Management Agency. Individual state agencies created the original data and forwarded it to the federal agencies. The Corps and the Federal Emergency Management Agency made the data generally available in 1994, with an updated version in 1996, in the form of a CD-ROM disk. Although the data were temporarily available through the Corps' web site, this not presently the case. Data for this appendix are from the 1996 disk.

D. The Main Stem of the Gila River

Although a major concentration of southwestern willow flycatcher nesting sites occurs in the upper Gila River in New Mexico, the river is reasonably free flowing there except for local diversions. The middle Gila River in southeastern Arizona has many willow flycatcher nesting sites, but it is impacted by Coolidge Dam. The hydrology of the middle river provides a key to understanding and controlling the riparian habitat favored by the bird. From a hydrologic perspective, the main stem of the upper Gila River has two distinct parts: the segments upstream from Coolidge Dam and those downstream from the dam. The dam has a storage capacity that is very large with respect to the annual water yield of the river, because the reservoir can store 3.5 times the mean annual water yield of the stream. This figure implies that the dam has the potential to substantially alter downstream hydrology, as well as the downstream geomorphology and ecology dependent on the river flows. The basic descriptive information for Coolidge Dam are as follows:

<u>*Coolidge Dam*</u>
Dam closed: November 15, 1928
Reservoir: San Carlos Lake
Storage Capacity: 1,073,000 ac ft
Storage Capacity as a Function of the Mean Annual Water Yield: 3.5
Maximum Release Capacity: 120,000 cfs
Owner: U.S. Department of Interior, Bureau of Indian Affairs

The three gages for assessing the fluvial hydrologic effects of the dam are as follows:
Upstream from the dam: Gage 09448500, Gila River at head of Safford Valley, near Solomon, Arizona, period of record 1914-1991.
Downstream close to the dam: Gage 09469500, Gila Rive below Coolidge Dam, period of record 1921-1991.
Downstream distant from the dam: Gage 09474000, Gila River at Kelvin, Arizona, period of record 1913-1991.

Given these records, it is possible to explore the downstream effects of Coolidge Dam two ways. First, it is possible to compare the downstream impacted flows with those unaffected flows upstream from the dam for the period after the dam was completed. Second, it is possible to compare pre-dam and post-dam conditions at the same gage sites. The upstream gage is located above diversions of irrigation waters for Safford Valley. The downstream gage is directly affect by the operations of Coolidge Dam, and includes inflows from the San Pedro River. All three gages have records extending to 1999, but the data that are pre-processed and readily available for this analysis extend only to 1991. This limitation is unlikely to affect the conclusions of the following analysis.

1. Did Coolidge Dam reduce the magnitudes of the annual peak flows downstream?

Yes. In the pre-dam record, mean annual peak flows were larger at Kelvin downstream from the dam, but in the post-dam era they were larger at Safford, upstream from the dam (Table 2). The gage immediately downstream from Coolidge Dam dramatically indicates the magnitude of the effects of the dam. Before the dam was closed, the gage site near the dam location had peak flows that were 74% as large as those upstream near Safford. The remaining 26% (and minor tributary inflows) entered the groundwater system of Safford Valley between the two sites and was lost to direct surface flow. When Coolidge Dam was closed, the flows in the main stem were substantially reduced immediately downstream from the dam: mean annual peak flows were reduced to only 5% of the magnitude of the flood peaks upstream from the dam at Safford. Further downstream, the annual peaks at Kelvin consist of flows from the dam and from tributaries. Before the dam was closed, the peak flows at Kelvin were about one and a half times larger than the peak flows near Safford, because the inflows from the San Pedro River were added to flows in the main stem of the Gila. After the dam closure, peak flows at Kelvin were only 66%the magnitude of flows at Safford. In absolute terms, before the dam was closed, the mean annual peak flow at Safford was 21,900 cfs, and at Kelvin it was 33,500 cfs. After the dam closed, the average annual peak flow was 18,000 cfs at Safford, a modest decline probably related to climatic adjustments, but at Kelvin the mean plunged to 12,000 cfs because of storage in San Carlos Lake behind Coolidge Dam. The result of these substantial declines in annual peak flows has been considerable channel shrinkage and simplification downstream from the dam, with the greatest changes occurring between the dam and the confluence with the San Pedro River.

2. Did the closure of Coolidge Dam change the timing of the annual peak flows downstream?

Yes, the dam altered the timing of annual peak flows (Table 3). Exact date of the annual peak flows are readily available for the Gila River near Safford and at Kelvin. During the pre-dam era, 60% of the annual peak flows of the Gila River near Safford and at Kelvin occurred in the months of July, August, and September. After the closure of the dam, flows upstream occurred in July, August, and September in 49% of the years, a moderate decline in temporal concentration probably related to climatological changes over the watershed. These changes were not transmitted to the segments downstream, however, because the annual peak flows at Kelvin remained concentrated in July, August, and September, months that accounted for 64% of annual peak flows even after the closure of Coolidge Dam. Inflows from the San Pedro River probably account for the late-summer concentration in the river near Kelvin.

3. Did the closure of Coolidge Dam change the variability of the annual peak flows downstream?

Yes. Before the dam was closed, the standard deviations of the annual peak flows at all three gage sites were greater than the average peak flow, indicating great variability (Table 4). In the period after the closure of the dam, the standard variation remained similar for the annual peak flows at the unimpacted site near Safford, but at the gage just downstream from the dam, the standard deviation declined to only 3% of its former value. At Kelvin, further downstream, the introduction of flows from the San Pedro restored some of the variability, but the standard deviations were still only 42% of the pre-dam value. The importance of these changes to the geomorphology and riparian ecology is that the natural arrangements of the fluvial environment were dependent on highly variable annual peak flows. After the closure of the dam, that variability disappeared, resulting in high simplified channel configurations and much less spatial diversity in the riparian vegetation system.

4. Has Coolidge Dam changed the mean annual mean flows downstream?

No. The mean annual mean flow has declined at all three gage sites, partly as a result of upstream withdrawals and partly as a result of hydro-climatic changes (Table 2). The mean annual flow downstream from the dam is maintained by releases from the reservoir to supply downstream water users, so the structure does not have a significant impact on changing the annual mean flow.

5. Has the dam affected low flows downstream?

No. The annual low flows in the Gila River have approached zero throughout the record. At the gage near Safford, the change between pre-dam and post-dam conditions is statistically insignificant for the annual low flows, and downstream from the dam many years experienced no flow both before and after the dam.

