Verde Watershed Symposium – State of the Watershed in 2001

Cliff Castle Lodge and Conference Center

Camp Verde, Arizona

Proceedings

May 17-19, 2001

Edited by Charlie Schlinger and Abe Springer, Northern Arizona University

Regional Hydrogeologic Investigation of the Upper and Middle Verde River Watershed

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BACKGROUND

The U.S. Geological Survey (USGS), in cooperation with the Arizona Department of Water Resources (ADWR) and Yavapai County, is conducting a regional hydrogeologic investigation of the upper and middle Verde River watershed. The investigation began in July 1999 and is expected to last for approximately 5 years. It is being performed in conjunction with comparable investigations in the adjoining Coconino and Gila County areas as part of the Rural Watershed Initiative (RWI) program that is managed by the ADWR. The goal of this investigation is to improve our understanding of the surface- and ground-water systems in the area. The population of Yavapai County, where most of the upper and middle Verde watershed is located, is growing rapidly; that growth brings an increased demand on water resources. An improved understanding of the hydrogeologic system will assist water managers in making decisions regarding current and future allocation of water resources.

The investigation has four main objectives. One objective is to create a comprehensive database of hydrogeologic data and references for the area that can be readily accessed and used. The database is being developed as part of a larger database that includes all three RWI projects. The second objective is to better understand the geologic features that affect the quantity of ground water that moves through the system and the paths the water takes as it flows through the system. The third objective is to develop a conceptual understanding of the hydrogeologic system, including where and how much water enters, flows through, and exits the system, and the interaction between ground water and surface water in the watershed. The final objective is to develop a numerical ground-water flow model that will enable us to test our hypotheses and modify them as warranted to better understand how the system works. The model will also be a useful tool for water-resource planners to examine potential effects of various development scenarios in the watershed.

CURRENT STATUS

Currently the database includes detailed information on wells and springs and digital maps of cultural features, topography, drainages, and geology; it is being updated as new data are collected. A bibliography of hydrologic data has been compiled and will be available for searching on the project Web site at URL http://az.water.usgs.gov/rwi/rwihome.htm/ Ten wells in the watershed have been instrumented to continuously monitor ground-water altitude; these data also are available on the Web site. Three additional wells are being added to the network. Streamflow was measured twice at many locations along the Verde River during the first year of the project and the data are available on the Web site. These measurements were made during periods of low flow and define both base flow of the river and reaches where flow is increasing or decreasing. Ground-water and surface-water chemistry samples have been collected from the Verde River and from springs in the headwaters area; additional sampling is in progress. Data from these samples will be used to help determine the sources of water that provide base flow to the Verde River and the paths the water takes as it flows toward the river.

In order to improve our understanding of the subsurface geology, an aerial geophysical survey is being scheduled for late May 2001. This survey will produce data that describe the magnetic properties of rocks in the subsurface. These data will be used to help define the geometries of the subsurface basins and provide information about the boundaries of the hydrogeologic system. The survey will cover parts of Big Chino Valley, Williamson Valley, Little Chino Valley, and the middle Verde area as far south as Camp Verde. Other geophysical and geologic data will be collected to supplement the aeromagnetic data and further refine our understanding of the subsurface geology and its potential influence on ground-water flow.

Stations for the collection of microgravity, streamflow, and precipitation data are currently being sited. The microgravity stations will be established throughout the watershed and will enable monitoring of changes in ground-water storage. The measurements will help determine how much water is being added to the basin as recharge, or withdrawn from them as discharge, over time. A new streamflow-gaging station is being installed in Williamson Valley at the same location where the USGS operated a station from 1965 until 1985. Streamflow in Williamson Valley infiltrates into the subsurface in Big Chino Valley; discharge data from the gaging station will help to quantify that infiltration volume. Three new precipitation gages also are being installed in the Verde River headwaters area. Many precipitation gages already exist throughout the basin, but because of the high variability of precipitation over the area, data from additional locations will help to more accurately quantify the volume of water entering the basin.

Many different types of data are being collected that generally fall into two categories: data that constrain the water budget, and data that describe the physical setting. The water budget consists of all the water entering the basin, such as precipitation and recharge to the aquifer, minus all the water exiting the system, such as stream and spring discharge and evapotranspiration. Effects of human activities, such as ground-water pumping, ditch diversions, and irrigation must also be considered in the water budget. Confidence in the hydrologic water budget will increase as the values for these components are better constrained. Furthermore, confidence in the conceptual model of the hydrologic flow system will increase as the understanding of the subsurface geologic formations and structures is improved.

Wildlife and Fisheries Inventory and Monitoring along the middle Verde River

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Although relatively close to the Phoenix metropolitan area, much of the Verde River that flows within the boundaries of Arizona Game and Fish Department's (AGFD) Region VI, i.e. that below Camp Verde, receives limited human use. Between Childs and approximately Sycamore Creek the river is within the Mazatzal Wilderness area, and between Childs and Red Creek it is designated as a Wild River. On 14-17 June 1999 and 21-25 August 2000 I conducted wildlife surveys along the Verde from Childs to Sheep Bridge (near Sycamore Creek). Major objectives of the trips were to document the level of river otter use and to search for riparian herpetofauna, particularly leopard frogs, along the river and in proximate portions of tributary drainages. Otters used the entire portion of river surveyed, with documented scat locations averaging 3.2 locations per mile along a 26 mile stretch in 1999, and 1.7 locations per mile along a 32 mile stretch in 2000 (annual numbers are not comparable because of different flow regimes prior to and during surveys). Crayfish appear to be among the otter's major prey based on observation of otter scat. No leopard frogs were found during the June 1999 trip. In 2000, lowland leopard frogs were found in two tributary drainages (Squaw Creek and Tangle Creek) but none were found along the Verde itself. The absence, or low densities, of leopard frogs along the river is speculated to be a result of adverse impacts from introduced fish and crayfish. During 2000 surveys, crayfish and exotic fish were documented in the Verde, Fossil Creek, Wet Bottom Creek, and in a pool in Red Creek near its confluence with the Verde. Along with the leopard frogs, only native fish were seen in Houston/Squaw Creek and Tangle Creek. One night bat netting in each 1999 and 2000 resulted in captures of 4 species (pallid, big brown, Yuma myotis, and Mexican free-tailed), and another free-tailed bat species (*Nyctinomops*) was audibly detected. Several small caves showed evidence of bat use. Limited small mammal trapping in 2000 resulted in poor capture success but documentation of two species, *Peromyscus leucopus* and *Perognathus pencillatus*. Six black bears were documented along the river in 2000 by sightings and tracks. Other wildlife work being conducted along the Verde within AGFD Region VI includes surveys for southwestern willow flycatchers (transients and one possible breeding pair have been documented) and management activities related to the several pairs of nesting bald eagles along the river. Fisheries management and research activities center on reintroduction of two big-river native fish, the Colorado pikeminnow and razorback sucker.

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Geomorphology and Hydrology of Fossil Springs Damsite

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A pending decision on possible removal of the diversion dam at Fossil Springs requires detailed evaluation. The springs are 14 miles above Fossil Creek's confluence with the Verde River and supply a perennial baseflow of about 46 cfs to the creek. The water of Fossil Springs is saturated with calcium carbonate, creating intricate travertine formations in the stream channel. At Childs in 1908 the Arizona Power Company constructed its first hydroelectric plant, diverting all of the water out of Fossil Creek with a small concrete structure at the present site of Irving. In 1916, the company added a second power plant, and a larger concrete diversion dam on a bedrock ledge about four miles upstream. In 1999, a decision to decommission the plants in 2004 was made. Such choices increasingly confront managers as hydroelectric power plants built in the early part of the 20th century age or deteriorate. Dam removal studies must attempt to determine outcomes of complete, partial, or nonremoval options on stream channels and ecosystems. This study addresses change at the Fossil Springs damsite since 1916. A detailed survey of geomorphology and vegetation at the damsite was conducted. Early surveys, descriptions, and photographs were collected. The relatively small reservoir behind Fossil Springs dam is almost filled with sediment, on which a diverse riparian community has established. The short undiverted reach upstream of the dam supports a native fish population. Concerns about the downstream consequences of releasing sediment trapped behind the dam and potential loss of valuable riparian and aquatic habitat upstream of the dam are balanced against the opportunity to restore the site to predam conditions. This study quantifies the amount of sediment through comparative analysis of modern and historic surveys. Analysis indicates that trapped sediment volume relative to watershed sediment production and Fossil Creek's sediment transport capacity is small.

Simply remove the Fossil Creek dam? Probably not…

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In 1916, the Fossil Creek dam was built near Strawberry, Arizona to provide power for rural communities throughout the Verde Valley. Before 1916, Fossil Creek was fed by springs at a rate of 3.75 million liters per hour. One of Arizona's most productive and diverse ecosystems, this perennial stream served as a unique riparian habitat supporting native fish and a diverse assemblage of native Arizona flora and fauna. However, the hydropower operation diverted nearly 100% of the flows from Fossil Creek leaving 22.4 km of the stream channel dry, ecologically degraded, and with little aesthetic value. In an effort to restore the creek, a coalition of environmental organizations has recently signed an agreement with Arizona Public Service to decommission the dam by 2005. The decommissioning will include partial removal of the dam and other related structures leading to a complete restoration of the ecosystem by 2009. This analysis evaluates the alternatives for decommissioning the Fossil Creek dam to restore the stream to its proper functioning condition. Removing the dam and returning the full flows will speed the restoration process, but two areas that remain of concern are the proliferation of exotic fish and vegetation into the restored stream channel and post-restoration recreational impacts. A management plan should be developed prior to the initiation of restoration activities and protect against these impacts.

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Watershed Condition of Select 5th Code Watersheds along the Verde River
Prescott National Forest

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The Prescott National Forest assessed watershed condition of lands from Big Chino Wash to Childs on the west side of the Verde River, Yavapai County, Arizona. The watershed assessment focused on three resource components: aquatic, riparian and soil conditions within the watershed, and related this information to designated critical habitat for spikedace (*Meda fulgida*) and loach minnow (*Rhinichthys cobitis*), two native threatened fish species. The aquatic assessment included information on water quality, macroinvertebrates, fisheries habitat, and geomorphology of the river. The data indicates that the aquatic habitat is within acceptable levels for water quality and fisheries habitat. The riparian assessment looked at the functioning of the stream and riparian vegetation. Results indicated the system is functioning or functional at risk with an upward trend, and riparian vegetation is improving. Soil condition information results found there is the opportunity to improve soil condition throughout much of the watershed. In addition to these resources, we reviewed other factors that can impact watershed condition such as: functioning of the tributaries/gully systems, grazing, roads and trails, pinyon/juniper woodlands, and land use patterns. We concluded that while there are many impacts within the Verde Watershed, and that soil and subsequently watershed conditions could be improved, these factors are not resulting in an impairment of the aquatic conditions and fisheries habitat.

High-Resolution Geophysical Data Reveal Hydrogeologic Framework of the Verde River Headwaters Region, Arizona

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A high-resolution aeromagnetic survey will contribute to understanding of the geologic framework of the Verde River headwaters region, Arizona. Radiometric data were also collected to map surficial rocks and sediments. The survey covers an area of approximately 792 km^2, and includes the southern half of Big Chino Valley and northern half of Little Chino Valley. Flight lines were oriented east-west, spaced 150 m apart, and flown at an altitude of 150 m above terrain, or as low as permitted by safety considerations. Total flight distance was 5600 km. Areas with exposed Tertiary volcanic rocks produce distinctive magnetic patterns. For example, many of the Tertiary latites coincide with very strong circular magnetic lows indicative of volcanic plugs, which may be more impermeable to groundwater flow. Tertiary basalts produce a "worm-like" magnetic anomaly pattern. Similar magnetic patterns are particularly evident over northern Little Chino Valley and indicate shallowly buried volcanic rocks, an important water-bearing unit. A large magnetic high overlies Paleozoic carbonate rocks exposed on Big Black Mesa. Because these rocks are weakly magnetic, the anomaly most likely is caused by Precambrian granitic rocks concealed beneath the Paleozoic units and exposed just northwest of the study area. The southwest margin of the magnetic high is cut by the Big Chino fault. The magnetic field over alluvial deposits of southern Big Chino Valley shows several linear northwest-trending, low-amplitude anomalies. Because alluvium is often weakly magnetic, some of these anomalies may originate from volcanic or Precambrian rocks concealed beneath the surface. Other possible causes include fluvial reworking of alluvial deposits or alteration along buried fault zones within or beneath the alluvium, which may act as groundwater barriers or conduits. Quantitative analyses of the aeromagnetic anomalies will require two- and three-dimensional modeling.

The radiometric data show the distribution of surface sediments and rocks having different chemical compositions. The thorium data distinguishes Oligocene sedimentary rocks beneath the latite from Miocene and younger sediments derived from weathering of the latite. This distinction is important because the older sedimentary rocks are another part of the aquifer in both Big and Little Chino Valleys. The potassium map reveals an area of arkose, west of the town of Chino Valley, not shown in published geologic maps. This arkose could be an important part of the artesian aquifer in the northwestern part of Little Chino Valley. Uranium data indicate areas of enriched uranium in surface sediments northwest of Paulden that may be due to chemical precipitation in playas. High uranium concentrations near Sullivan Buttes and the city of Prescott may indicate a higher potential risk for indoor radon.

