Developing Flow-Ecology Science to Support Decision Making
Verde River Watershed, Arizona

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The Verde River above Horseshoe Reservoir in central Arizona is unregulated and retains perennial flow. In an arid land, theVerde River is a rare green corridor that is enjoyed by humans while supporting abundant plants and wildlife. Although surface water diversions for irrigation have operated in the Verde Valley since the late 1800s, and groundwater pumping occurs throughout the watershed, a natural flow regime predominates and substantial aquatic and riparian diversity remain. However, the ecological integrity of the Verde River could be threatened by the water demands of a rapidly expanding population. Thus far, scientific studies have focused on groundwater conditions while the relationships and water needs of the riverine ecosystem have gone largely unstudied. Developing scientific understanding of the functional relationships between stream flow, aquifers, and the biological system is essential to managing this rare southwestern river ecosystem.

Ecologically sustainable water management provides the paradigm in which scientific data and expert opinion are compiled and synthesized into easily accessible formats available to decision makers. With this information in hand, consequences from various growth and water management scenarios can be integrated with scientific studies of river and aquifer function, providing continuing information pertinent to water management. In collaboration with academic and community partners, we have initiated such a process on the Verde River, beginning with an ecological flows study. The intent is to integrate river ecology science into on-going hydrology and water supply studies in a manner that supports ecosystem function and allows science to be translated into decision-making.

The long-term goal of the Verde River ecological flows study is to develop quantitative flow-ecology (i.e. stressor-response) models linking hydrologic variation to ecological response on the Verde River and eventually throughout the watershed. Phase I is nearly complete and consists of: 1) an orientation meeting that introduced the concept and solicited input; 2) a draft background report describing the physical and biological characteristics of the Verde River, written by the Arizona Water Institute; 3) an experts' workshop in which participants shared their knowledge, and consensus was developed around conceptual flow-ecology models and a prioritized research agenda; and 4) a final report (in preparation), peer-reviewed by workshop participants, that incorporates the background report, adds outcomes from the workshop, and provides an integrated synthesis of information.

The experts' workshop was attended by 35 people from 15 institutions, with expertise that included hydrology, geomorphology, riparian ecology, ichthyology, ornithology, mammalogy, herpetology, entomology, and water quality. Building on the background report, experts worked in facilitated sessions to identify ecological responses to

hydrologic variation through the development of flow-ecology response curves. The workshop provided a forum for distilling various complex relationships into concise hypotheses, and for identifying key research needed to test those hypotheses. The final report documenting literature surveys and outcomes from the workshop will be available from the Arizona Water Institute and The Nature Conservancy in Fall 2007.

Plants and animals that depend on aquatic and riparian ecosystems have developed life cycles that are keyed to the natural pattern of stream flows, including intra-annual and inter-annual flow variations. Groundwater levels in floodplain alluvial aquifers are also highly responsive to stream flow regimes. Flow-ecology response curves describe the relationship between hydrologic variability (e.g. decreased magnitude of base flow) and ecological response (e.g., change in a species' population). Flow-ecology response may be linear or threshold (Figure 1) or even parabolic; field and laboratory data and/or modeling studies are needed to develop the nature and shape of relationships. The main objective in developing these relationships is to capture a "mechanistic" or process-based relationship between some component(s) of the hydrograph and one or more ecological response variables. Ideal ecological response variables are sensitive to existing or potential future flow alterations, can be validated with monitoring data, and are valued by society.

Developing flow-ecology response functions correlates ecological risk, which cannot be managed directly, to stream flow conditions, which can be managed through water-use policies. Thus, results from an ecological flows study can help water managers integrate human and ecosystem water needs in a spatially comprehensive manner.

Workshop discussions focused on potential consequences of reductions in the river's base flow. This was based on analyses by USGS personnel (e.g. Blasch and others 2006; Wirt and others 2005), the historic loss of flow from Del Rio Springs (Wirt and others 2005, p. A11), and anticipated increase in water demand by the growing human population. The Verde River exhibits a relatively steady base flow regime throughout the majority of the year, most especially in the upper reaches (Figure 2) Although it was recognized that natural flood regimes play a critical role in maintenance of healthy riparian vegetation (see, for example, Leenhouts and others 2006), workshop participants chose to not focus on flood-related processes in the Verde, due to an assumption that no new dams will be constructed on the river in the foreseeable future.