6. What are the geomorphic and ecologic implications of the downstream impacts of Coolidge Dam?

The closure of Coolidge Dam signaled major changes in the geomorphology and riparian ecology of the Gila River downstream from the structure. The dam affected these changes largely be changing the magnitude and variability of the annual peak flows. The dam drastically reduced the size of the annual flood, which is the channel-forming discharge in the river. In continuously flowing streams the channel forming discharge is usually considered to be the bankfull discharge, which also often recurs approximately once per year over a decade or longer. Because the annual flood peaks were reduced by the dam, their channel forming power was also reduced, and the overall size of the channel declined downstream from the dam. The dam also substantially reduced the variability of the annual flood, so that the resulting channel was not only smaller than its predecessor, it was also much more simplified in its form and materials as shown in historical ground photographs. The highly variable floods that created and maintained a complex channel with islands, bars, subchannels, braids, and an active flood plain was replaced by a simple, single thread channel with almost no islands, bars, subchannels, or braids. The once active flood plain has converted (mainly through decreased flows with minor channel incision) to an inactive terrace, a change wherein the surface once had frequent interaction with the main channel by being overflowed and through sediment exchanges, but now it is isolated from the channel and no exchanges occur. Coolidge Dam stores all the fine sediment (sand and silt) than once moved downstream as part of the system. As a result, the only fine materials in the downstream river system are fine sands that make up the inactive terraces high above the active river.

The riparian vegetation developed on this geomorphic substrate is also simplified, because the constantly changing fluvial landscape has become geomorphologically frozen. Monotypical riparian forests, especially those dominated by tamarisk, became increasingly common in some reaches, while in other reaches the normal locations for cottonwood and willow became less common, so that forests of those types also became less common. The lack of fine materials restricts the available substrate for willow. The available natural habitat for southwestern willow flycatcher therefore has declined since the closure of the dam. As distance from the dam increases, tributary flows from the San Pedro River restore some natural characteristics to the river's flow, forms, and vegetation, but does not restore the biological component of the ecosystem in the sense that tamarisk dominates the native vegetation. Still further downstream, however, Ashurst-Hayden Dam diverts all the flow of the river except unusual floods, and from that point downstream the channel is little different from the surrounding desert

E. The Verde River

The Verde River hosts several nesting sites for the southwestern willow flycatcher, and offers potential for recovery of the bird. Major features of the river impacted by human activities are the dams and the hydrology they control. The Verde River has several distinct segments determined by human use of the stream. The upstream portion, above Clarkdale, experiences only minor diversions and no impacts from dams. A dam at Sullivan Lake, the starting point of the river, has completely filled with sediment, so that it functions as a run-of-the-river structure with few hydrologic effects. The middle portion of the river through the Verde Valley has significant diversions but no dams, while the lowest portion has flow controlled by Bartlett and Horseshoe Dams. The basic descriptive information for the dams are as follows (U.S. Army Corps of Engineers 1996):

Bartlett Dam
Dam closed: 1939
Reservoir: Bartlett Lake
Storage Capacity: 178,186 ac ft
Storage Capacity as a Function of the Mean Annual Water Yield: 0.44
Maximum Release Capacity: 175,000 cfs
Owner: U.S. Bureau of Reclamation and Salt River Project

<u>*Horseshoe Dam*</u>

Dam closed: 1945

Reservoir: Horseshoe Lake

Storage Capacity: 131,500 ac ft

Storage Capacity as a Function of the Mean Annual Water Yield: 0.33

Maximum Release Capacity: 250,000 cfs

Owner: U.S. Bureau of Reclamation and Salt River Project

In order to analyze the combined effects of Bartlett and Horseshoe dams, the investigation reported in the following paragraphs used the data from two gage sites.

Upstream from the dam: Gage 09508500, Verde River below Tangle Creek, above Horseshoe Dam, Arizona, period of record 1945-1991.

Downstream close to the dam: Gage 09510000, Verde River below Bartlett Dam, Arizona, period of record 1904-1991.

Given these records it is possible to explore the combined effects of Bartlett and Horseshoe dams by comparing the flow of the Verde River below Bartlett Dam after the dams were completed in 1945 with the flow near Tangle Creek upstream from the dams during the same post-dam period.

1. Did Bartlett and Horseshoe dams reduce the magnitudes of the downstream mean annual peak flows?

Yes. The mean annual peak flow downstream from Bartlett Dam declined by two thirds after the dams were built (Table 5). The annual peak flows below Bartlett Dam were also only about half the magnitude of the annual peak flows upstream from the dams near Tangle Creek. The resulting active channel downstream from the dams is smaller than it was previously. However, large releases from the spillway at Bartlett Dam in floods of 1978, 1980, and 1993 restored some of the high flow channel processes on a temporary basis. The largest flows in the post-dam period are similar to the largest ones in the pre-dam period, but these very large flows were much more common in the pre-dam era as opposed to the post-dam period. Because the *mean* annual peak is much lower in the later period, the original high-flow geometry is not now functionally maintained. It does not receive periodic infusions of water, sediment, and nutrients, so that it is now an unchanging, inactive part of the landscape.

2. Did the closure of Bartlett and Horseshoe dams affect the variability of the annual peak flows?

Yes, but not in the expected way (Table 6). Coolidge Dam reduced the variability of downstream annual peak flows because it has a large storage volume with respect to the mean annual flow and flood flows of the Gila River. Bartlett and Horseshoe dams, on the other hand, are smaller relative to the Verde River (their combined storage amounts to only 77% of the mean annual water yield of the watershed), and they have large spillways and outlet works. By reducing the mean annual peak flows through storage, but releasing large amounts of water in a few floods, Bartlett and Horseshoe increased the variability of peak flows downstream. The geomorphic and ecologic implications of this change are that the functional part of the channel is limited (as it is in the Gila River case), but there are geomorphic surfaces downstream from the dams that are like the previous natural high flow channels, but they are only remnants of unusual events and are not active.

3. Have Horseshoe and Bartlett dams affected mean annual mean flows downstream?

Probably not. The mean annual flows downstream from the dams were greater after the dams were completed, probably as a result of increased precipitation and runoff in the watershed during the post-1945 period. Because there are no records from the Verde River below Tangle Creek, this explanation cannot be directly tested. In any case, the dams did not reduce the mean annual mean flow, and their variation is similar in the pre- and post-dam period.