Gravity data collected for the study area show large gravity lows over the city of Prescott and Big Chino and Williamson Valleys. The gravity low over Big Chino Valley indicates that the valley fill is 1 km thick or greater. The gravity lows over the city of Prescott and Williamson Valley may be caused by low-density granite or high-porosity valley fill.

GEOMORPHIC CONDITIONS OF THE RIPARIAN ZONE, UPPER VERDE RIVER

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INTRODUCTION

This paper presents a general overview of the geomorphic conditions on 50 km of the upper Verde River (UVR) based on 108 stream cross-sections. A stream classification system was developed by Rosgen (1996) on the basis of measured morphological characteristics and combinations of river formed variables obtained from hundreds of actual river sites. A central concept of the classification system is to provide a mechanism to help others see and visualize the many unique river forms without intensively analyzing all of the many contributing variables, and to provide the basis to better understand the significance of the physical process interactions that occur within river systems.

Classification can be defined as the ordering of objects into sets on basis of their similarities or their relationships. The most effective classification systems are based on objective, quantifiable criteria that permit consistent use of the system. Understanding the processes and characteristics of fluvial systems requires knowledge of their inherent hierarchical structure. Modern rivers reflect the effects of current climate, lithology, depositional and erosional history, and the mediating effects of broad vegetation zones.

The morphology of a river reflects past events, and also the stream flow and sediment regime determined by climate and landform. The fundamental components of river's morphology are its dimension, pattern, and profile. These components represent the integrated response of a river that enables it to be in balance with the prevailing energy gradients, sediment supply and sediment transport characteristics. Stream systems can be described with increasing detail at subsequent levels of organization by identifying the driving variables at finer scales of resolution.

Fundamental Principles: River form and fluvial processes evolve simultaneously and operate through mutual adjustments toward self-stablilization (Rosgen 1996). The appearance of a river is the product of adjustment of river boundaries to the magnitude of stream flow and erosion debris from its watershed. Rivers are modified by the influence of channel materials, basin relief, and other valley morphology features along with local history of erosion and sediment deposition. All rivers must transport erosion products while maintaining their own competence for self-perpetuation. As drainages enlarge, so do requirements for stream flow and sediment transport. In the generalized sediment balance relationship, a change in any one of the variables sets up a series of mutual adjustments in the companion variables with a resulting direst change in the characteristics of the river (Lane 1955, Rosgen 1996). Channel gradient generally decreases in a downstream direction with an increase in stream flow and a corresponding decrease in sediment size; stream gradient is directly related to bed-material load and grain size and inversely related to stream flow. Steep gradient streams are relatively straight (low sinuosity). They dissipate energy along the longitudinal profile in relatively closely spaced features called steps and pools. Their spacing is inversely related to slope and proportional to the bankfull width. As gradient decreases, the nature of these alternating steep and flat components of a reach, change. The profile change into a series of riffles and pools spaced farther apart as a function of the channel width. Since channel dimensions, stream pattern, and longitudinal profile are all interrelated and delicately adjusted to just carry the sediment load and flows of the watershed, inappropriate changes (man made) in these variables result in predictable responses that are often ill advised.

Hierarchical Analysis: A hierarchical assessment provides the physical, hydrologic, and geomorphic context for linking the driving forces and response variables at all scales of inquiry (Rosgen 1996). There are four levels to this hierarchy. Level I describes the geomorphic characteristics that result from the integration of basin relief, landform, and valley morphology. Level II provides a more detailed morphological description of stream types extrapolated from field determined reference reach information. Level III describes the existing condition or "state" of the stream as it relates to its stability, response potential, and function. Additional field parameters are evaluated that influence the stream state (e.g., riparian vegetation, sediment supply, flow regime, debris occurrence, depositional features, channel stability, bank erodibility, and direct channel disturbances). These analyses are both reach-and feature-specific and are especially useful as a basis for integrating companion studies (e.g., fish habitat indices, and surveys of riparian communities). Level IV is where measurements are taken to verify process relationships inferred from preceding analyses. The objective is to establish empirical relationships for use in prediction (e.g., to develop Manning's "n" values from measured velocity; correlating bedload versus discharge by stream type to determine sediment transport relationships; or calculating hydraulic geometry from gaging station data). Developed empirical relationships are specific to individual stream types for a given stat, and enable extrapolation to other similar reaches for which Level IV data is not available. By using these relationships, existing data from gage stations and research sites can be analyzed and extrapolated to similar stream types.

RESULTS AND DISCUSSION

Stream classification data used in the Level I through IV analyses of the UVR include year (Yr), station number (STN), bankfull width (BFW), bankfull maximum depth (BFMD), flood prone area (FPA), valley distance (VD), stream distance (SD), channel slope (CSLP) and valley slope (VSLP), width/depth ratio (W/D Ratio), entrenchment (ENT), sinuosity (SIN), channel type (CHT), percent of sediment size (D50), and dominant substrate size (DOM). An example is shown in Table 1. Only Level I and II analyses are covered in this paper.

Valley Type: The upper Verde River valley is a type IV valley. Rosgen (1996) describes it as the classic meandering, entrenched or deeply incised, and confined landform. This valley is the typical canyon and gorge type often with gentle elevation relief and valley-floor gradients of less than 2 %. Steeper reaches are well interspersed with low gradient

Table 1. Examples of stream classification data for Upper Verde River Cross-sections.

Yr	STN	BFW	BFMD	FPA	VD	SD	CSLP	VLSP	W/D	ENT	SIN	CHT	D50
		………………….....m.	………………..				%	%					mm
97	15b	9.71	0.48	21.02	840	843	0.223	0.224	35.96	2.16	1.000	B4c	6.8
97	111	9.28	0.52	32.63	545	619	0.115	0.130	33.14	3.52	1.135	C4	1.5

97	5	9.15	0.67	12.76	76.4	97	1.330	1.688	24.73	1.39	1.270	F3	154.0
97	33	6.03	0.75	16.09	771	1104	0.272	0.389	11.17	2.67	1.430	E4	9.6

ones to create a good diversity of habitats. These valleys are generally structurally controlled and incised in highly weathered materials. F type streams are often found in this valley type, however, where the width of the valley floor accommodates both the channel and a floodplain. C channels are also often found in this type valley. This is the case on the UVR where 34 % of the channels are C type channels and 15 % are F channels. Depending on streamside materials, the sediment supply is generally moderate to high.

Stream Types:

B stream type (47%)

- B types exist primarily on moderately steep to gently sloped terrain (2 to 4%), with the predominant landform seen as a narrow and moderately sloping basin.

- Many B types are the result of the integrated influence of structural contact zones, faults, joints, colluvial-alluvial deposits, and structurally controlled valley sideslopes that tend to result in narrow valleys that limit the development of a wide floodplain. B channels are moderately entrenched, have a cross-section width/depth ratio (greater than 12). They display a low channel sinuosity, and exhibit a “rapids” dominated bed morphology. Bedform morphology, which may be influenced by debris constrictions and local confinement, typically produces scour pools (pocket water) and characteristic “rapids”. Streambank erosion rates are normally low as are the channel aggradation/degradation process rates. Pool-to-pool spacing is generally 4-5 bankfull widths, decreasing with an increase in slope gradient. Meander width ratios (belt width/bankfull width) are generally low which reflect the low rates of lateral extension. B stream types are usually found within valley types II, III, and VI (Rosgen 1996).

C stream type (34%)

- C types are located in narrow to wide valleys, constructed from alluvial deposition. The C type channels have a well-developed floodplain (slightly entrenched), are relatively sinuous with a channel slope of 2% or less and a bedform morphology indicative of a riffle/pool configuration. The shape and form of the C stream types are indicated by cross-sectional width/depth ratios generally greater than 12, and sinuosities exceeding 1.4. The C type exhibits a sequencing of steeps (riffles) and flats (pools) that are linked to the meander geometry of the river where the riffle/pool sequence or spacing is on the average one-half a meander wavelength or approximately 5-7 bankfull channel widths. The primary morphological features of the C channel are the sinuous, low relief channel, the well-developed floodplains built by the river, and characteristic “point bars” within the active channel. The channel aggradation/degradation and lateral extension processes, notably active in C types, are inherently dependent on the natural stability of streambanks, the existing upstream watershed conditions and flow and sediment regime. Channels of the C type can be significantly altered and rapidly de-stabilized when the effects of imposed changes in bank stability, watershed condition, or flow regime are conbined to cause an exceedance of a channel stability threshold. C streams may be observed in valley types IV, V, VI, VIII, IX, and X. This channel type is also found on the lower slope positions of the very low gradient valley type III (Rosgen 1996).

E stream type (5%)

- E streams are conceptually designated as evolutionary in terms of fluvial process and morphology. The E stream represents the developmental "end-point" of channel stablility and fluvial process efficiency for certain alluvial streams undergoing a natural dynamic sequence of system evolution. The E type system often develops inside of the wide, entrenched and meandering channel of the F stream type, following floodplain development on and vegetation recovery of the former F channel beds. The E types are slightly entrenched, exhibit very low channel width/depth ratios, and display very high channel sinuosities which result in the highest meander width ratio values of all the other stream types (20 to 40). The bedform features of the E channel are predominantly a consistent series of riffle/pool reaches, generating the highest number of pools per unit distance of channel, when compared to other riffle/pool stream types (C, DA, and F). E types generally occur in alluvial valleys that exhibit low elevational relief characteristics and physiographically range from the high elevations of alpine meadows to the low elevations of coastal plains. While E streams are considered as highly stable systems, provided the floodplain and the low channel width/depth characteristics are maintained, they are very sensitive to disturbance and can be rapidly adjusted and converted to other stream types in relatively short time periods. The E type typically develops within valley types VIII, X, and XI (Rosgen 1996).

F stream type (15%)

- F streams are the classic "entrenched meandering" channels described by early day geomorphologists, and are often observed to be working towards re-establishment of a functional floodplain inside the confines of a channel that is consistently increasing its width within the valley. F types are deeply incised in valleys of relatively low elevational relief, containing highly weathered rock and/or erodible materials. The F stream systems are characterized by very high channel width/depth ratios at the bankfull stage, and bedform features occurring as a moderated riffle/pool sequence. F streams can develop very high bank erosion rates, lateral extension rates, significant bar deposition and accelerated channel aggradation and/or degradation while providing for very high sediment supply and storage capacities. The F stream types occur in low relief valley type III, and in valley types IV, V, VI, VIII, IX, and X (Rosgen 1996).

One of the most important observations about the channel classes of the UVR is the lack of D channels. D channels are multiple channel systems described as "braided streams" within broad alluvial valleys or on alluvial fans (Rosgen 1996). Braided channels are characterized by high bank erosion rates, excessive deposition, and annual bed location changes. The conditions that result in channel braiding include high sediment supply, high bank erodibility, moderately steep gradients, and very flashy storm runoff conditions. Although flashy runoff can occur in the UVR as indicated by the flow duration curves, most of the other conditions do not hold. This lack of

D channels is an important piece of evidence indicating that the surround uplands watershed condition is fairly satisfactory. The UVR is simply not experiencing high levels of sediment input. The channel classes, entrenchment ratio, and continued narrowing and deeper are not indicative of a river system with high sediment loading. The Verde is processing all of its sediment and then some because it still shows evidence of downcutting.

Morphology: The UVR has a low sinuosity for the most part due to confinement within canyon walls. Sinuosity is the ratio of channel length to down-valley length. Ratios close to 1 indicate that the channel is fairly straight due to the river's entrenchment in the local bedrock. In some locations it begins to meander where the valley widens. Current channels types are moderately entrenched and with moderate gradients. They are riffle-dominated, with infrequent pools, stable plan-views and profiles, and generally stable banks. Some other observations are:

- C channels: Wide, shallow channels with well-developed floodplains are established in relatively broad, gently sloped valleys

- F channels: These have entrenched wide, shallow, and meandering channels with little or no adjacent floodplain.

- E channels: Narrow, deep channels that generally occur in wider valleys with well-developed floodplains.

- The river is mostly a single channel system

A minimum of one reference reach for each stream type identified is required, but usually multiple reaches are used, one for each change in channel bed material (i.e., one for C3 and for C4 types– D50 particle size of cobble and gravel, respectively). Using these guidelines, in the 50 km of the UVR studied, we would have needed a minimum of 14 reference reaches. In reality, 108 cross-sections were located and data were collected. Forty seven percent of the channel cross-sections were identified as B, 34 % as C, 15% as F, and 5% as E channel types. Channel substrates ranged from silt/clays (6) to boulders (2). The channel classes for the UVR, by substrate, were $B_{3,4,5,6}$, $C_{3,4,5}$, $F_{2,3,4,5,6}$, and $E_{4,5}$. Ground surveys revealed the presence of 3 terraces above the present flood plain. The highest terrace is located about 3 m (9.8 ft) above the present river surface, with the second terrace about 1.5 - 2 m (4.9 to 6.6 ft), and the third terrace about 0.5-1 m 1.6 to 3.3 ft). The active flood plain is currently about 0.4 m (1.3 ft) above the river surface at base flow.

