



The Verde River is a critical component of life in central Arizona and beyond, for both natural and human communities. The Verde River and its perennial tributaries provide about 400 miles of interconnected, perennial flow and riparian habitat. The river sustains a wide variety of plants and animals, provides recreational opportunities, and serves as a primary water source for several towns and cities, including metropolitan Phoenix. Perennial flow begins at a series of springs near the confluence with Granite Creek, which supply base flow for the upper 26 miles of the river. Groundwater inflow and tributary surface water adds to the base flow downstream and through the Verde Valley. There are two dams on the lower Verde River, forming Horseshoe and Bartlett lakes. This study focused on the upper and middle Verde River, above the Camp Verde stream gage.

Apparent conflicts have developed between human communities in different parts of the watershed and between human demands for water and those of the plants and animals that use the river. Such issues are not unique to the Verde River, and experience in watersheds around the world has shown that conflict can be resolved through better understanding of the water needs of the ecosystem. With that information in hand, water managers can work for solutions that meet the needs of all users.

### DESCRIPTION OF STUDY

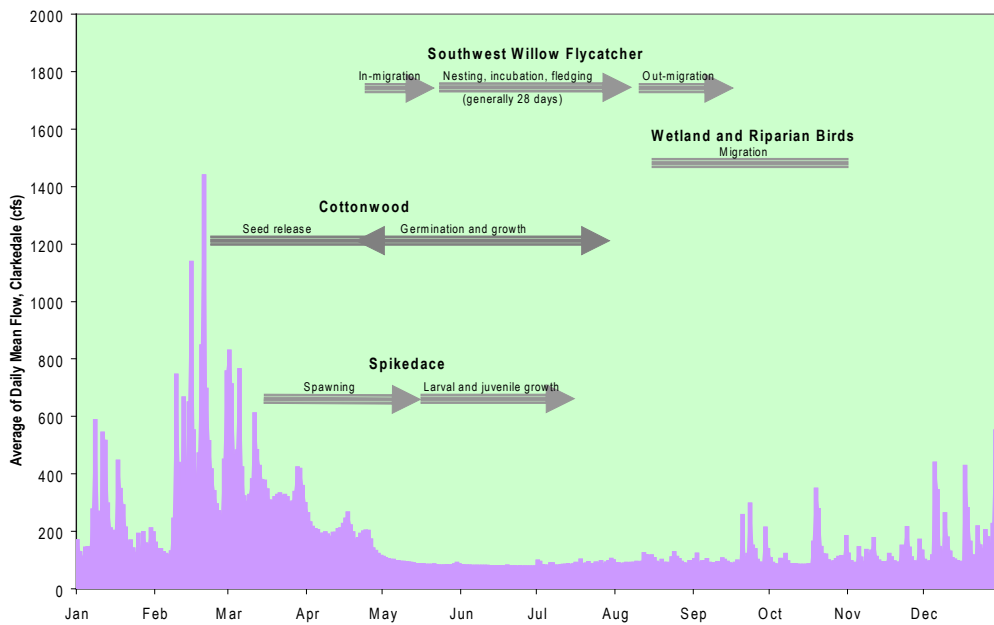
The Verde River Ecological Flows study is a collaboration between The Nature Conservancy, Arizona Water Institute, and Verde River Basin Partnership. Funds were provided by an AWI grant and the Laurie Wirt Memorial Fund.



The purpose of the study is to develop a conceptual understanding of how the Verde River ecosystem would respond to variations in the river's hydrology—especially to decreases in river flows. The study team compiled and summarized what is known about the river's physical and ecological characteristics, drawing upon available data and what is known about hydrology-biology relationships on similar rivers. The team then convened a two-day workshop that brought together 35 scientists from 16 agencies, universities, and organizations. These experts in river hydrology, geomorphology, and a range



Figure 1. Verde River watershed, showing extent of perennial flow.



**Figure 2.** Conceptual ecological model for the Verde River. The purple area shows average daily flow for the period of record (1963-2007) at the Clarkdale gage. The grey lines and arrows show approximate timing for life stages of key river-dependent animals and plants. These life stages are tied to particular flow regimes on the river that provide habitat, prey base, or other environmental conditions necessary for reproduction and survival. River dependent organisms developed life histories that are tied to the natural flow regime; changes in the flow regime affect their ability to thrive.

of life sciences pooled their knowledge to produce a set of flow-ecology response models for the Verde River. These models are a set of hypotheses predicting how a reduction in flow would affect specific species of plants or animals. In addition, workshop participants identified major gaps in the available information and outlined a research agenda.

## ENVIRONMENTAL FLOWS

When water managers reserve a portion of the flows in a river for the support of river ecosystems, the reserved amount is termed “environmental flow.” The concept includes not only the minimum or base flow needed, but also how the flow varies over time: its magnitude, frequency, duration and timing, and depth to groundwater near the stream. The first step in designing environmental flows is to develop scientifically credible estimates of ecosystem water needs.