4. Have Horseshoe and Bartlett dams affected mean annual low flows downstream?

Yes. The mean annual low flows are lower after the dams were closed. Before the closure of the dams, the mean annual low flow values were all greater than about 50 cfs, but after the closing of Bartlett Dam in 1939, most years experienced low flows below 50 cfs, with many years recording some days with zero flow. The generalization that dams increase low flows in order to deliver water to downstream users does not apply to the dams on the Verde River. As a result, ecosystems downstream from the dams often experience no-flow conditions.

5. What are the geomorphic and ecologic implications of the closure of Horseshoe and Bartlett dams?

Because of the hydrologic changes introduced into the Verde River hydrology by Horseshoe and Bartlett dams, the channel downstream from the structures is smaller and less complex than the original pre-dam channel. Because flood discharges shape the channel, and because these flows have been significantly reduced by the dams, the downstream channel has a limited active component. Spills from the dams have scoured enlarged channel geometries, but these high-flow channels are not active. They were created and then immediately abandoned by the subsequent small discharges, whereas in the pre-dam conditions they would have been periodically reoccupied.

The ordinary low flows during the year must be somewhat higher than in pre-dam conditions because although the daily mean discharges are broadly the same in pre- and post-dam eras, the lack of large annual high flows means that the only way to achieve the observed means in the post-dam period is to have somewhat elevated low flows. These low flows do not influence the geomorphology of the channel, because they do not generate sufficient stream power to move the bed and bank materials. The ordinary low flows do provide ecological benefits in the form of increased groundwater recharge and more abundant surface water most of the time. The dams have created a new situation for the lowest flows each year (as opposed to ordinary low flow conditions). Before the dams, the Verde flowed continuously, but after the dams, many years experience one or more days of zero flow. The absence of water on the surface and the resulting dry channel clearly represents a radical departure from the ecological conditions that existed before the dams. If these non-flow conditions occur for several weeks during the months when the southwestern willow flycatcher is in the region, the lack of water in the channel would be a deterrent to use of the impacted river and its riparian habitat by the bird.

Horseshoe and Bartlett dams store fine sediments that prior to their construction would have continued to move downstream. With the dams in place, these fine sediments are now largely absent from the Verde River below the dams. The channel and its near-channel active landforms are dominated by cobbles and boulders which do not form suitable substrate for vegetation likely to be useful as willow flycatcher habitat. The remaining dense vegetation along the system is mostly confined by inactive terraces and consists mostly of mesquite bosques that are remnant populations. Cottonwood, willow, and tamarisk colonize only a few small and isolated locals.

F. The Middle Rio Grande

The middle Rio Grande is the location of several nesting sites of the southwestern willow flycatcher, and potentially offers more habitat for the recovery of the species than is presently available. A key to habitat management and restoration of the river is its hydrology and the effects of dams. The northern Rio Grande flows from its headwaters in the San Juan Mountains into the large basin of the San Luis Valley in southern and southwestern Colorado. After crossing the border with New Mexico, the stream flows generally southward through the Rio Grande Gorge, and then through a rift valley to the southern edge of the state near El Paso, Texas. Three dams along this main stem are of interest in considering impacts on southwestern willow flycatcher habitat. The Rio Grande Dam and Reservoir is located in the Rocky Mountains headwaters area, and does not impact flows in the lower elevation riparian areas used by the southwestern willow flycatcher. Cochiti Dam is a large flood control structure at Cochiti Pueblo, near Santa Fe, in the middle reaches of the stream, and is a potential consideration for flycatcher habitat. Elephant Butte Dam is near Truth or Consequences in southern New Mexico. The dam is one of the oldest large dams in the United States and serves as a flood control, water storage, and diversion structure that may also affect flycatcher habitat. Basic information about the dams follows:

Rio Grande Dam
Dam closed: 1916
Reservoir: Rio Grande Reservoir
Storage Capacity: 52,192 ac ft
Storage Capacity as a Function of the Mean Annual Water Yield: No Data
Maximum Release Capacity: 8,300 cfs
Owner: San Luis Valley Irrigation District

Cochiti Dam
Dam closed: 1975
Reservoir: Cochiti Lake
Storage Capacity: 722,000 ac ft
Storage Capacity as a Function of the Mean Annual Water Yield: 0.61
Maximum Release Capacity: 136,360 cfs
Owner: U.S. Army Corps of Engineers

Elephant Butte Dam
Dam closed: 1916
Reservoir: Elephant Butte Reservoir
Storage Capacity: 2,337,298 ac ft
Storage Capacity as a Function of the Mean Annual Water Yield: 2.03
Maximum Release Capacity: 47,500 cfs
Owner: Bureau of Reclamation

Stream gages with long records geographically bracket Cochiti and Elephant Butte dams, and are useful for assessing the dams' impacts on downstream hydrology, geomorphology, and ecology.

Upstream from Cochiti Dam: Gage 08313000, Rio Grande at Otowi Bridge, NM, 1895-1991
Downstream from Cochiti Dam and upstream from Elephant Butte Dam: Gage 08319000, Rio Grande at San Felipe, NM, 1927-1991

Downstream from Elephant Butte Dam: Gage 08361000, Rio Grande Below Elephant Butte Dam, 1916-1991

The lengths of these gaging records provides data for a before and after assessment of the hydrologic effects of Cochiti Dam, as well as upstream vs. downstream comparisons for both Cochiti and Elephant Butte dams.

1. Did Cochiti Dam affect the magnitude of the mean annual peak flows of the Rio Grande?

Yes, but not as much as might be expected. Annual peak flows were always less downstream from the site of the dam, because flows were dissipated across flood-plain surfaces downstream from the dam site (these flood plains are likely to have supported important willow flycatcher habitat). Annual peak flows declined downstream after the dam was closed, but they also declined upstream, so part of the change was produced by hydroclimatic controls and operations of dams in the Rio Chama, a major tributary upstream from Cochiti and the gage at the Otowi Bridge (Table 7). The mean annual peak declined about 20% upstream from the dam, and about 24% downstream, but the means are only part of the story. Cochiti Dam eliminated the extreme flows downstream, as evidenced by floods in 1979 and 1985. The dam reduced the downstream peak flows by one third to one half in these two events. As the record becomes longer (it is now only 24 years long for the dam) more instances of this type will likely affect the mean annual peak values more strongly.