Base flow provides habitat for fish and other aquatic organisms, consisting chiefly of riffles, runs, glides, and pools. We can say with confidence that populations of most native fish would decline with base flow declines, and with major flow reductions, disappear. This is due chiefly to the loss of habitat with reduction in stream flow. Decreased base flow would be expected to first impact native fish species that are predominantly "riffle dwellers", such as speckled dace and spikedace, because these habitats, having a relatively shallow water depth, would be dewatered first with a decrease in stage (i.e. a decrease in discharge). Pool dwelling fish, such as roundtail chub, would be affected with additional declines in base flow, as pools became limited in extent, resulting in reduced habitat and increased competition.

The extent of fish habitat loss coincident with a given reduction in base flow, and the probable effect on a given species life stage, would best be defined through delineating stage-discharge relationships and compiling detailed habitat data at representative study sites, and utilizing those data to further quantify flow-ecology response models.

Base flows provide water for streamside marsh communities and contribute to maintaining groundwater levels that support deeper rooted woody riparian plants. Riparian vegetation response to stream flow regime and depth to groundwater fluctuations have been extensively studied. Workshop participants diagramed flow-ecology response relationships for cottonwood, mesquite, tamarisk and willow vegetation and for sedge and cattail communities. Studies on the San Pedro River in southeast Arizona (e.g. Lite and Stromberg 2005) have demonstrated that decreased water availability results in a shift of the riparian community from cottonwood-willow dominance to tamarisk dominance and a decrease in streamside herbaceous vegetation.

A major finding of the ecological flows workshop and literature surveys was the strong influence of the physical systems on the plants and animals that live in and near the river. In many cases, the river's hydrology and geomorphology form the primary drivers of which species are present and how viable their populations appear. Better understanding of the physical systems will be critical to understanding and managing the ecosystem. With basic data for the Verde River on stage-discharge, river cross-sections and longitudinal profiles, riparian vegetation condition, and depth to groundwater at representative study sites, we would be able to confidently predict changes in the distribution and extent of aquatic and riparian communities with changes in surface flow and groundwater levels. Thus, physical characterization of the Verde River forms the base of the research platform, upon which biological studies would then be developed.

Extensive research has occurred on other rivers in the Southwest to understand the occurrence and movement of groundwater and human and natural system utilization of groundwater and surface water. Results from this research are generally transferable to the Verde River, but specific quantified values must be confirmed and refined for the Verde River. The Verde River Flow Ecology Study Phase I report is the first attempt to present known and presumed relationships between stream flow, groundwater level, and ecological response for the Verde River. It presents a prioritized research agenda for developing the additional information needed in order to meet ecosystem water requirements while also managing water in the most effective and efficient manner in the Verde River watershed.

References

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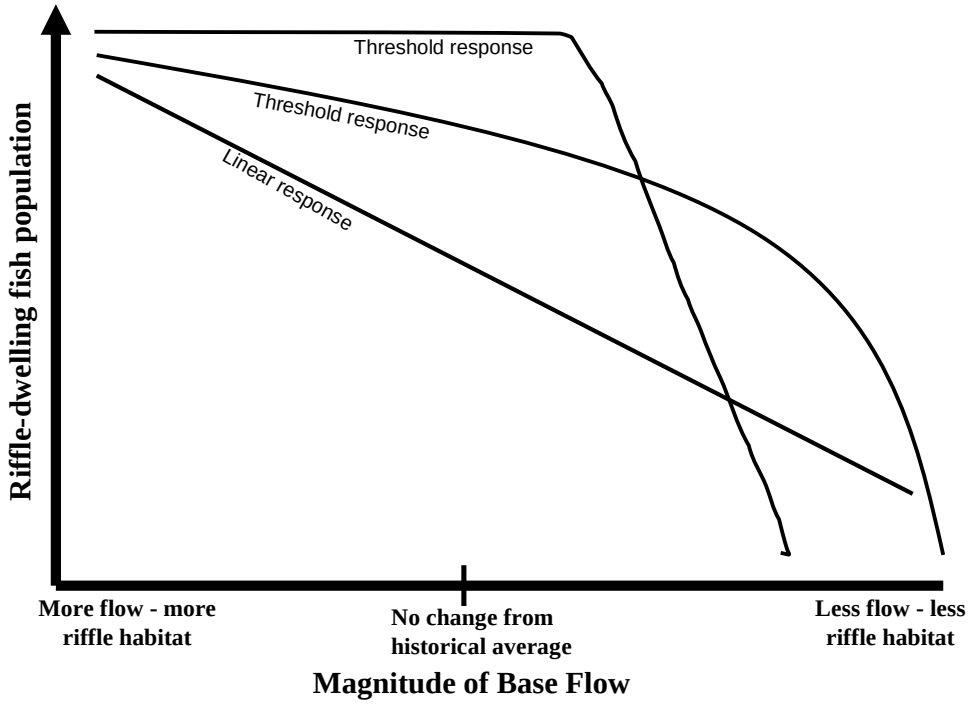