Cross-sections: **Profiles were plotted for each measured cross-section on the UVR (example shown in Figure 2). Accompanying estimates of discharge were derived from the computer program XSPRO, a channel cross-section analyzer (West Consultants 1998). This is an interactive program that can be utilized by watershed specialists in analyzing stream channel cross-section data. It is designed to handle channel geometry and hydraulic conditions for single transects in steep (gradients > 0.001) streams. Several resistance equations are supported, including those designed for large roughness channels. Options include development of stage-to-discharge relationships and evaluating changes in channel cross-sectional area. XSPRO can assist resource specialists in analyzing instream flow needs, performing hydraulic reconstructions, designing effective channel and riparian**

structures, and monitoring channel changes. We currently have about 180 of these sets of output. The output includes channel statistics by 0.1 m increments from from bankfull stage to 4.0 m. Estimated discharge is one of the statistics. The channel profile is also available for each cross-section (Figure 2).

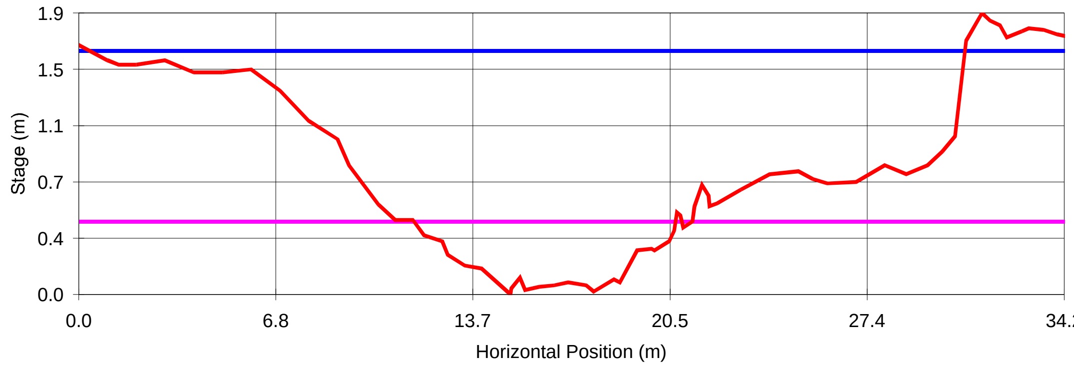

Figure 2. Example of Verde river channel cross-section UVR-97-15b, a B4c channel, with two terraces, generated by XSPRO. The lower line is bankfull discharge and the upper line is the high water mark.

Physical data and historical photography examined indicate that the river continues to be in a degradational phase, with many sections in quasi-equilibrium. Effects of small dams on the main channel and several tributaries may have been a reduction in sediment and bedload materials that would have been naturally contributed to the riverine ecosystem and alteration of the hydrologic and sediment regimes of the alluvial river.

The upper reaches of the Verde River watershed are part of the Colorado Plateau, while the lower reached lie within the Transition Zone-Central Highlands section below the below the Basin and Range Province. Its canyons and gorges with basalt flows are interlayered with sandstone and limestone formations. The soils of the upper watershed are mostly derived from granites and sandstones (south of the river) and from basalts north of the river.

The study area was surveyed and the channel types classified according to Rosgen (1996) for the purpose of studying the relationships between channel types, fish habitat, and fish distribution. Profiles of the main channel indicate the presence of a least 2 terraces located above the present floodplain. The first and second terraces can be found within 1.5-2.7 m and 0.9-1.7 m above the floodplain, respectively. These same terraces were identified in historic photographs circa 1936 for reaches below the study area and are indicative of at least 2 major periods of channel degradation pre-1900's. The 2 terraces are characterized by fine loamy-clay soils. These terraces are most evident in low gradient reaches. In a few sections typified by F-type channels, the active channel has incised into the floodplain to form a terrace composed of sands, gravels, and boulders. Leopold (1951) also reported the presence of the fine substrate terraces and suggested downcutting was occurring prior to the late 1800's. A major flood that occurred in 1891 was viewed as being largely responsible for channel widening of the river and the subsequent constriction owing to vegetation encroachment and adjustments to flow conditions. The floods of 1993 appear to have had a similar effect on channel geometry.

Tributaries: Some tributaries had channel elevations about 1-3 m above the river's main channel at their point of entry. These tributaries provide evidence that the main channel has incised and is currently capable of processing sediments being contributed from its upland watershed. Three of the eight tributaries examined in this study had alluvial fans at their confluences to the main river. This could indicate either naturally high sources of sediment, changes in upstream land uses with subsequent changes in stream flow and sediment supply, or a combination of these factors.

Several factors may contribute to channel down cutting in the Verde River. One factor is the construction of dams (Collier et al. 1996). The geomorphologic effects of dams are understood and documented (Galay 1983, Williams and Wolman 1984, and Ward and Stanford 1995). Church (1995) suggests that 1-3 m of degradation may occur within a decade or two of channel regulation, since entrained sediments are no longer replaced from upstream sources. Aggradation may occur in some reaches downstream because transported materials and other sediments from contributing tributaries can not be moved as efficiently because of the regulated or impeded flow. The UVR and its tributaries have several small dams that may be affecting the sediment equilibrium, but their effect is probably very minor due to their size.

SUMMARY AND CONCLUSIONS

Using Rosgen's (1996) stream classification system, the UVR is type IV valley that is deeply incised and confined. The main stream channel types are B (46%), C (34%), E (5%) and F (15%). In some reaches, the river is tightly confined by canyon walls, and the riparian zones are very narrow. In other reaches the riparian zone is less confined. In the lower gradient reaches as many as 3 terraces are evident above the current flood plain. The highest is about 3 m above the river, the second is at 1.5 – 2 m, and the lowest about 0.5 m. Pebble counts indicate that channel substrates are primarily coarse sands, gravels, and cobbles. Pebble count measurements (D50) on substrates indicate that 4% of the cross-sections were cobble, 19% were fine sands or less, 34% were gravel, and 43% were coarse sand. Major floods in 1891 and 1993 produced channel widening. Post-flood vegetation encroachment and adjustments to lower flows were largely responsible for subsequent channel narrowing and deepening. Channel degradation of 1 to 3 m in some reaches has occurred since the 1930s as evidenced by elevated tributary channels. In other reaches, some aggradation has occurred because of flood deposits and tributary channel inputs. However, the river does not show evidence of major sedimentation problems due to the lack of type D channels.

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AN OVERVIEW OF ROCKY MOUNTAIN RESEARCH STATION VERDE RIVER WATERSHED RESEARCH OVER THE PAST FIVE DECADES

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The Rocky Mountain Research Station, part of the research and development branch of the USDA Forest Service, has been conducting research in or adjacent to the Verde River basin since establishment of the Fort Valley Experimental Forest in 1908 (Baker 1999). The Beaver Creek Project was established in 1956 east of Camp Verde to study the effects of vegetation management on water yields, erosion, forage production, timber production, and wildlife populations. Twenty watersheds ranging in size from 27 to 830 ha were instrumented with stream gauges, precipitation gauges, and other equipment. Over 700 publications have been produced from the Beaver Creek Project alone. Several other smaller watersheds studies were installed near Prescott (Mingus Watersheds) and southwest of Flagstaff (Rattle Burn). Since 1993, research has focused on the upper Verde River and Fossil Creek. Studies are currently in progress on fish populations, riparian vegetation, water quality, and channel geomorphology.

BEAVER CREEK

The Beaver Creek Experimental Watershed is located about 80 km (50 mi) south of Flagstaff, Arizona, in Coconino and Yavapai Counties. Established in 1956 by the USDA Forest Service as a major center for watershed management research within the pinyon-juniper and ponderosa pine vegetation types, the site encompasses 111,375 ha (275,000 ac) on the Coconino National Forest. The watershed study was established to investigate the influence of various vegetative manipulations of pinyon-juniper and ponderosa pine on water yield and to evaluate changes in livestock forage, timber production, wildlife habitats, recreational values, and soil movement.

A paired watershed approach was used to evaluate treatment responses. Two watersheds with similar characteristics, both physical and biological, were selected and measurements of streamflow, sediment production, water quality, vegetation, and animal use were made on each watershed before any treatment was applied. After a period of time, one watershed was selected for application of a management treatment and measurements continued on both the treated and control watersheds. Changes caused by management practices applied to the treated watersheds were evaluated by comparing post treatment values with pretreatment data, and with data from the control watersheds. All water-oriented studies on Beaver Creek were terminated by 1982, and final results of the initial treatment studies were reported on during the latter part of the 1980s.

Beaver Creek is characteristic of much of the Coconino National Forest along the Mogollon Rim. The watershed includes plateaus, sloping mesas and breaks, and steep canyons. Bedrock underlying the area consists of igneous rocks of volcanic origin, below these are sedimentary rocks of Kaibab, Coconino, and Supai formations.

Elevations range from 900 to 2,400 m (3,000 to 8,000 ft) above sea level. Vegetation ranges from semi-desert shrub at the lower elevations, to pinyon-juniper woodland from 1,500 to 1,800 m (5,000 to 6,000 ft), and then ponderosa pine above 2,000 m (6,500 ft). Precipitation and streamflow vary greatly from year to year. Seasonally, flow is concentrated in a few months of each year when the snow melts.

The Beaver Creek Experimental Watersheds are still listed as a biosphere reserve, a component of a worldwide network in UNESCO's Man and the Biosphere (MAB) Program. The 20 plus years of research conducted during the life of the Beaver Creek watershed project resulted in a large collection of physiographic, climatic, streamflow, floral, and faunal data with inconsistent (both spacial and temporal) formats. This information has been difficult to retrieve by those familiar with the project, let alone someone not familiar with it. Fortunately, computers have greatly facilitated access to large and varied data bases, and World Wide Web sites (http://www.rms.nau.edu/lab/4302/ and http://www.ag.arizona.edu/OALS/watershed/) have further advanced our ability to assess and disseminate such data.

These data include precipitation (Daily, watershed average daily, monthly, seasonal, and annual totals, storm events, precipitation nutrient data), weather (air temperature and humidity, daily maximum, minimum, and average, monthly and annual average, and Wind and snowfall), Stream flow (annual, daily, events, peak annual discharge, sediment flow, and stream flow nutrients), and herbage and timber production.

Data sets from Beaver Creek are organized to reflect the components of a water budget; that is, precipitation inputs (quantity and quality) minus streamflow outputs (quantity and quality) equals evapotranspiration (as modified by geology, soil, elevation, and vegetation). A bibliography of research conducted at Beaver Creek has been organized and placed on the Web (Baker and Ffolliott 1998). This bibliography currently contains nearly 700 references to technical reports and bulletins, articles, theses and dissertations, books, and proceedings that relate to watersheds management research in this arid and semi-arid environment. Additional citations will be added as they become available. Additional information sources such as the Madrean Bibliography, that applies to the southwestern United States and northern Mexico, have been added. The geographical scope of this bibliography is the Madrean Biogeographic Province north of 27° latitude, including the Madrean Archipelago region within the southwestern United States. Significant literature from similar ecosystems on adjacent areas has been included in the compilation of the bibliography, because of the significant ecological overlap.

In the past four years a partnership was formed to disseminate information on arid land watershed management. The participants in this project are the Rocky Mountain Research Station Flagstaff Lab of U.S. Forest Service, The University of Arizona Cooperative Extension, and The University of Arizona's Arid Lands Information Center, with funding from the International Arid Lands Consortium (IALC). The goal of the project is to provide a unique reference and educational tool on arid and semiarid watershed management using information and experience developed from research in different vegetation types in Arizona. The first materials were put on the web in

December 1997, and new material will be added, and maintained, as we develop them during the life of this project.

MINGUS WATERSHEDS

Three experimental watersheds were established about 37 km (23 mi) northeast of Prescott in 1958 Ffolliott and Thorud 1975). These watersheds were instrumented to study the effects of chaparral vegetation management on water yield. Results of the studies were similar to those from chaparral watersheds in the Sierra Ancha Experimental Forest east of Lake Roosevelt on the Salt River (Hibbert et al. 1986). Annual stream flow amounts were found to increase by up to 8 mm (0.30 in) when chaparral vegetation was reduced, particularly along stream channels.