When the annual peak flow is expressed as a function of the annual mean flow, the Rio Grande appears to have a hydrologic behavior that is different from the behavior of the Gila and Verde rivers described above. In those streams, the annual peak flows were 20 to 40 times greater than the annual mean flows, showing tremendous variability. In the middle Rio Grande, the annual peak flows are only 2 to 5 times greater than the annual mean, with or without Cochiti Dam. As a result, the downstream impacts of the dam are played out within a more narrow range of hydrologic conditions and a more restricted set of river landforms than was the case with the Gila and Verde rivers.

2. Did Cochiti Dam affect the variability of annual peak flows of the Rio Grande?

Yes, the dam reduced the variation, but that variation was already relatively small before the structure was closed (Table 8). The standard deviation of annual peak flows of the Rio Grande at San Felipe, downstream from Cochiti, declined by about a third after the closure of the dam. Some of that decline would have occurred in any case because of upstream controls on the Rio Chama and hydroclimatic changes. In the case of the Gila and Verde rivers, the standard deviation of annual peak flows was greater than the mean of those values in pre-dam periods and even in the post-dam periods. In other words, the peak flows may have been reduced in magnitude by the dams, but they retained some variability. In the middle Rio Grande, this variability is much less, with the standard deviation of annual peak flows generally less than the mean. In other words, the peaks flows are more consistent and produce a much less complex geomorphology and riparian ecology. The maintenance of levees, pilot channels, and other engineering efforts in the middle Rio Grande also promote this simplification of the geomorphology and riparian ecology.

3. Did Cochiti Dam alter the annual mean flows of the Rio Grande?

Partly. Although the dam is large with respect to the river, capable of storing 60% of the mean annual runoff upstream, its operation is predicated on passing normal flows of water through to downstream users in agricultural and urban areas (Tables 7 and 8). Upstream from the dam, moderate hydroclimatic changes caused mean flows to increase after the dam was closed, and the dam appears not to have a detrimental effect on this parameter downstream. On the other hand, the variation of mean flows declined about 20% downstream from Cochiti, indicating that the structure is modulating the variability of mean flows.

4. Did Cochiti Dam affect mean annual low flows in the Rio Grande?

Partially. The dam sustains low flow conditions that existed prior to its construction. The variation of low flows declined by about one third, meaning that low flows were less variable after the closure of the dam.

5. What are the likely downstream geomorphic and ecological effects of Cochiti Dam?

Reduced magnitudes for annual peak flows combined with decreased variation in annual peak, mean, and low flows all promote a geomorphic and riparian system downstream that is simplified from its original configuration. Engineering structures along the river downstream from Cochiti have designs that use this simplification to constrain the river and eliminate its processes from large areas of what were once active riparian zones along the course of the river. The river functions more like a canal than a natural river.

Cochiti Dam stores sediment in its reservoir, so that the reaches of the river immediately downstream from the structure are starved for material. Erosion of some river reaches has resulted along the stream for a distance of up to 150 miles, where infusions of sediment from the Rio Puerco and Rio Salado restore large amounts of sediment to the system. Some sediment augmentation is in order below the dam for restoration purposes, appropriately limited, however, to avoid excessive sedimentation in reaches of the channel where elevation of the bed poses tributary flooding problems in the Albuquerque area.

6. What have been the downstream effects of Elephant Butte Dam?

Elephant Butte Dam completes the conversion of the Rio Grande from a river to a canal. Mean annual peak flows downstream from the dam are less than one third their values in the middle river upstream, and the annual variability of the peak flows is tiny compared with other river reaches (Tables 7 and 8). Water diversions, and to a lesser degree evaporation and seepage losses, depreciate the flow, so that annual mean flows in the channel are also low. These mean flows are predicated on downstream water delivery requirements, and because the dam and reservoir are so large (able to store more than twice the mean annual inflow from upstream) the downstream system is highly consistent with respect to annual mean flows. Annual low flows show more variability, but in recent years they have been exceptionally low, with many years experiencing some days of zero flow.

7. What are the geomorphic and ecological effects of Elephant Butte Dam?

The Rio Grande downstream from Elephant Butte Dam is not a river in the normal sense of the word. It does not physically function in response to hydroclimatological forcing mechanisms, and is a simple conduit for water viewed as a commodity. The channel is highly simplified and relatively unvariable. Though the channel and near-channel landforms can support riparian habitats suitable for southwestern willow flycatchers, such arrangements are highly limited and artificial.

G. The Lower Colorado River

The lower Colorado River contains several southwestern willow flycatcher nesting sites, and prior to about 1950 numerous willow flycatcher specimens were observed and collected there. Because of the potential extent of riparian forest in the lower Colorado River, the hydrologic behavior of the river as influenced by upstream dams is critical for understanding environmental change and planning restoration of the river. Numerous large dams throughout the upstream basin exert some control on the flow of the Colorado River between Arizona and California, but the major controls on that segment of the river are three dams immediately upstream: Hoover, Davis, and Parker dams. These dams strongly influence the hydrology of the river, and thus also influence the geomorphology and riparian ecology of the stream, both of which are directly linked to habitat useful for the southwestern willow flycatcher. Basic information about the dams follows:

Hoover Dam
Dam closed: 1936
Reservoir: Lake Mead
Storage Capacity: 30,237,000 ac ft
Storage Capacity as a Function of the Mean Annual Water Yield: 2.24
Maximum Release Capacity: 200,000 cfs
Owner: U.S. Bureau of Reclamation

Davis Dam

Dam closed: 1953
Reservoir: Lake Mohave
Storage Capacity: 1,818,300 ac ft
Storage Capacity as a Function of the Mean Annual Water Yield: 0.13
Maximum Release Capacity: 216,000 cfs
Owner: U.S. Bureau of Reclamation

Parker Dam

Dam closed: 1938
Reservoir: Lake Havasu
Storage Capacity: 619,400 ac ft
Storage Capacity as a Function of the Mean Annual Water Yield: 0.05
Maximum Release Capacity: 314,000 cfs
Owner: U.S. Bureau of Reclamation

The most useful stream gage for assessing the hydrology of the river from Parker Dam to the United States/Mexican border is at Yuma: Gage: 09521000, Colorado River at Yuma, AZ, 1905-1984. The gage provides a data-based view of the hydrology of the river during three distinct periods: first, before any of the large dams was in place (1905-1936); second, when Hoover and Parker dams were the only influence on the lower river (1937-1953); and third, when all three structures were in place along with their associated withdrawal systems. Unfortunately the gage record ends too soon to assess the most recent history of the river after 1984.