F**igure 1. Examples of some possible flow-ecology response curves for population of a riffle-dwelling fish species with change in magnitude of base flow from historical average.** Because less water means less habitat, and fish populations are sensitive to the amount of available habitat, it follows that reduced base flow would result in decreased populations of riffle-dwelling fish (riffles being the shallowest habitat, they would be dewatered before runs or pools). Response could be linear or threshold, and if threshold, could require moderate or large base flow reduction prior to reaching a threshold. The nature of the response and the shape of the response curve can be developed through field, laboratory, and/or modeling studies. Expert consensus developed through a facilitated workshop can be used to develop preliminary hypotheses of flow-ecology responses, thus focusing the research agenda on those data most needed to refine and quantify flow-ecology response models.

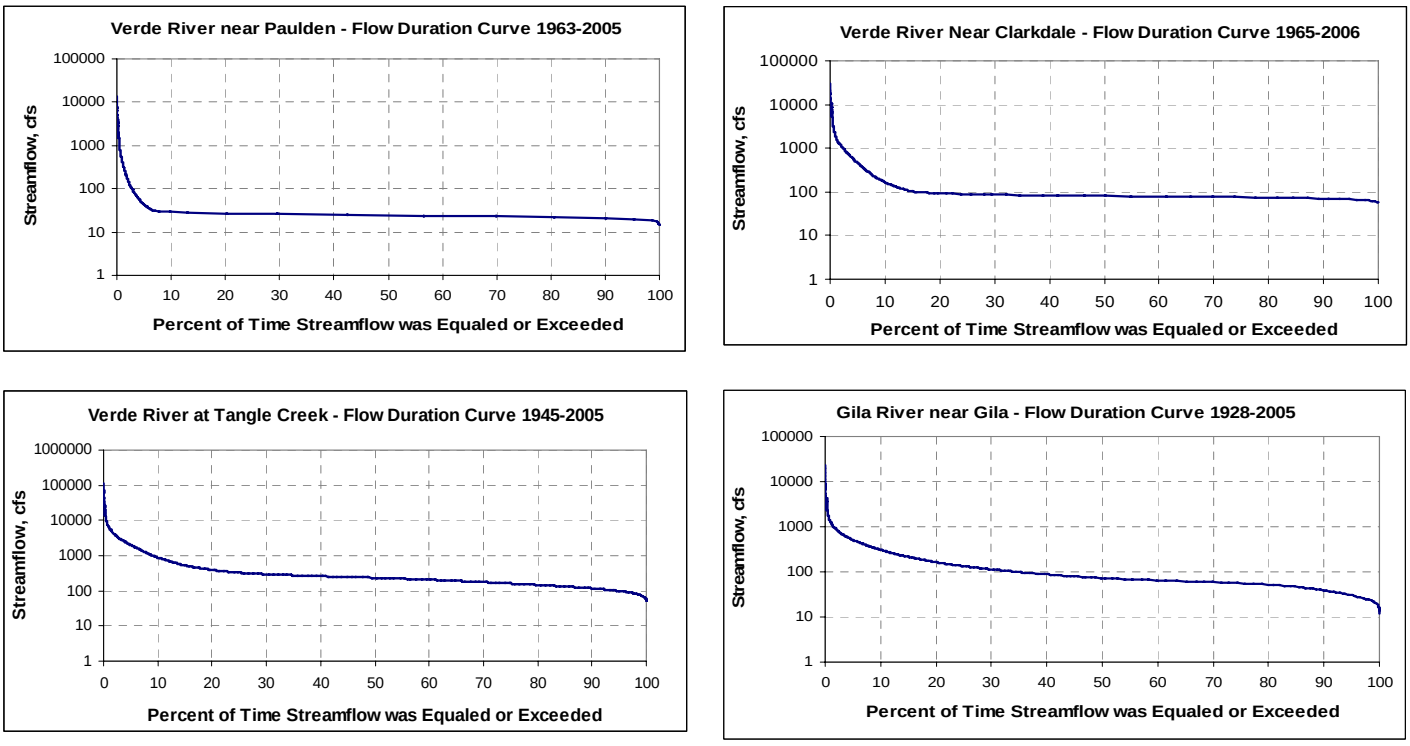

Figure 2. Flow duration curves for three USGS gauging stations on the Verde River. Near Paulden is the most upstream, in the upper Verde canyon; near Clarkdale is upstream from the Verde Valley; at Tangle Creek is most downstream, but still upstream from Horseshoe Reservoir. Note the dominance of base flow conditions in the upper river with increasing runoff inputs downstream. For comparison purposes, flow duration curve for Gila River near Gila, New Mexico, is also shown.