UPPER VERDE RIVER

The upper Verde River area of north-central Arizona overlaps the Central Highlands and the Plateau uplands biogeographic provinces. The upper Verde River area occupies about 6,656 km^2 (2,600 mi^2) of Yavapai and Coconino Counties. The watershed encompasses the northern valley of the Verde River; bounded by the escarpment of the Mogollon Rim to the north and northeast and by the Black Hills to the southwest. The Mogollon Rim escarpment is the boundary between the Plateau uplands province and the Central highlands province. It is a steeply sloping cliff that rises 305 to 610 m (1,000 to 2,000 ft) from the Verde Valley floor to elevations of (5,500 to 7,500 ft). The rim is dissected by deeply incised canyons. South of the Rim, the landscape is characterized by many buttes and mesas. The Verde River is the major stream that drains the study area. Perennial flow begins in Section 15, Township 17 N., Range 1 W. The watershed extends another 120 km (75 mi) to the Northwest towards Fraziers Wells, but stream flow is only intermittent in that portion. The river flows along the foot of the Black Hills eastward to Perkinsville then southeastward where it leaves the study area at Tapco, just upstream of Clarkdale and below its confluence with Sycamore Creek. Elevations along the Verde River range from about 1,290 m (4,240 ft) where the Verde River perennial flow begins to about 1,036 m (3,400 ft) at Tapco. Perennial flow in the Verde River and its major tributaries is maintained by ground-water discharge.

The majority of the upper Verde River watershed where flow is perennial is within the boundaries of and managed by the Prescott National Forest. Smaller areas in the upper elevations to the north, northeast, and east are managed by the Kaibab and Coconino National Forests. The western portion of the watershed, at the beginning of perennial flow and headwards in the ephemeral flow reaches of the Chino Valley, is mainly private and State of Arizona lands.

Since 1993, the Rocky Mountain Research Station's Riparian Ecological Systems Project has been investing considerable resources in studying the upper Verde River above Clarkdale. After the 1993 flood on the river, studies were installed to examine the native and exotic fish populations (Rinne et al. 1998, Rinne et al. 1999). This consisted of seven permanent sites that have been sampled annually since 1994 as well as surveys of the entire upper river (Rinne 1999). Research has also focused on habitat preferences of species like the spikedace (*Meda fulgida*) (Rinne and Stefferud 1996, Neary et al. 1996, and Rinne and Deason 2000). Studies have been established to monitor changes in riparian vegetation, stream hydrology, and channel geomorphology (Medina et al. 1997, Rinne and Neary 1997, Neary and Rinne 1997). The results of many of these studies will be presented at this conference.

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BASE FLOW TRENDS AND NATIVE FISH IN THE UPPER VERDE RIVER

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INTRODUCTION

Although much attention has been given to the effects of storm flows on native fish in Arizona's rivers (Minckley 1973, Rinne and Minckley 1991), the minimum base flows are the most critical for fish survival. Concerns have been raised about potentially negative effects of drought, consumptive water use, watershed management, water diversion, and nonnative fish introductions on native fish populations. The latter topic is covered in more detail by a following paper and other publications (Rinne and Stefferud 1999, Rinne 2000). Significantly reduced baseflows could put these fish populations at risk. Because of the controversy over threatened and endangered fish such as the spikedace (*Meda fulgida*) in the upper Verde River, it is important to examine the recent trends in minimum base flows on this river.

> Because of the vagaries of climate (Green and Sellers 1964), characteristic to the Southwest (Nations and Stump 1981), and its aridity (Jaeger 1957), patterns of stream flow are highly variable. An alternating pattern of episodic floods and drought are the norm in the basin. The interactions of these factors result in definition of aquatic habitat or the lack of it (Rinne 1995a).

The upper Verde River is one of the few remaining reaches of wild, free-flowing rivers in Arizona. Furthermore, this reach of river is a rarity in the Southwest because it supports a native fish community (Stefferud and Rinne 1995). Study of the reach of river upstream from Sycamore Creek began in 1994 following major flooding events on the Verde in winter 1992-93. The main objective of the study is to examine the sustainability of the native fish fauna relative to abiotic and biotic factors. Specifically, the role of the changing hydrograph with time and space, and the effect of introduced fishes on the sustainability of the native fish fauna are being examined (Stefferud and Rinne 1995, Rinne and Stefferud 1996). Southwestern fishes are highly adapted to the varying cycles of feast (flood) and famine (drought) (Minckley 1973, Deacon and Minckley 1974, Rinne and Minckley 1991). However, they are not able to adapt to the complete loss of surface flow, the obvious, critical component to their survival (Rinne 1995b).

Examination of the base flow hydrology in the upper Verde River basin was undertaken in 1997 to determine the trends in minimum base flows over the past three decades (Neary and Rinne 1997). Because of recent droughts and the extensive, rapidly increasing urban development in Chino Valley, the headwater of the Verde River drainage system, concerns have arisen over the ability of the river to sustain its native fish population. Understanding of this trend is very important for resource managers to arrive at decisions regarding land use activities and sustainability of the Verde River spikedace (*Meda fulgida*) and other native fish. This paper is an update of the 1997 Neary and Rinne paper. It reexamines base flow trends in the upper Verde River in light of recent trends in urban development in Chino Valley and Prescott to determine potential impacts on the habitat and sustainability of the native fish fauna.

METHODS

Stream flow data were obtained from the U.S. Geological Survey, Water Resources Division, Arizona District, records for the Paulden stream gage (No. 9503700) from 1963 through 1999. Although Neary and Rinne (1997) discussed data from the Clarkdale gage (No. 9504000), and the Camp Verde gage (No. 9506000), this analysis considers only records from the Paulden gage. The Paulden gage is located on the upper Verde River (perennial flow) between the confluence of Granite Creek (ephemeral flow) and Hell Canyon (ephemeral flow), about 14 km below the beginning of perennial stream flow. Its contributing drainage is about 5,568 km^2, or 40% of the Verde's 14,000 km^2 basin area (House et al. 1995). Flow data are available on the Verde Watershed Association's web site at (http://www.verde.org). Monthly and annual discharge data were taken from U.S. Geological Survey gage summary tables. Mean daily flows were analyzed to determine the minimum mean daily flow on an annual basis. Precipitation data were taken from the Prescott precipitation station (No. 026796) for the period 1931 through 1999. The rain gage is about 46 km south of the Paulden stream flow gage.

RESULTS AND DISCUSSION

Base Flow Trends: Mean monthly discharges at Paulden from 1964 to 1994 ranged from 0.65 to 3.62 m^3/s (23 to 128 ft^3/s). The mean maximum discharge of 40.77 m^3/s (1,440 ft^3/s) normally occurs in February, and the mean minimum discharge of 0.45 m^3/s (16 ft^3/s) occurs in May. During the period of record (1964-1999), the maximum peak daily flow was 387.85 m^3/s (13,700 ft^3/s) in 1993. An instantaneous peak flow of 657 m^3/s (23,200 ft^3/s) occurred during the 20 February 1993 storm (House et al. 1995). The minimum daily flow was 0.42 m^3/s (15 ft^3/s) during a 11-day period in 1964.

The annual minimum daily flows for the period of record, representing the lowest base flow during each year, are shown in Figure 1. They range from a low of 0.42 m^3/s (15 ft^3/s) in 1964 to a high of 0.71 m^3/s (25 ft^3/s) in 1985, 1986, 1994, and 1995. There is a trend of increasing annual minimum daily flows over this period. The cause of the slight downturn since 1995 may be nothing more than natural, climate-related oscillations observed in other years. It is certainly within the measured range of variability. The 5-year running average rises from 0.52 m^3/s (18.4 ft^3/s) in 1967 to 0.68 m^3/s (24.2 ft^3/s) in 1995, a 32% increase. As of 1999, there does not appear to be any evidence to indicate that water use in the upper Verde River watershed over the past three decades has affected the annual minimum daily flow.

Long-term Trends: Since stream flow gaging at the Paulden did not start until 1963, it is difficult to determine where the current trends in minimum daily base flow fit in the long-term pattern of minimum daily base flows.

Mechanisms: The trends of increasing annual minimum daily flows at both the Paulden and Clarkdale stream gaging sites suggests that base flows in the upper Verde River watershed are increasing in response to increases in precipitation. There is no evidence of decreases in evapotranspirational losses. No major vegetation management programs have occurred in the past three decades that would reduce transpirational losses of water. Photo comparisons show the opposite trend may be occurring due to increasing pinyon-juniper density and biomass. The remaining mechanism which might explain the increases in minimum daily base flows is precipitation.

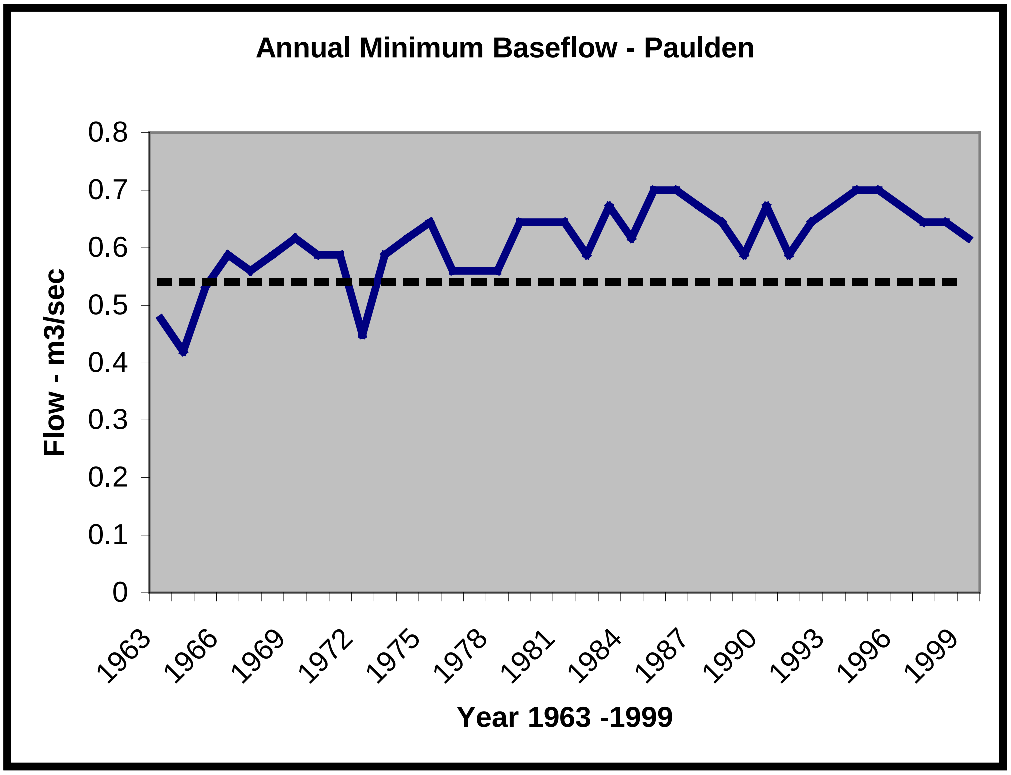

Figure 1. Annual minimum base flows, Paulden gage, Upper Verde River, 1964 – 1999.

Rainfall: During the 1932 to 1999 time frame there have been wetter and drier periods as indicated by cumulative departure curves (e.g. wetter, 1932-1946; drier, 1946-1964; wetter 1965-1972; drier, 1973-1981; wetter, 1981-1988; drier, 1989-1999). The 1964-1999 segment shows a general wetting trend during the period of increasing minimum daily flows in that cumulative departures from the mean have become more positive since the low point in 1964. This indicates that annual minimum daily flows are still seem to generally respond to oscillations in precipitation and not some other hydrologic process such as evapotranspiration. A downward trend in vegetation density in the watershed could possibly reduce evapotranspiration and increase base flows. Based on photographic evidence, vegetative cover in the upper Verde River riparian zone over the past 30 years has been increasing, not decreasing. There is not enough evidence on upland areas to argue one way or the other.

Storm Flow: During the period of time in which annual minimum daily base flows at the Paulden gage have been increasing, annual maximum daily peak flows have also been increasing (Figure 2). Since peak flows have a high degree of year-to-year variability, they are indicators of an increasingly wetter climate. Peakflows have definitely increased over the period of record, culminating in the high flows of February, 1993, that were estimated to have a return period of 70 years.

Groundwater Pumping: A recent proposal by the City of Prescott to pump up to 17.0 million m^3 (45 billion gallons) of groundwater from the Big Chino Basin could seriously impact minimum daily flows on the Verde. Pumping the full allotment (equivalent to 0.54 m^3/sec; dotted line in Figure 1) could significantly affect base flow in the upper Verde River in the driest of the past 38 years. Wirt and Hjalmarson (2000) concluded that 80% or more of the upper Verde's base flow comes from interconnected aquifers in the Big Chino Valley. They also noted that groundwater pumping at a rate of 24.61 m^3/min (6,500 gal/min) in the spring of 1964 to fill several lakes decreased base flows at Paulden by 25% (Figure 2). The 1964 pumping was two- thirds the potential maximum rate that the Prescott pumping would involve. With base flow reductions, both native and non-native fish populations would be forced into remnant pools, thereby aggravating an already serious predation problem that is contributing to the decline of native fish species.