1. Have the dams changed the mean annual peak flows on the Lower Colorado River?

Yes, dramatically. One of the primary reasons (in addition to water supply and hydropower) that the dams are in place is to provide flood control, and they excel at this mission (Table 9). Before the dams were in place, the Lower Colorado River had a large channel to accommodate annual peak flows that averaged almost 93,000 cfs. With Hoover and Parker dams in place, these annual peak flows declined to about 18,000 cfs, and with all three dams in place after 1953 the annual peak flows averaged only 5,500 cfs, a mere 6% of their former, pre-dam magnitude. The dams reduced the variability of these annual peaks in absolute terms as well (Table 10), so that the standard deviation of the annual peak flows declined from their natural value of 51,500 cfs to only 3,500 cfs. However, in terms of the prevailing means, the variability was roughly the same throughout the record, with the standard deviation always less than the mean.

2. Have the dams changed the mean annual mean flows on the Lower Colorado River?

Yes, the dams have substantially reduced annual mean flows for the Lower Colorado River (Table 9). Before the dams were in place, the mean annual mean flow in the Lower Colorado River was more than 21,000 cfs, but by the time all three dams were in place and water withdrawals from their reservoirs into canals became a feature of the system, the mean annual mean flow had dropped to only 2,100 cfs. This annual mean flow is now less that the annual lowest flows that existed prior to the construction of the dams. The variability of the mean annual mean flows also declined to a similar degree, so that the relative variability when assessed as a function of the mean remained little changed (Table 10). In other words, the entire hydrologic system has shrunken in response to dams and diversions.

3. Have the dams changed the mean annual low flow conditions on the Lower Colorado River?

Yes, to a degree similar to the other changes outlined above (Tables 9 and 10). Before the dams were in place, the mean annual low flow was 2,900 cfs, but now the mean annual low flows are a paltry 500 cfs, or a reduction to only 17% of the pre-dam values. Absolute variability has declined in a similar fashion, with standard deviations expressed as a function of the mean remaining less than one throughout the record.

4. What are the geomorphic and riparian ecological implications of the hydrologic effects of the dams?

The Lower Colorado River is a miniature ghost of its former self, with its entire hydrologic, geomorphic, and ecologic system shrunken to a fraction of its former size. Channelization and levees have aided the effects of major water withdrawals and successful flood control efforts centered on the major dams of the river. The channel has changed completely from a braided, multi-threaded system to one characterized by a narrow single thread. Where once there was a complex series of landforms and environments at each cross section of the stream, there now remains a highly simplified system that is more similar to a canal than a river. The flood plain outside the channel that once was active is now largely inactive. The diverse riparian habitat system, favorable for a variety of species including the southwestern willow flycatcher, has become a highly simplified system with limited diversity.

The timing of these impacts of dams is instructive. Biologists observed that the decline in many riparian bird species became significant in the 1950s. By that time, the effects of Hoover Dam had been seen in the fluvial system of the Lower Colorado River for a decade and a half. But they were then compounded by the closure of Davis Dam in 1953. From 1954 onward, the full impact of flow changes with associated geomorphic and ecologic changes became apparent. The accelerated decline of bird populations that had depended on the previously existing hydrologic, geomorphic, and vegetative system, simply reflected these dramatic changes in river processes and forms.

H. Recommendations

The foregoing review of the effects of dams on regulated rivers in the range of the endangered southwestern willow flycatcher leads to a set of logical recommendations for the recovery of the bird population. The purpose of these recommendations is to set out what is needed for the reestablishment of a functional hydrologic and geomorphic system, which serves as a physical substrate for an ecosystem likely to support suitable habitat for the bird in the Southwestern United States.

1. Dam Operating Rules and Rivers as Ecosystems and Commodities

Issue: Dam operating rules and decision-making are focused on obvious, direct economic goals, and treat rivers simply as commodity water and power resources, leaving little administrative space for endangered species. As a result, operating rules address commodity management rather than broader objectives.

Recommendation: Treat the rivers as landscapes and ecosystems, and as public trust resources rather than merely as commodity resources. Laws, regulations, and agreements governing the distribution of water are exceptionally difficult to change, but in the past these arrangements have evolved to meet new needs. The continued evolution of the arrangements benefits everyone and avoids a potential judicial clash between the laws of the river and the ESA. Generally, include these broadened objectives in revisions of the laws of the river as well as interstate water compacts and administrative rule decisions. Include recovery of endangered species as one of the multiple objectives in all dam operating rules so they are recognized as part of the multiple objective decision process, and to insure that tradeoffs and costs can be clearly understood. Apply this recommendation generally in the recovery plan, and specifically to all major dams in the range of the southwestern willow flycatcher.

2. Hydrodiversity, Geodiversity, and Biodiversity

Issue: Downstream geomorphic systems have become highly simplified because of dam operations, with the resulting loss of ecologic complexity needed for flycatcher habitat.

Recommendation: Allow occasionally complex flow regimes with a wide range of discharge levels within the shrunken channel system as well as flood or spike flows, all to reintroduce the complexity of hydrodiversity and geodiversity, which will lead to biodiversity. In many years, this new regime would not necessarily result in increased water releases, but rather releases on a schedule different from the present one. High or spike flows should be released in winter months to most benefit the native vegetation and should be avoided in summer months when they most benefit exotic vegetation. Examples where this recommendation should be explored in detail include Cochiti, Elephant Butte, Coolidge, Bartlett/Horseshoe, Stewart Mountain, and Hoover/Parker dams, as well as Bradbury Dam on the Santa Ynez River of California and other smaller California coastal streams.

3. Water for Recovery

Issue: Many solutions for improving habitat for the southwestern willow flycatcher require increased availability of water in active channels or in near-channel areas. This issue is important throughout the range of the southwestern willow flycatcher.

Recommendation: Water purchases, other acquisition procedures, and other water management strategies are likely to be required in a comprehensive recovery of the species. Because agricultural withdrawals from rivers and groundwater are much larger than by any other economic sector, the agricultural community must be part of any long-term solution. Engage agricultural interests in all major watersheds in the range of the southwestern willow flycatcher to consult with agencies and other parties to take proactive measures to provide more water in rivers throughout the range of the southwestern willow flycatcher. Examples where this recommendation should be explored in detail include the Lower Colorado River near Yuma, lower San Pedro River, middle Gila River, and the Middle Rio Grande.