Flow-ecology response models describe the relationships between hydrologic variability and ecological response. They provide a visual representation of how change in base flow in the Verde River is likely to affect the species of interest, given what is known about how the species uses the river. The flow-ecology response curves developed during this study are based on expert knowledge of the physical systems and species, both through field observations and scientific literature. They are reasonable hypotheses that will require careful study of the Verde River ecosystem to refine and confirm.

## RESULTS

For some animals and plants, such as cottonwood trees, considerable data exist that link success at various life

cycle stages to stream flow and groundwater levels. Others, such as fish, have more complex responses that are more difficult to quantify. However, for even the most complex organisms, enough is known to develop conceptual flow-ecology response models that may be tested with the results of future research. Some flow-ecology response models indicate threshold relationships, others indicate linear relationships; in either case, models indicate when certain parts of the biological community may be lost as flow declines. When refined with adequate data, response models provide advance warning of species loss from the river system in time to prevent it.

## Riparian and Wetland Plant Communities

Riparian forest response to stream flow regime and depth-to-groundwater fluctuations have been extensively studied in southwestern rivers. Cottonwood and willow trees rely primarily on groundwater and are sensitive to fluctuating levels. Declines of one meter have killed cottonwood and willow saplings; mature trees have been killed by drops of one meter that were abrupt and permanent. Tamarisk, on the other hand, is a deep-rooted species that can switch between rain-fed soil water and groundwater, giving it a higher tolerance to water stress. Depth to groundwater adjacent to the river is tied to the volume of streamflow. If streamflow declines, so does the groundwater level.

More intermittent flows, deeper groundwater levels, and larger groundwater fluctuations all are linked with: 1) declines in cottonwood and willow abundance; 2) decreases in structural diversity; and 3) increases in non-native species such as tamarisk. If threshold values are exceeded for streamflow permanence and depth to

groundwater, cottonwoods, willows and alder will die and are likely to be replaced by more drought-tolerant plants, such as tamarisk, desert willow, and mesquite. The riparian forest is likely to shift from tall trees to short trees or shrublands.

Wetland plants are highly sensitive to declines in surface water level. If base flow were to decline, the extent of saturated soils would shrink. Wetland vegetation would shift closer to the channel where it is at higher risk of flood scour. If perennial flow became intermittent and channel soils drier, the abundance of wetland plants would decline sharply. Plant community composition would shift from plants such as cattail, rush and spike rush to plants such as bermuda grass. In addition, species diversity would decrease as the number of no-flow days per year increased.

### Native Wildlife

Workshop participants developed flow-ecology models for a variety of wildlife species. Loss of wetland and riparian plants and shifts toward more dry-adapted plant communities would have predictable consequences for wildlife due to habitat changes. Reductions in the extent and diversity of riparian habitat would likely lead to declines in the populations of several bird species. The southwestern willow flycatcher, an endangered species, is riparian-dependent and prefers the high-density foliage

of cottonwood-willow forests for nesting. The health of the species thus is linked with the health of these forests. Another bird of conservation concern, the yellow-billed cuckoo, also breeds in riparian woodlands and typically require large patches of mature forest. Both birds are insect eaters and would likely be affected if reductions in base flow led to declines in insect populations.

Other birds likely to be affected by habitat constriction caused by reduced river flow are wetland species such as the common yellowthroat, Virginia rail, sora, and least bittern. These birds are closely associated with cattail marshes.

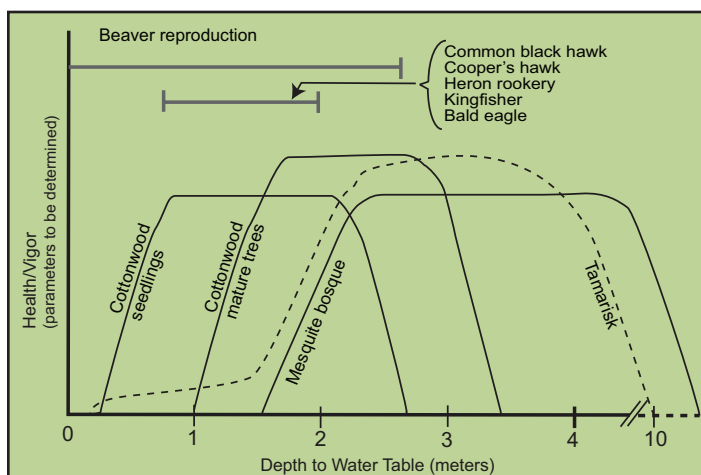
The three aquatic mammal species found in the Verde Valley: beaver, muskrat, and river otter, would be expected to respond negatively to reduced river flows, especially in dry summer months. Beavers, which depend on cottonwoods and willows, would likely suffer from the loss of these trees. Otters benefit from pools created by beaver dams and would probably be affected by a decrease in beavers.