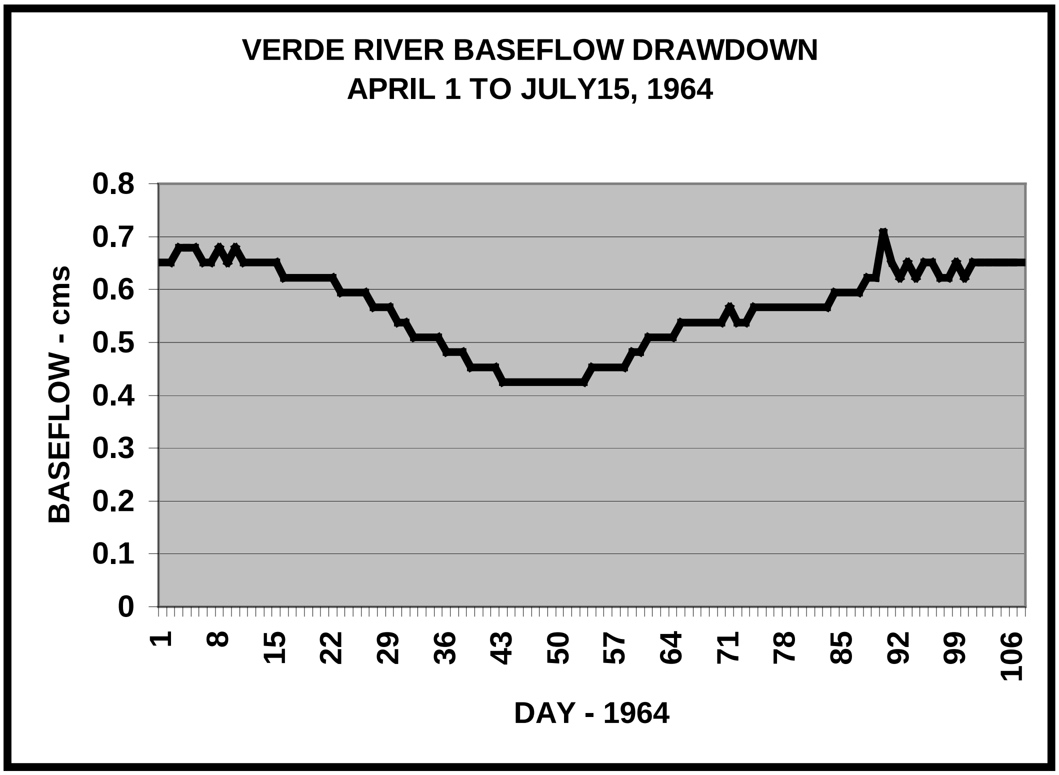

Figure 2. Base flow drawdown from groundwater pumping in the Chino Valley, Paulden Gage, April 1 – July 15, 1964.

Significance to Fishes: Miller (1961) first reported the decline of native southwestern fishes as a result of man's activities. Dam construction, diversion and groundwater mining were listed as major factors resulting in aquatic habitat alteration and loss in the Southwest. Rinne and Minckley (1991) further emphasized the continuing decline of the native, desert fishes in the region. The upper Verde has been largely spared from the first two major impacts, the influence of the last, groundwater pumping, may be yet to come. Just as floods have been documented to be beneficial to native fishes in this reach of river (Rinne and Stefferud 1996), base flows are critical to sustain the native fish community in times of reduced precipitation and runoff. The quantity and quality of stream flow, in time and space, strongly dictate fish habitat and in turn fish populations.

Shallow water, riffle-dwelling species such as loach minnow (*Rhinichthys cobitis*), spikedace (*Meda fulgida*), speckled dace (*R. osculus*), and longfin dace (*Agosia chyrsogaster*) would be affected first if streamflow is decreased. Speckled dace, longfin dace and spikedace, a threatened species currently inhabit the upper Verde (Stefferud and Rinne 1995). All three species have been demonstrated to inhabit low gradient riffles (Rinne 1992, Neary et al. 1996, Rinne and Stefferud 1996) and would be the first to be negatively impacted if stream flow is decreased. Initially, a decrease in flow would reduce reproductive potential in riffles and ultimately would force these two species into pools inhabited by the native predatory species, roundtail chub (*Gila robusta*) (Rinne 1992) and introduced smallmouth bass (*Micropterus dolomieui*) and yellow bullhead (*Ictalurus nebulosus*, Rinne and Neary 1997).

CONCLUSIONS AND RESCOMMENDATIONS

At the USGS Paulden gage, near the beginning of perennial flow on the Verde River, mean daily minimums range from 0.42 to 0.71 m^3/sec (15 to 25 ft^3/sec). The annual minimum mean daily flows at this gage exhibits a trend of increasing minimum flows over the past 3 decades. At the present time, these increases in minimum base flows on the upper Verde River appear to indicate that adequate flows will be available in the near future to sustain the Verde's fish population. However, this trend will require future evaluation and monitoring to determine if rapid urbanization of the Prescott and Chino Valley areas in future years begins to impact the base flow of the upper Verde River.

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Changes in Fish Populations in the Upper Verde River, 1994-2001

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Introduction

Sampling for fishes in the upper Verde River has been conducted in the upper Verde River has been conducted at seven established sites since spring 1994 (Stefferud and Rinne 1995).
The primary objective of sampling was primarily to examine the hypothesis whether abiotic (floods, physical habitat) or biotic (non-native fishes) factors were more determinant of fish community structure. Of special interest, was the native and nonnative components of the total fish community. In addition, data collection has provided a large data base on the fish populations in the upper Verde River. Data suggests: 1) a general decline in total abundance of fishes, 2) a general decline of all native fishes; 3) an inverse increase in non-native, larger predatory species such as the smallmouth bass (*Micropterus dolomieui),* green sunfish (*Lepomis cyanellus),* and yellow bullhead (*Amerius natalis),* and the small-sized bait species, red shiner (*Cyprinella lutrensis),* 4) an almost complete loss of smaller-sized native species including the threatened spikedace, *Meda fulgida;* and 5) a lack of recruitment of young-of-year of the three, large-sized, longer-lived native species.

Results of fish sampling, 1994-2001

Total fish abundance

Initial sampling in 1994 produced almost 9,000 total individual fishes. Abundance dropped seven-fold in 1995 to about 1300 individuals at the seven sites (Fig. 1). Estimated numbers of total fishes rebounded in 1996 (73% increase over 1995) and less so in 1997 (31% increase over 1995). Numbers then declined in 1998 and 1999 before increasing markedly in 2000 (117% over 1999). Total numbers of fishes increases slightly (20%) in 2001. Increases in 1997, 2000, and 2001 were largely due to large increases of the non-native red shiner (700% in 1997 and almost 200% in 2000; see Fig. 11).

Native/non-native species ratios

Native fish species predominated (> 80%) the total fish community from 1994 to 1996, before becoming inverse in abundance (ca. 20%) in 1997 (Fig. 2). Relative proportion of native species increased from 3% between 1997 and 1998 and about 7% between 1998 and 1999 before dropping in half (to 15%) in 2000. Proportions of natives increased 7% in 2001 and comprised 19% of the total fish community.

Changes in abundance by species

During initial sampling, longfin dace (*Agosia chrysogaster)* numbered over 1300 individuals before plummeting to only a dozen individuals in 1995 (Fig. 3). This usually common low desert cyprinid increased to almost 300 individuals in 1996 before dropping successively from 1996 to a two individuals collected in 1999, one in 2000, and 2 again in 2001.

Similar to longfin dace, another small-sized (<100 mm) cyprinid, speckled dace (*Rhinichthys osculus)*, was most abundant in 1994 (171 individuals) before dropping 85% in 1995, then tripling in number in 1996 (Fig. 4). A single individual was collected at the seven sites in 1997, 12 in 1998 and then only 9 individuals since. This species was absent from all sites in 2001.

The threatened spikedace, as with longfin and speckled dace, was most abundant in 1994, dropping dramatically in 1995, increasing slightly in 1996 before becoming absent from samples from 1997 to 2001 at the seven established sampling sites (Fig. 5). Less than a dozen individuals were collected in 1997 below the Black Bridge sampling site during a comprehensive sampling effort (Rinne 1999).

The two sucker species, Sonora (*Catostomus insignis)* and desert (*Catostomus clarki)*, were very abundant (1810 and 2644, respectively) in 1994 (Figs. 6, 7). Numbers dropped dramatically for both species in 1995, increased slightly in 1996, and then dropped down and have remained less than 15 to 20% of their abundance in 1994.

As with all the other native species, the remaining, larger-sized, longer-lived species, roundtail chub (*Gila robusta*), was most abundant in 1994 and has declined continually, and successively to 2000, then climbed slightly in 2001 (Fig. 8).

Of six non-native species, half have generally increased in abundance between 1994 and 2000, and the other half have oscillated in numbers (Figs. 9 to 14). Smallmouth bass (*Micropterus dolomieui)* increased steadily from about a dozen individuals at the seven sites in 1994 and 1995 to three times that number in 1996-97, before almost doubling between 1997 and 1998 and increasing another 60% from 1998 to 1999 (Fig 9). This non-native predator then declined by 50% between 1999 and 2000. The rationale for this drop of the smallmouth bass population in the upper Verde in 2000 appears to be sampling-related, especially based on its increase (300%) in 2001. Green sunfish (*Lepomis cyanellus)* increased between 1994 and 1995, decreased to 1996 and than has steadily and markedly increased to almost 200 individuals at the seven sites in 2001 (Fig. 10). Red shiner (*Cyprinella lutrensis)*, a bait species, has cycled in abundance since 1994 (Fig. 11). The species displayed a three-year cycle of abundance, being most common in 1994, 1997 and again in 2000. Numbers remained high in 2001. This species comprised a major component (> 85%) of the non-native fish assemblage in these four peak years.

Yellow bullhead likewise oscillated in numbers between 1994-2000, with a three-year pattern of abundance also being evident (Fig. 12). This species has increased steadily in numbers since 1994.

Fathead minnow (*Pimephales promelas)*, also a bait species, has generally been absent in samples taken since 1994. Mosquitofish, in contrast, first appeared in samples in 1997 and has steadily increased in abundance since appearing in samples in 1997, with a decline in 2001 (Fig. 13).

Finally, common carp (*Cyprinis carpio)* has remained low in numbers (< 2 dozen) every since 1994 (Fig. 14). The species also displayed the same three year cycle of abundance as did red shiner and yellow bullhead.

Recruitment of young-of-year of larger-sized species

Based on autumn sampling at two of the seven sites, the three large-sized species are not recruiting young-of-year. Recruitment for Sonora sucker was normal in 1994 and 1995 before dropping and remaining low up to 2000 (Fig. 15). Desert sucker and roundtail chub recruited successfully in 1994 (Figs. 16, 17) before showing poor recruitment of young-of-year every since.

In summary, total fish abundance in the upper Verde River, based on sampling at seven sites for 8 years has declined dramatically. Similarly, all native species have declined in abundance; nonnative fishes have increased. The small-sized species are either absent or almost so from samples and young-of-year of the three large-sized species are rare and not present in normally expected ratios to adults. This could be due to either lack of successful spawning or loss of young through predation.

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Figure 1. Change in total fish abundance, 1994-2001, Upper Verde River, Arizona

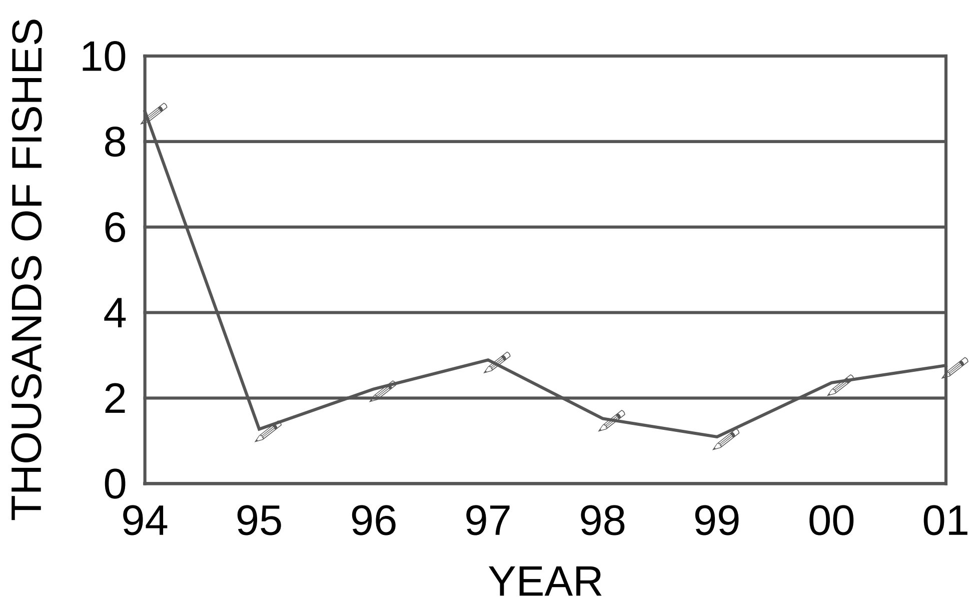


Figure 2. Relative native (circle) and non-native fishes (crosses), 1994-2001, Upper Verde River, Arizona