4. Instream Flows, Reactivated Channels, and Habitats

Issue: Flycatchers, Rio Grande silvery minnow, and many other endangered species require a continuous flow of water in the rivers they use, yet dams and diversions dessicate some channel reaches and completely eliminate flow.

Recommendation: Provide low level instream flows (enough merely to establish a wetted perimeter and a visible surface flow) during low flow periods downstream from dams and diversions as a general policy in the recovery plan applicable throughout the range of the southwestern willow flycatcher. Measure these flows at stream gages to assure the water is positively affecting the intended flycatcher habitat and at the appropriate times such as winter to sustain native vegetation and during the late spring to late summer breeding season of the bird. Procure water rights for delivery at desired times to hydrate flycatcher habitat.

Examples where this recommendation should be explored in detail include the Colorado River near Yuma, the Rio Grande downstream from San Acacia Dam, and the Gila River downstream from Ashurst/Hayden Dam.

5. *Shrinkage of River Channels and Habitat*

Issue: Reservoir storage and diversions have caused river channels and their associated landscapes to become drastically more narrow through shrinkage because of water withdrawals. Levees with narrow spaces between them have stabilized the restricted widths. As a result, the original natural riparian forest and potential southwestern willow flycatcher habitat has also shrunk, becoming discontinuous along the alignment of channels.

Recommendation: Increase the width of the active channel zone and improve the along-channel connectivity of rivers by insuring continuous instream flows and allowing occasional minor floods with peak flows large enough to expand channel systems from their present shrunken dimensions. Make flows large enough to accomplish this expansion and increase the space between the levees (by moving them further apart, leaving a larger channel area) throughout the range of the southwestern willow flycatcher. Examples where this recommendation should be explored in detail include the Rio Grande, Lower Colorado River, coastal California streams, and streams in the Central Valley of California.

6. *Reactivated Flood Plains and Habitats*

Issue: Flood plains, oxbows on single-thread channels, and secondary channels on braided streams have become inactive because of flood suppression by dams, entrenchment, and isolation by levees, and elimination of beaver, all of which have reduced the vitality of native riparian forests or completely eliminated them.

Recommendation: Permit overbank flows in selected locations to expand wetlands and riparian forests by larger releases from dams when excess water is available, or manage conveyance to include peak flows. Install gates temporarily (permanently where possible) in selected levees to reactivate flood plains and abandoned channels behind the structures. Pump, syphon, or divert water to flood plains abandoned by channel entrenchment. For these rivers (e.g., Colorado River), the flood plain refers to the flood plain of the existing river rather than the pre-dam historic flood plain. Reintroduce beaver on small and intermediate systems.

7. *Sediment Augmentation and Habitat Restoration*

Issue: Dams trap sediments and release erosive clear-water discharges, stripping downstream areas of sediment (mostly sand, silt, and clay in interior streams, mostly sand and coarse sediments in California streams) and eliminating the native vegetation and habitats that were developed on the deposits, including habitat areas for the southwestern willow flycatcher.

Recommendation: Augment the sediment supply of river reaches downstream from Coolidge, Bartlett, Stewart Mountain, Parker and smaller dams on Coastal California streams to replace the fine sediments artificially removed in upstream reservoirs, with due care to insure that sediments containing hazardous levels of heavy metals, pesticides, and herbicides are not re-mobilized, and that downstream fish habitats are not adversely affected. Augmentation may use sediments from the upstream reservoirs delivered through a slurry system, or from other sources using mechanical methods. A thorough assessment of anticipated consequences should precede such an effort to insure that there will be sufficient water discharges to move the sediment to desired locations on bars and flood plains.

8. *Multi-Species Planning*

Issue: Planning for recovery of the southwestern willow flycatcher is directly related to planning for other endangered riparian bird species and native fishes, because they all are dependent on the same hydrologic, geomorphic, and vegetation systems. Decisions that affect one species will inevitably affect all of them, yet recovery planning and implementation efforts are not formally connected.

Recommendation: Formally connect planning and decision making for the recovery of the southwestern willow flycatcher with the recovery of the Rio Grande silvery minnow on the Rio Grande, and with the native fishes in the Lower Colorado River. Determine likely interaction effects of implementing a plan for one species on the other endangered species.

I. Conclusions

Dams were structured to regulate flows to simplified regimes in order to deliver water to downstream users, generate hydroelectricity, enhance navigation, and provide recreation. The unintended and unforeseen effects of creating this artificial hydrology have included simplified fluvial geomorphology and riparian systems which reduce potential southwestern willow flycatcher habitat and restrict restoration. To increase habitat and provide restoration of riparian habitat and the physical systems on which it depends requires partially reversing some of the changes in hydrology produced by dams. Dams and their operations provide opportunities to resolve some of the habitat issues in recovering the southwestern willow flycatcher population. Existing theory and practice for the management of dams and the hydrology they produce, both downstream and upstream in their reservoirs, provide enough understanding to use the structures in recovery efforts.

The hydrology of the Gila, Verde, Rio Grande, and Lower Colorado rivers has been dramatically altered by dams, but all dams are not created equal (Table 11). Their effects vary from one river to another, depending on the original purpose of the structures, their architecture, their operating rules, and the original natural characteristics of the stream channels downstream. Despite these differences, however, dams generally cause the restriction of southwestern willow flycatcher habitat by reducing the extent and complexity of riparian ecosystems through two mechanisms: channel shrinkage and reduced hydro- and geocomplexity. Reduced peak flows and reduced variability of flows of all magnitudes and frequency leads to this channel shrinkage and simplification of the riparian system. These changes in scale and complexity have caused environmental changes unfavorable to the maintenance of willow flycatcher habitat. Restoration of such habitat depends in part on reversing the hydrologic changes brought about by dams to reintroduce larger and more variable flows downstream from dams. Dams and their operation represent opportunities to manage the hydrology, geomorphology, and vegetation that are indispensable components of the flycatcher's habitat. Dams have been major actors in the changes of southwestern rivers and their riparian habitats, and they represent tools for reversing the changes to more favorable conditions for the recovery of the willow flycatcher population.

J. Literature Cited

Please see Recovery Plan Section VI.

Table 1. General water and dam data for major water resource regions of the American Southwest.