### Fish

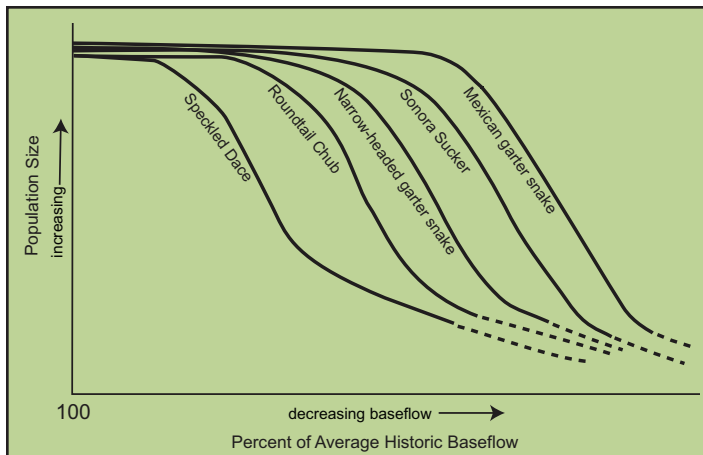
The models predict that populations of most fish would decline with base flow declines, and would disappear with major flow reduction except at a few isolated springs. Habitat loss would affect spawning, juvenile, and adult life stages with specific effects dependent on habitat needs. Some native fish species show a strong preference for specific habitats - such as riffles versus pools - for various life stages. Population size for riffle specialists would be expected to decrease first as riffles would be the first dewatered habitat. Pool dwellers, such as chub and sucker, would persist longer with reduction in base flow.

The speckled dace depends on riffles and would likely suffer significantly with reductions in this habitat type. Roundtail chub occupies pools adjacent to swifter riffles and runs, so initially it would be less affected by flow reduction. But the models show populations of these fish, along with other pool-dwelling native species such as the speckled dace and Sonora sucker, would ultimately decline. Loss of riffle habitat would also reduce the chances of restoring Verde River natives, such as the threatened spikedeace.

Reduced base flow is also predicted to damage the Verde River's value as a sport fishery, with higher water tem-



**Figure 3.** Hypothetical flow-ecology response model for cottonwood saplings, mature cottonwood trees, tamarisk, and mesquite. Saplings have a smaller root system than mature trees, and thus require shallower groundwater. The differing depth-to-water tolerances exhibited by cottonwood, willow, mesquite, and tamarisk leads to dominance of one species over another across the floodplain according to the height of different surfaces above groundwater. Similar replacement can take place over time at a given site with a rising or falling water table.



**Figure 4.** Hypothetical flow-ecology response model for native fish and garter snake. The riffle-dwelling native fish species, such as speckled dace, are most vulnerable to a decrease in base flow, because shallow-water riffles would be the first habitat to be dewatered. Fish species that prefer deeper-water run and pool habitats would be affected as base flow continues to decline. Two garter-snake species depend on small fish for much of their diet, and would decline with loss of their prey. They would also be affected by reductions in instream and marsh vegetation that they use to avoid predators.

peratures, lower dissolved oxygen content, and reduced visibility affecting the abundance, size, and catchability of sport fish.

The models suggest that shrinking aquatic habitat is also likely to threaten reptiles and amphibians. Conditions that result in disconnected pools that concentrate predators would likely expose amphibians, such as the lowland leopard frog, to more predation in and between pools. The Verde's two species of gartersnakes depend on fish and frogs for their diet, along with streamside plants for cover, and would likely decline along with those groups.

## A Research Agenda for the Future

Compiling existing information and tapping expert knowledge provided a valuable platform from which to launch additional in-depth research specific to the Verde River, with the goal of putting values on conceptual flow-ecology response models. Workshop participants developed a watershed-wide research framework that integrates across disciplines and across spatial and temporal scales. In accordance with that framework, the next phase of study involves data collection at an initial set of sites from the headwaters through the Verde Valley. Data collection will concentrate on defining the extent of aquatic habitat with varying base flow and the distribution and composition of riparian vegetation with varying stream flows (including floods) and depth to groundwater. Also, a recently-compiled native fish database will be used to determine spatial and temporal patterns of native and non-native fish distribution in the watershed. It is expected that with additional funding, the network of study sites will be expanded, thus incorporating additional physical and ecological variability. These data should provide the essential basis for quantifying the responses of plants and animals to changes in river flow.

### FOR MORE INFORMATION:

The full report on the Verde River Ecological Flows study is available at [www.azconservation.org](http://www.azconservation.org).

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**Figure 5.** Riffle and pool habitat in the upper Verde River. A) Riffle habitat, with speckled dace. As base flow is reduced, riffle habitat will become narrower and shallower, restricting fish movement. When the shallow, faster-moving riffles, runs and glides dry up, fish habitat is reduced to disconnected pools. B) Pool habitat, with Sonora sucker. When fish are concentrated in a few remaining pools, they become more vulnerable to predation by pool-dwelling non-natives.