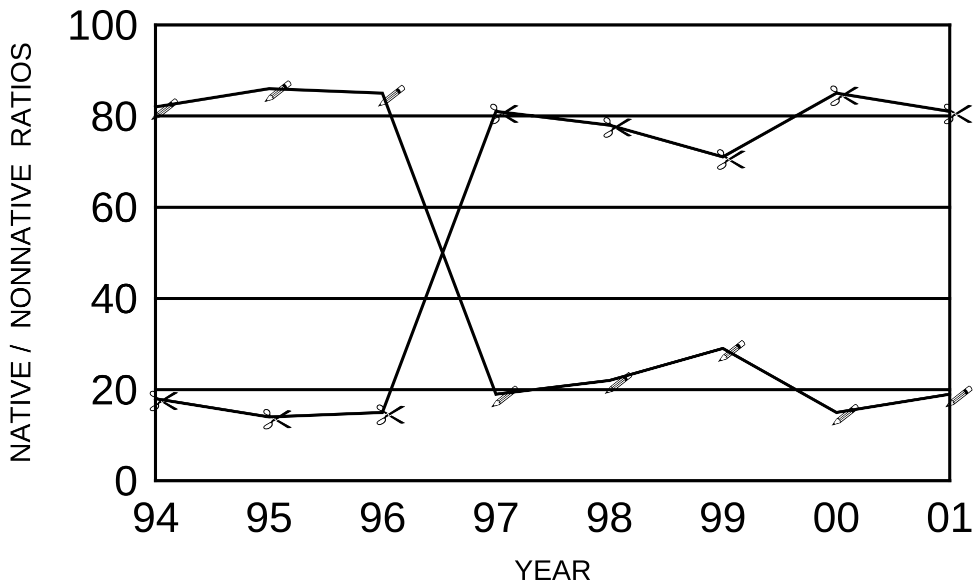


Figure 3. Change in abundance of longfin dace, 1994-2001, Upper Verde River, Arizona

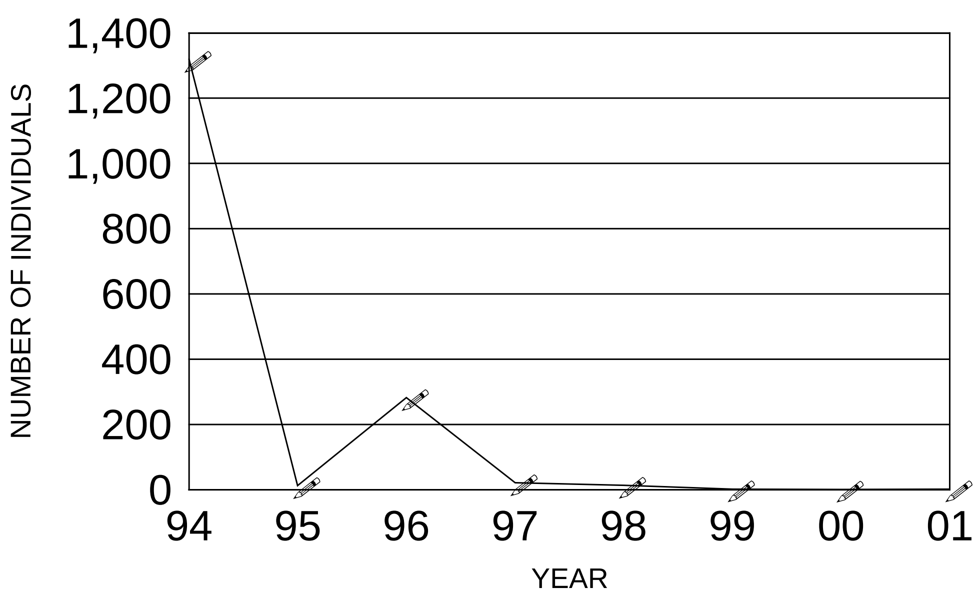


Figure 4. Change in abundance of speckled dace, 1994-2001, Upper Verde River, Arizona

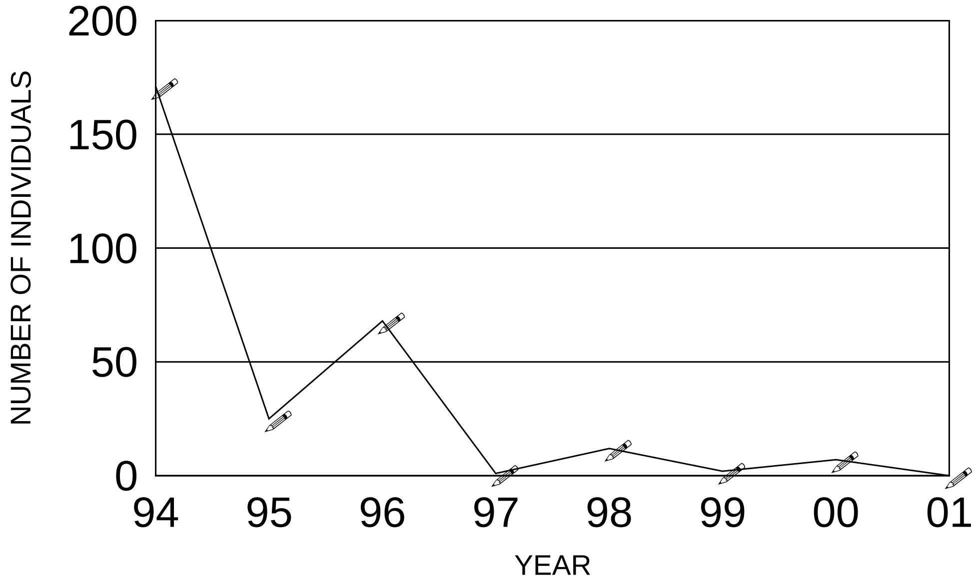


Figure 5. Change in abundance of spikedace, 1994-2001, Upper Verde River, Arizona

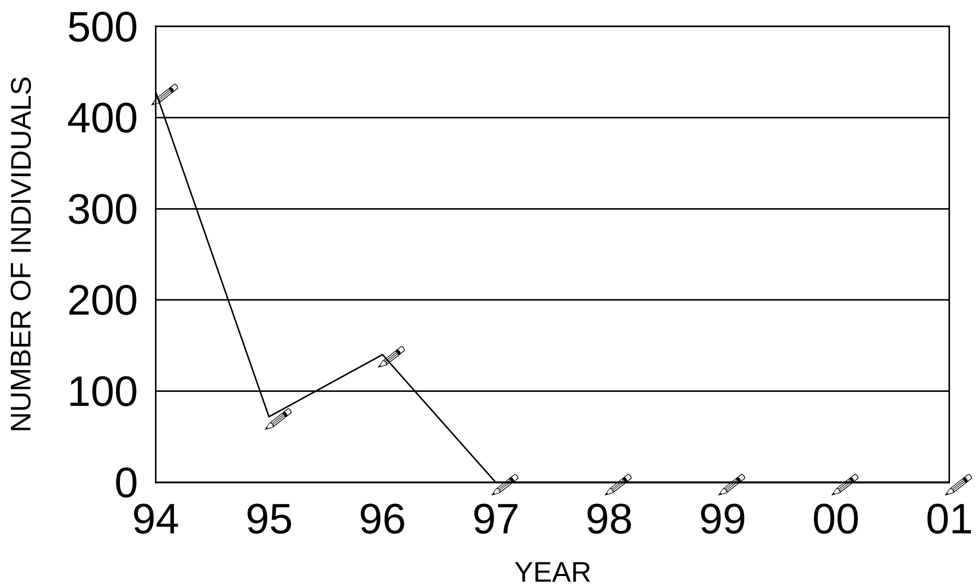


Figure 6. Change in abundance of Sonora sucker, 1994-2001, Upper Verde River, Arizona

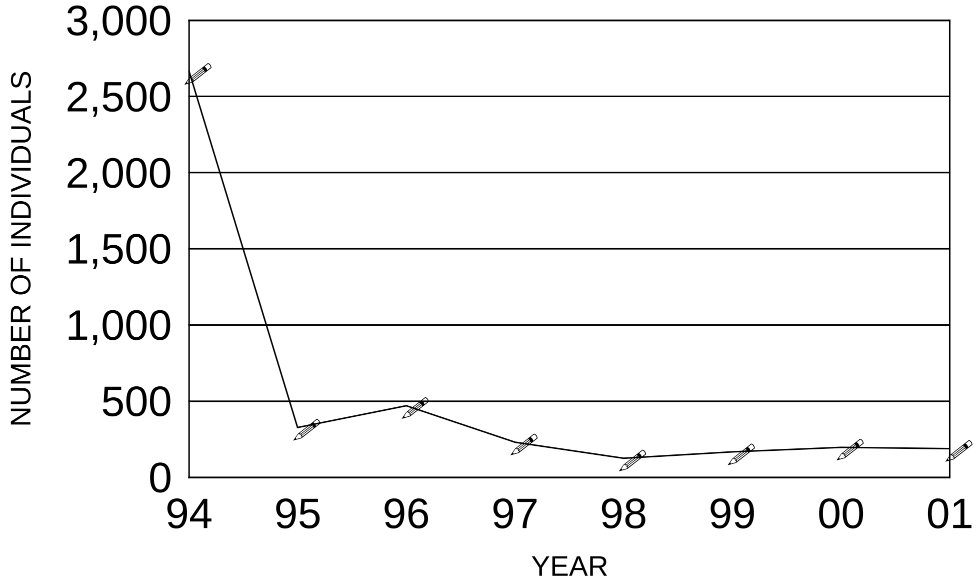


Figure 7. Change in abundance of desert sucker, 1994-2001, Upper Verde River, Arizona

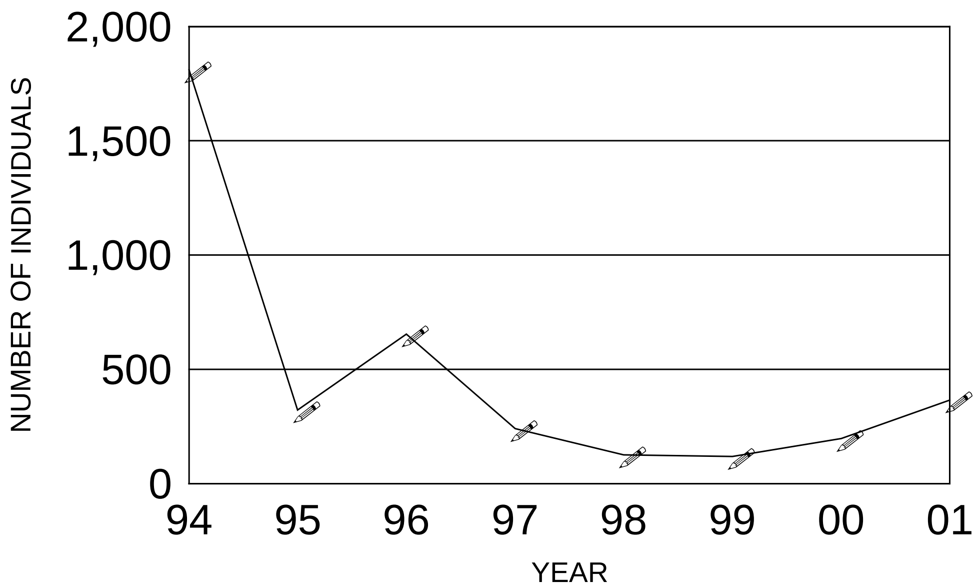


Figure 8. Change in abundance of roundtail chub, 1994-2001, upper Verde River, Arizona