Water Resource Region	**Rio Grande**	**U. Colorado**	**L. Colorado**	**Great Basin**	**California**
Dams and Storage Capacity, Runoff					
Total Number of Dams	716	1,164	446	803	1,530
Number of Dams Storing more than 100,000 ac ft.	18	25	23	13	94
Total Storage (ac ft)	21,013,562	46,364,999	48,373,154	5,979,380	74,161,688
Total Annual Runoff (ac ft) [1]	5,487,880	15,063,670	18,982,714	6,596,655	72,910,402
Storage/Runoff	3.83	3.08	2.55	0.91	1.02
Human Population [2]	2,566,000	714,000	5,318,000	2,405,000	32,060,000
Surface Fresh Water Withdrawals (ac ft per yr)					
Public Supply	146,720	118,720	781,760	284,480	3,225,600
Domestic	0	448	224	1,792	13,440
Commercial	2,240	784	8,400	16,800	357,280
Irrigation	5,152,000	7,828,800	4,704,000	4,502,400	20,384,000
Livestock	9,520	56,000	7,616	86,240	248,640
Industrial	112	4,480	6,160	34,720	21,280
Mining	2,240	4,480	29,120	2,240	69,440
Thermoelectric	2,240	163,520	243,040	23,520	226,240
Total	5,308,800	8,187,200	5,566,400	4,950,400	24,528,000
Ground Fresh Water Withdrawals (ac ft per yr)					
Public Supply	398,720	39,200	533,120	392,000	3,057,600
Domestic	28,000	12,320	49,280	14,560	125,440
Commercial	19040	6270	24,640	11,200	86,240
Irrigation	1,590,400	42,560	2,475,200	1,220,800	12,208,000
Livestock	30,240	4,480	36,960	10,304	258,720
Industrial	11,200	2,240	47,040	67,200	584,640
Mining	59,360	22,400	141,120	79,520	17,920
Thermoelectric	17,920	15,680	50,400	2,912	4,032
Total	2,161,600	129,920	3,360,000	1,803,200	16,352,000

[1] Total annual runoff is the USGS estimate from Solley et al. (1998) for the amount of water yielded from the watershed. The upper basin is that which passes Lee's Ferry, while the lower basin is that plus additions from the lower basin.

[2] For the Lower Colorado River, population data do not include those living outside the watershed but who use water from trans-basin diversions. In southern California, about 17 million depend in some degree on water from the Colorado River, and other diversions from the basin affect residents in New Mexico (and by connection Mexico and Texas) as well as Colorado. Note: Public Supply data for the Lower Colorado River do not account for 2.6-2.7 maf/yr diverted to southern California.

Sources: Dams and runoff data from Graf (1999), human population data from U.S. Census information 1990, surface and ground water data from Solley *et al.* 1998.

Notes: Figures may not add to totals because of independent rounding. Original published water use data were in millions of gallons per day, converted to ac ft per year by dividing by 3.259×10^5 to convert gallons to ac ft, and multiplying the result by 365 to convert from days to year.

Table 2. Mean annual peak, mean, and low flows for the Gila River upstream (near Safford), immediately downstream (below Coolidge Dam), and more distant downstream (at Kelvin) of Coolidge Dam. The notation "/m" indicates values expressed as divided by the mean annual mean flow.

Flow	Near Safford		Below Coolidge Dam		At Kelvin	
	cfs	(/m)	cfs	(/m)	cfs	(/m)
Mean Annual Peak Flow						
Pre-Dam	21,834	29.78	16,236	32.47	33,512	89.13
Post-Dam	18,015	42.79	902	2.81	12,076	28.08
Mean Annual Mean Flow						
Pre-Dam	733	1.00	500	1.00	376	1.00
Post-Dam	421	1.00	321	1.00	430	1.00
Mean Annual Low Flow						
Pre-Dam	53	0.07	4	0.01	9	0.02
Post-Dam	47	0.11	3	0.01	33	0.08

Table 3. Monthly frequency of annual peak flows, Gila River gages upstream and downstream from Coolidge Dam, before and after closure of the structure.

Safford				**Kelvin**		
Month Frequencies				**Month Frequencies**		
Pre-Dam				**Pre-Dam**		
Month	**Frequency**	**%**		**Month**	**Frequency**	**%**
1	1	7%		1	1	7%
2	0	0%		2	1	7%
3	0	0%		3	0	0%
4	1	7%		4	0	0%
5	0	0%		5	0	0%
6	0	0%		6	0	0%
7	1	7%		7	3	20%
8	6	40%		8	3	20%
9	2	13%		9	3	20%
10	1	7%		10	1	7%
11	0	0%		11	0	0%
12	3	20%		12	3	20%
Total =	15	100%		Total =	15	100%
Safford				**Kelvin**		
Month Frequencies				**Month Frequencies**		
Post-Dam				**Post-Dam**		
Month	**Frequency**	**%**		**Month**	**Frequency**	**%**
1	5	7%		1	4	6%
2	7	10%		2	4	6%
3	6	9%		3	4	6%
4	0	0%		4	0	0%
5	0	0%		5	0	0%
6	1	1%		6	0	0%
7	7	10%		7	9	13%
8	14	21%		8	28	41%
9	12	18%		9	7	10%
10	10	15%		10	5	7%
11	1	1%		11	0	0%
12	5	7%		12	7	10%
Total =	68	100%		Total =	68	100%

Table 4. Standard deviations (S.D.) for the annual peak, mean, and low flows for the Gila River upstream (near Safford), immediately downstream (below Coolidge Dam), and more distant downstream (at Kelvin) of Coolidge Dam. C.V. is the coefficient of variation, or the standard deviation divided by the mean, a way of standardizing comparisons across different magnitudes of discharge.

Flow	Near Safford		Below Coolidge Dam		At Kelvin	
	S.D., cfs	**C.V.**	**S.D., cfs**	**C.V.**	**S.D., cfs**	**C.V.**
Standard Deviation of Annual Peak Flow						
Pre-Dam	27,299	1.25	25,441	1.57	34,404	1.03
Post-Dam	23,194	1.28	787	0.87	14,468	1.20
Standard Deviation of Annual Mean Flow						
Pre-Dam	122	0.17	137	0.27	177	0.47
Post-Dam	281	0.67	204	0.64	254	0.59
Standard Deviation of Annual Low Flow						
Pre-Dam	2	0.04	1	0.25	3	0.33
Post-Dam	3	0.06	5	1.67	3	0.09

Table 5. Mean annual peak, mean, and low flows for the Verde River upstream from Bartlett and Horseshoe dams at Tangle Creek, and downstream from the structures, below Bartlett Dam. No data are available for the gage below Tangle Creek for the pre-dam period. The notation "/m flow" indicates values expressed as divided by the mean annual mean flow.