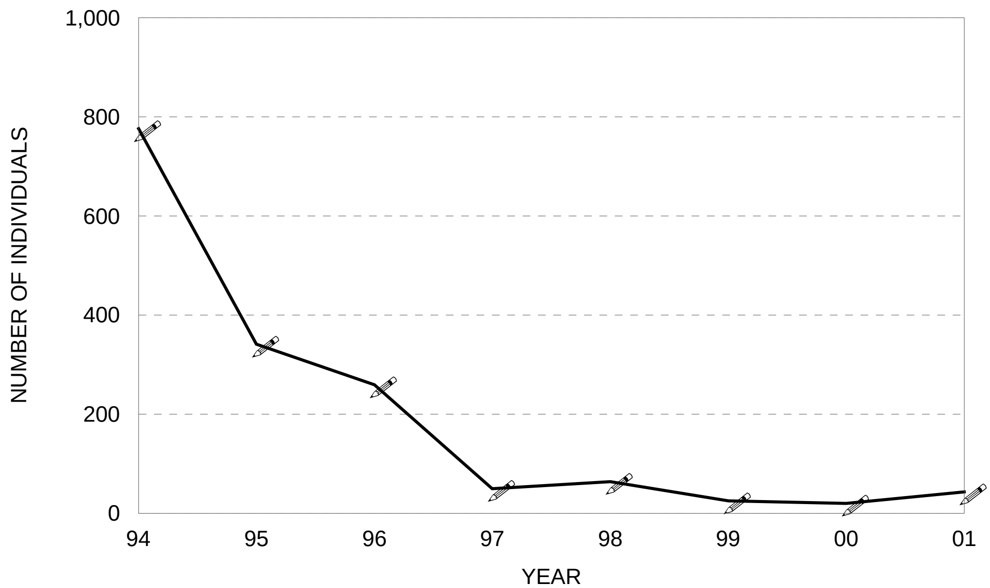


Figure 9. Abundance of smallmouth bass, 1994-2001,

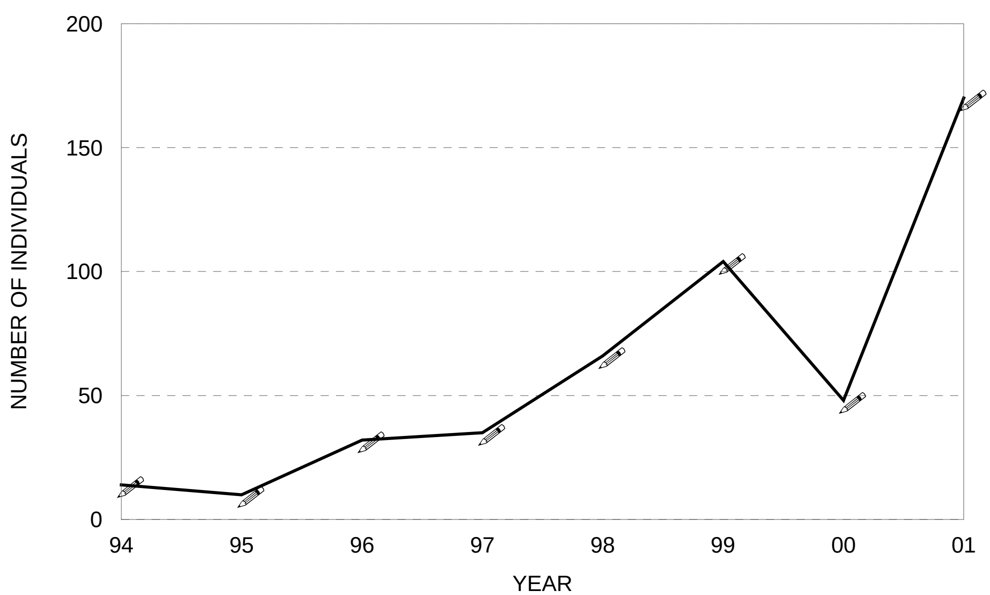


Figure 10. Abundance of green sunfish, 1994-2001, upper Verde River, Arizona

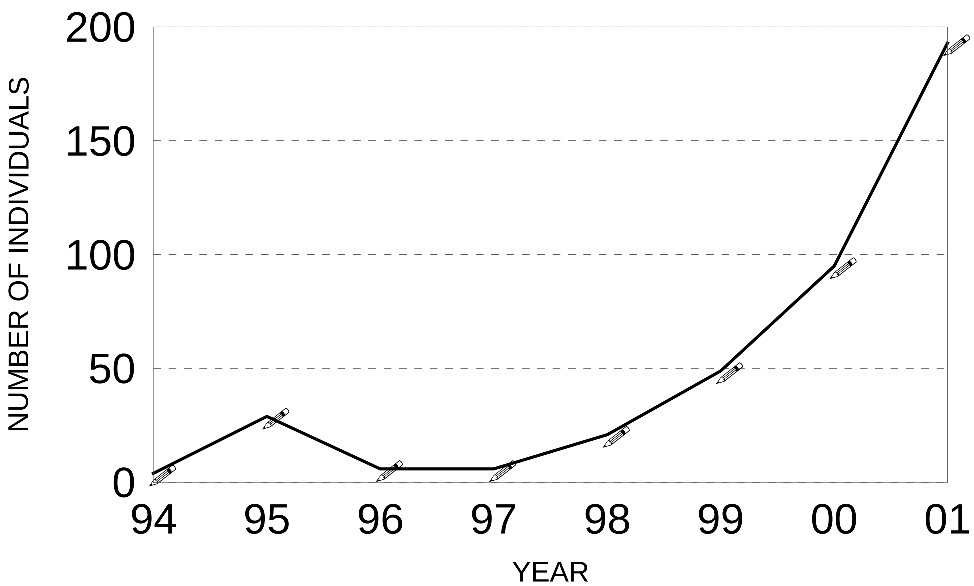


Figure 11. Abundance of red shiner, 1994-2001, upper Verde River, Arizona

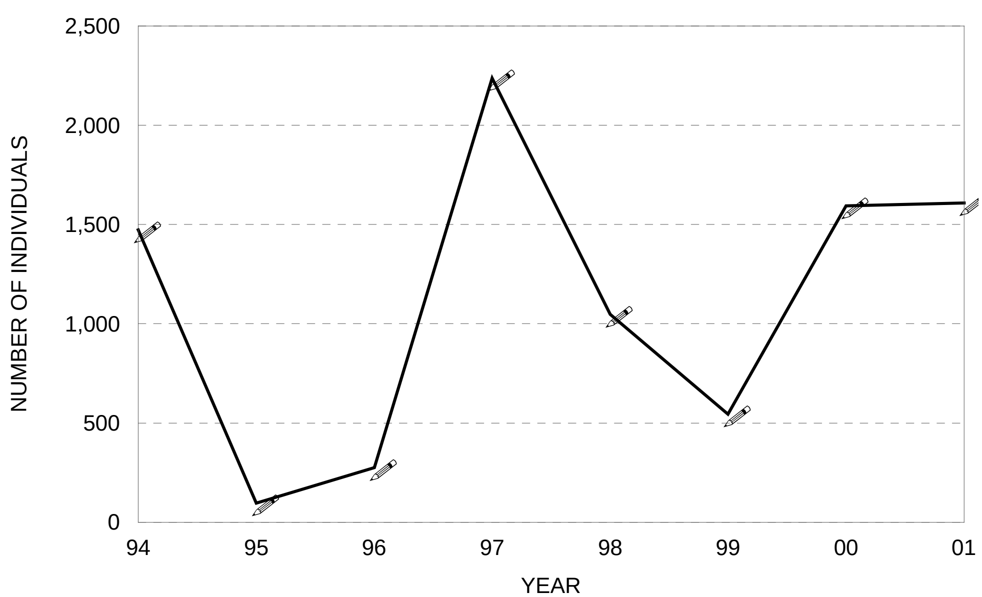


Figure 12. Abundance of yellow bullhead, 1994-2001, upper Verde River, Arizona

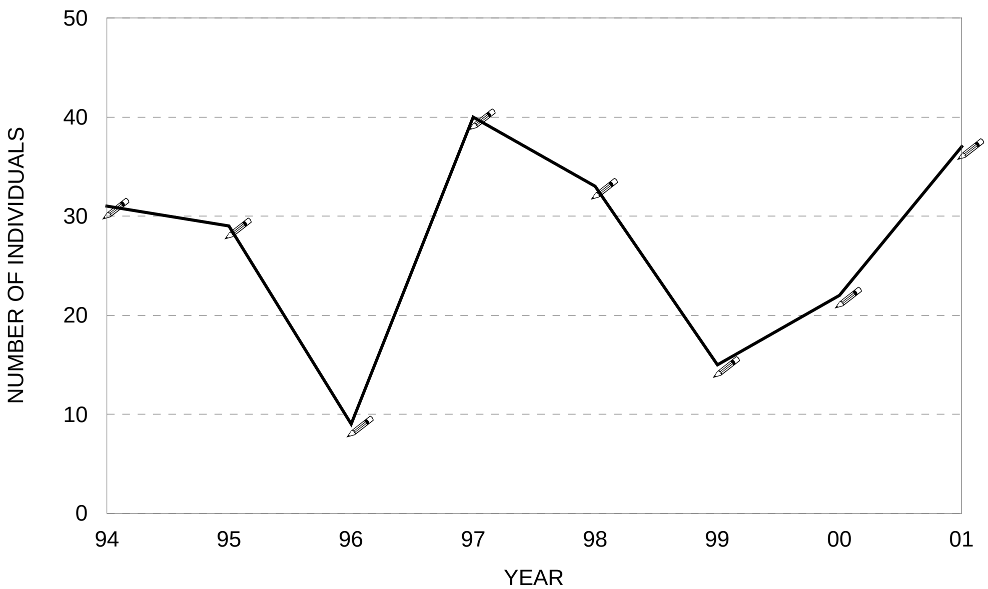


Figure 13. Abundance of mosquitofish, 1994-2001, Upper Verde River, Arizona

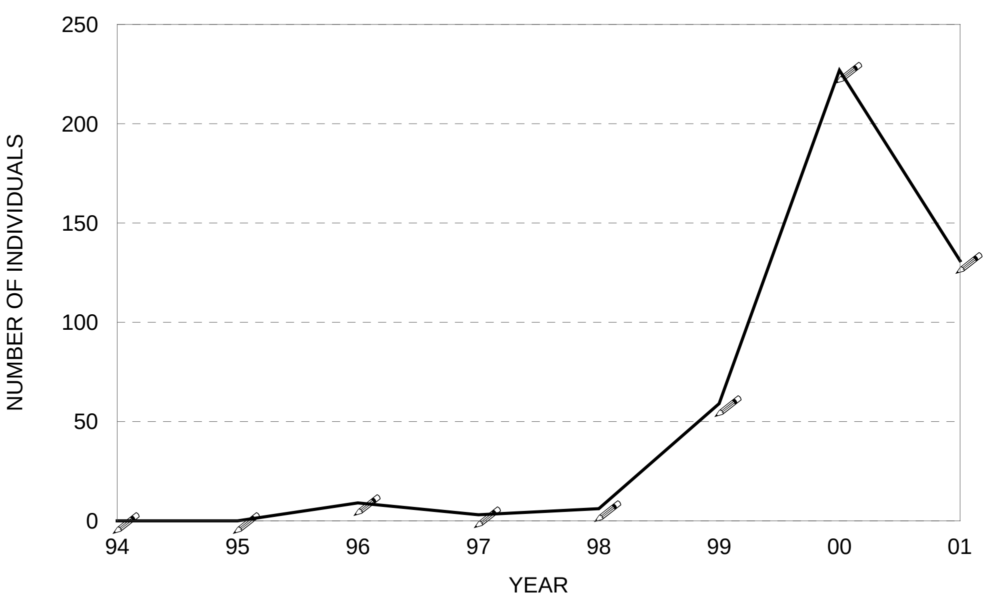


Figure 14. Abundance of common carp, 1994-2001, upper Verde River, Arizona

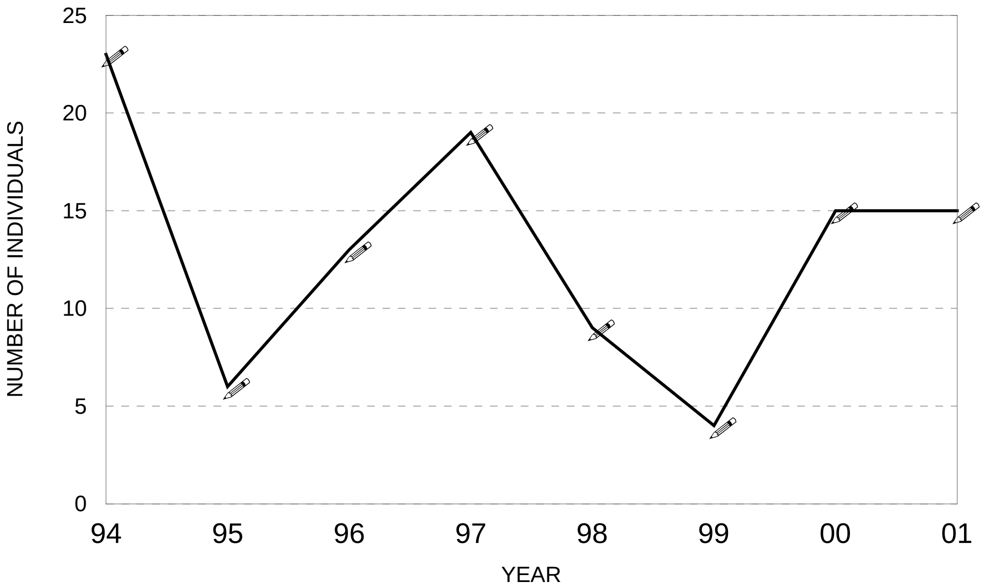


Figure 15. Relative proportions of YOY (circles) and adult (x's) Sonora sucker, 1994-2000.