Flow	Below Tangle Creek		Below Bartlett Dam	
	cfs	(/m)	cfs	(/m)
Mean Annual Peak Flow				
Pre-Dam	--	--	22,231	26.9
Post-Dam	15,065	27.1	8,173	8.3
Mean Annual Mean Flow				
Pre-Dam	--	--	826	1.0
Post-Dam	555	1.0	991	1.0
Mean Annual Low Flow				
Pre-Dam	--	--	79	0.10
Post-Dam	94	0.17	14	0.01

Table 6. Standard deviations (S.D.) for the Verde River annual peak, mean, and low flows upstream from Bartlett and Horseshoe dams at Tangle Creek, and downstream from the structures, below Bartlett Dam. No data are available for the gage below Tangle Creek for the pre-dam period. C.V. is the coefficient of variation, or the standard deviation divided by the mean, a way of standardizing comparisons across different magnitudes of discharge.

Flow	**Below Tangle Creek**		**Below Bartlett Dam**	
	S.D., cfs	**C.V.**	**S.D., cfs**	**C.V.**
Standard Deviation of Annual Peak Flow				
Pre-Dam	--	--	18,734	0.83
Post-Dam	16,963	1.12	15,395	1.88
Standard Deviation of Annual Mean Flow				
Pre-Dam	--	--	465	0.56
Post-Dam	376	0.68	383	0.69
Standard Deviation of Annual Low Flow				
Pre-Dam	--	--	39	0.49
Post-Dam	23	0.25	20	1.43

Table 7. Mean annual peak, mean, and low flows for the Rio Grande upstream from Cochiti Dam (at Otowi Bridge), downstream from Cochiti Dam (at San Felipe), and downstream from Elephant Butte Dam. The notation "/m" indicates values expressed as divided by the mean annual mean flow.

Flow	At Otowi Bridge		At San Felipe		Below Elephant Butte	
	cfs	(/m)	cfs	(/m)	cfs	(/m)
Mean Annual Peak Flow						
Pre-Cochiti	7,633	5.16	6,342	4.80	2,324	2.40
Post-Cochiti	6,156	3.74	4,839	3.04	2,596	2.59
Mean Annual Mean Flow						
Pre-Cochiti	1,478	1.0	1,322	1.0	969	1.0
Post-Cochiti	1,646	1.0	1,591	1.0	1001	1.0
Mean Annual Low Flow						
Pre-Cochiti	261	0.18	208	0.16	75	0.08
Post-Cochiti	363	0.22	211	0.13	11	0.01

Table 8. Standard deviations (S.D.) for the mean annual peak, mean, and low flows for the Rio Grande upstream from Cochiti Dam (at Otowi Bridge), downstream from Cochiti Dam (at San Felipe), and downstream from Elephant Butte Dam. C.V. is the coefficient of variation, or the standard deviation divided by the mean.

Flow	**At Otowi Bridge**		**At San Felipe**		**Below Elephant Butte**	
	S.D., cfs	**C.V.**	**S.D., cfs**	**C.V.**	**S.D., cfs**	**C.V.**
Standard Deviation of the Annual Peak Flow						
Pre-Cochiti	5,099	3.45	4,358	0.69	902	0.39
Post-Cochiti	3,376	0.55	2,104	0.43	833	0.32
Standard Deviation of the Annual Mean Flow						
Pre-Cochiti	715	0.48	685	0.52	379	0.39
Post-Cochiti	696	0.42	663	0.41	407	0.41
Standard Deviation of the Annual Low Flow						
Pre-Cochiti	130	0.50	155	0.75	203	2.71
Post-Cochiti	155	0.43	99	0.47	27	2.45

Table 9. Mean annual peak, mean, and low flows for the Colorado River at Yuma, downstream from Hoover, Davis, and Parker dams. The notation "/m flow" indicates values expressed as divided by the mean annual mean flow.

Flow	At Yuma	
	cfs	(/m)
Mean Annual Peak Flow		
Pre-Dam	92,913	4.41
With Hoover and Parker	17,899	2.00
With all dams	5,479	2.55
Mean Annual Mean Flow		
Pre-Dam	21,067	1.00
With Hoover and Parker	8,949	1.00
With all dams	2,145	1.00
Mean Annual Low Flow		
Pre-Dam	2,901	0.14
With Hoover and Parker	2,568	0.29
With all dams	514	0.24

Table 10. Standard deviations (S.D.) for the Colorado River at Yuma, downstream from Hoover, Davis, and Parker dams. C.V. is the coefficient of variation, or the standard deviation divided by the mean, a way of standardizing comparisons across different magnitudes of discharge.

Flow	At Yuma	
	S.D., cfs	C.V.
Standard Deviation of the Annual Peak Flow		
Pre-Dam	51,471	0.55
With Hoover and Parker	7,004	0.39
With all dams	3,499	0.64
Standard Deviation of the Annual Mean Flow		
Pre-Dam	7,844	0.37
With Hoover and Parker	4,299	0.48
With all dams	1,338	0.62
Standard Deviation of the Annual Low Flow		
Pre-Dam	1,755	0.61
With Hoover and Parker	2,228	0.87
With all dams	253	0.49

Table 11. Summary of the most significant downstream effects of dams on river regulation for selected river segments in the southwestern willow flycatcher range.

River	Segment	Effects of Regulation
Gila River	Below Coolidge Dam	Loss of annual peak flows, loss of complex flows, sediment starvation (fine materials)
	Below Ashurst/Hayden Dam	No instream flows
Rio Grande	Below Cochiti Dam	Decreased flow variability at all discharges, loss of annual peak flows
	Below San Acacia Dam	No instream flows
	Below Elephant Butte Dam	Loss of peak flows and variability at all flows
	Below Caballo Dam	No instream flows
Lower Colorado River	Below Parker Dam	Reduced flows at Yuma
	Below Mexican Diversions	No instream flows
Verde River	Below Horseshoe and Bartlett Dams	Loss of annual peak flows, frequent loss of low flows, loss of flow variability at all levels, sediment starvation (fine materials)
California Coastal Rivers	Santa Ynez below Bradbury Dam	Loss of annual peak flows, frequent loss of low flows, sediment starvation (sand and coarse materials)