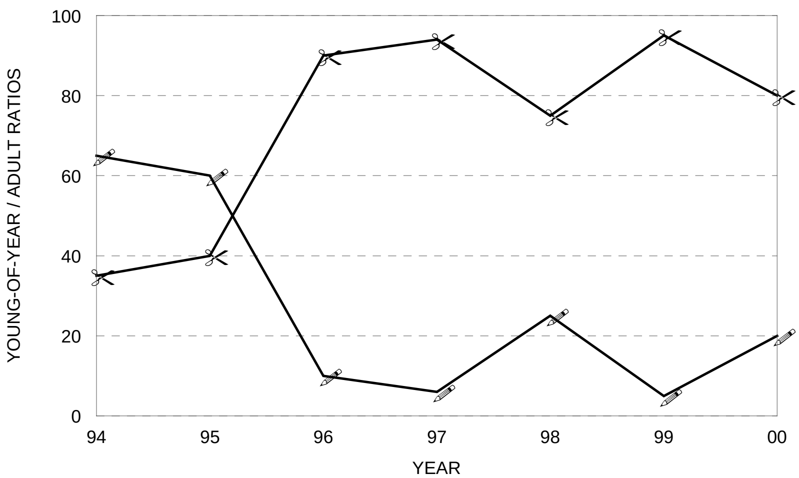


Figure 16. Relative proprotions of YOY (circles) and adult desert sucker (x's), 1994-2000.

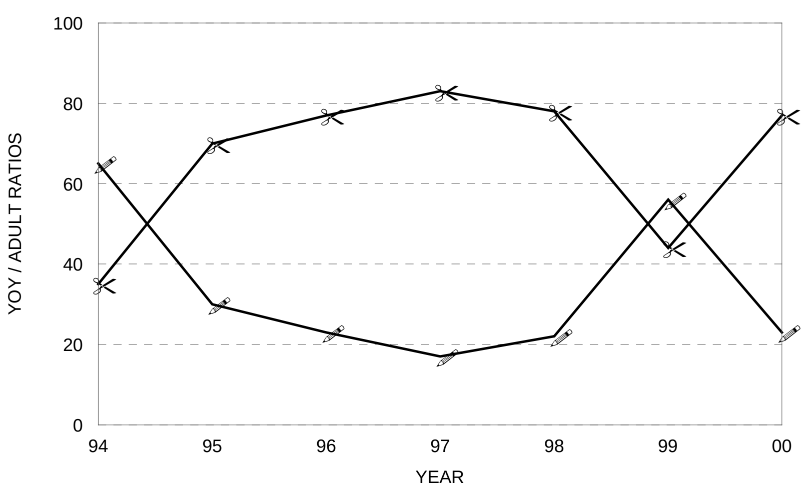
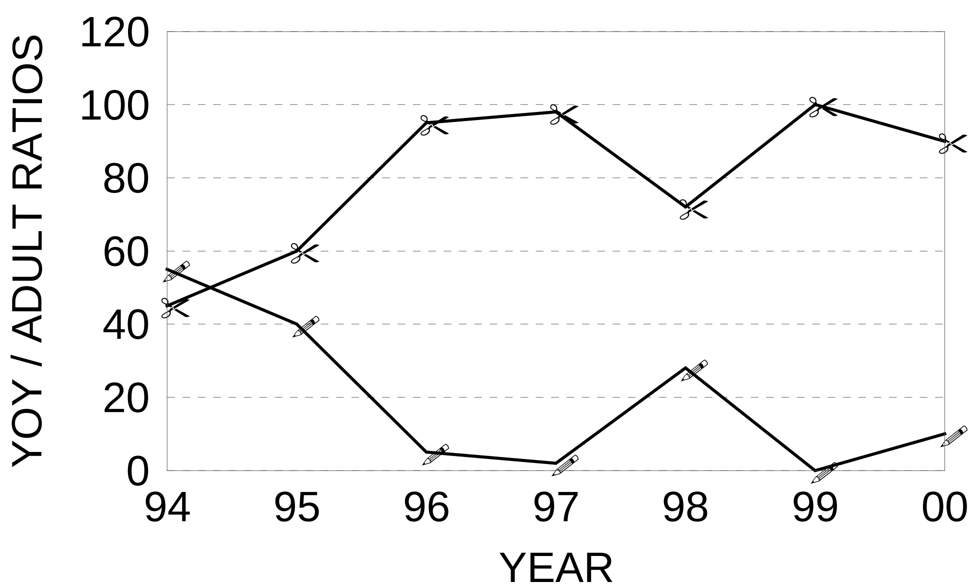


Figure 17. Relative proprotions of YOY (circles) and adult roundtails (x's), 1994-2000.



SUBSURFACE SOLUTION CAVES, SINKHOLE DEVELOPMENT, AND LOCAL CHANNELIZATION OF GROUNDWATER; SEDONA, ARIZONA

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Abstract:

The Devils Kitchen sinkhole in the Sedona area of Yavapai County, Arizona has collapsed in historic time. Five other geologically active sinkholes also occur in an area of six by ten miles near Sedona. All sinkholes occur in Permian Schnebly Hill and Hermit formation sandstone strata that are not responsible for their development. The Mississippian Redwall Limestone and Devonian Martin Dolomite (320-400 million years old) lie beneath the insoluble sandstone strata. All sinkholes occur along prominent northwest-trending sub-parallel joints (fractures) in the Schnebly Hill/Hermit formation strata that have allowed surface waters to percolate downward and enlarge solution caves over millions of years. The sinkholes formed when large limestone solution caves grew too big to support their roofs. As they collapsed, a column of broken rock propagated upward and eventually breached the ground surface. In-hole video camera photos within a Sedona water well has revealed the existence of voluminous, water-filled solution cavities in Redwall Limestone. On March 12, 2001 rapid snowmelt runoff in Red Canyon (drainage area about 0.5 sq mi) flowed directly into the Palatki sinkhole at a rate of about 1 cu/ft/sec. This form of direct short-circuiting of surface waters into a deep-seated aquifer was recognized years ago prior to the establishment of the Sedona sewer system. Large segments of the subsurface cave system are probably oriented sub-parallel to the northwest joint alignment. While the regional water table in the Sedona area displays an overall southwestern gradient, toward the Verde Valley, local groundwater flow through the cave system beneath Sedona may first travel either to the northwest or southeast, at right angles to the generally perceived gradient. Eventually, groundwater discharges from cave openings in the truncated outcrop surface of the Redwall Limestone, lying beneath Pliocene Verde Lake beds along the edge of Verde Valley, and allows artesian wells to flow at Spring Creek, Page Springs, Montezuma Well, etc.

ABSTRACT

Upper Verde Valley Riparian Area Historical Analysis

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Researchers compared the historical riparian system with the modern system to determine changes in woody riparian vegetation. Historic aerial photographs from 1940, 1954, 1968, 1977, 1989, and 1995 were interpreted, along the Verde River from 2 miles below the Oak Creek Confluence to 7 miles above Clarkdale. Aerial photos were scanned and georeferenced to create digital images which were used to map historic riparian vegetation in ArcView. Historic land use and river morphology were mapped also.

Historic precipitation data was evaluated in the watershed contributing to Verde River streamflow. Index wells were identified and three cross-sections were generated showing change in the water table at Centerville, Cottonwood, and Bridgeport. Historic peak streamflow was evaluated to determine the influence of flooding.

Results showed a continual increase in area of high-density mesquite, while total mesquite coverage change very little. This modest shift from lower to higher density mesquite is probably climate-related. High-density cottonwood-willow stands increased in area until 1977 and the decreased after 1977, while medium- and low-density cottonwood-willow area changed very little. Decreases in cottonwood-willow appear largely due to flooding. Land use trends showed a change from an agricultural to an urban setting. From 1940 to 1968, the Verde River channel area and adjacent bare sediment area decreased. Then from 1968 to 1995, channel area increased while adjacent bare sediment area remained generally steady.

Climate and flooding seem to have had the greatest influence on changes in the area of riparian vegetation in this study. However, urbanization, increased depth to groundwater, human-introduced competitive plant species, and sand & gravel extraction may have influenced decreases in riparian vegetation, while decreased cattle grazing may have influenced vegetation increases.

Verde Watershed Symposium
Submitted Abstract for Conservation Easement Presentation & Poster
11 May 2001

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Conservation Easements: Tool for Water Resource Protection

Presentation

Communities and agencies charged with management of water resources are confronted with eminent loss of the large, intact landscapes that have protected the public water supply. Consensus on goals, much less regulatory authority, is understandably slow to emerge from the discussion over control and management of urban growth. While public policy is only in the formative stages, the marketplace already trades an important tool for water resource protection: the conservation easement.

Easements for resource protection are a low-cost, flexible, limited property interest that is increasingly used by public and private sector alike. This presentation will offer a visual overview of the use of easements for water resource protection, including benefits from the perspectives of both agency and large landowner. Brief project information about successful efforts in the west to protect aquifers and surface systems will be presented. Arizona-based efforts to establish programs offering landowners incentives for conservation will be mentioned. Specific benefits of the use of conservation easements in the Verde basin will be covered. Sources of "how-to" information will be offered.

Poster

Private owners of working landscapes often have production goals that are consistent with resource protection. Owners cherish their landscape for the life style and connectivity between past and future that traditional landscapes give them. They struggle to find family-friendly solutions to estate and inheritance problems, tax issues, and land-transfer dilemmas. Conservation easements have been widely used to address just these family problems. This self-supported poster wall will present the benefits for large landowners of donating or selling a conservation easement over their ranch or farm. An 8.5x11-inch version of the poster will be available as a take-away.

The Role of The SRP Verde Reservoirs in Water Resources Management at The Salt River Project.

By: Charlie Ester, Manager, Water Resource Operations, SRP
Dallas Reigle, Senior Hydrologist, Water Resource Operations, SRP

The Salt River Project (SRP), the nation's first multipurpose reclamation project, provides water to over two million people in the Phoenix, Arizona metropolitan area through the management of six reservoirs (with a storage capacity of about 2.3 million acre-feet) on the 13,000 square mile Salt-Verde watershed (Figure 1). Median inflow to the reservoir system and the median water use in the 240,000-acre service area are about equal at 950 thousand acre-feet per year.

Figure 1: Salt and Verde River Watersheds

The SRP is comprised of two different companies. The private Salt River Valley Water Users' Association delivers nearly one million acre-feet per year to 240,000 acres in Phoenix metro area. The Salt River Project Agricultural Improvement and Power District serves more than 750,000 electric customers in the Phoenix metropolitan area and Gila county.

The reservoir system, Figure 2, is operated conjunctively with 250 deep wells in the Salt River Valley to provide a reliable and renewal supply of water to SRP shareholders. Total storage

Figure 2: Profile View of the SRP Reservoir System

projections out multiple seasons provide a means for SRP to project the amount of water needed from the Verde and Salt side of the system, the amount of supplemental groundwater production required, and the annual allocation.

The 309,613 acre foot combined capacity of the Verde Reservoirs represents just 13% of total SRP Reservoir storage capacity. Average annual inflow of the Verde is nearly 450,000 acre feet, or 1.5 times the storage capacity of the reservoirs. The small nature of the reservoirs on the Verde and the runoff volatility of the watershed have led to a general philosophy in managing the Verde water supply. To maximize storage conservation, the reservoirs must be managed to minimize spill during the winter months.

To meet these objectives, the reservoirs on the Verde are utilized almost exclusively to meet water demands from the fall, through the winter, and into spring until the risk of significant inflow events has diminished. During the summer, a minimum flow is released from Bartlett Dam or greater amounts if necessary to supplement releases being made from the Salt system.

This paper will present the philosophy behind the management of the Verde Reservoirs and detail the annual planning process SRP utilizes to maintain full water allocations, balance the probability of spilling water downstream of the system, and reducing the risk of future allocation reductions to SRP shareholders.

WATERSHEDS AND FISHERIES RELATIONSHIPS: STATE OF KNOWLEDGE, SOUTHWESTERN UNITED STATES

John N. Rinne and Daniel G. Neary

ABSTRACT: Research on the relationships between watersheds and fishes became an emphasis for management and research in the Southwest during the last three decades of the 20th century. Although watershed research had been progressing since the 1950s, greater consideration of the linkages between watersheds and fisheries began with the passage of the National Environmental Policy Act (1969), the Endangered Species Act (1973), and the Clean Water Act (1973). The immense diversity of both the Southwest terrain and climate has and will continue to make study of watershed effects on fishes and their habitats extremely difficult. Cycles of flooding and drought, wildfires, and introduced fish species are being demonstrated to be primary controlling factors that override many watershed management activities conducted by humans.

KEY WORDS: Watershed management research, fishes, flooding, drought, wildfire, exotic species

Verde Watershed Symposium
Submitted Abstract for Watershed Science Poster

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*(corresponding author)

Conservation of Southwestern Native Fishes in the Verde River, Arizona.

Native fishes of the Southwest represent a unique community found nowhere else in the world. Although less diverse than communities found in other regions of the United States, the species are specially adapted to the high temperatures, large floods, and turbid waters found in southwestern streams. Unfortunately, this fish community is imperiled or eliminated from much of its former range because of human needs for water and the introduction of nonnative fish and invertebrate species. Over the past ten years, some native fish populations in the Verde River have declined precipitously while exotic fish populations have increased significantly. The changes are probably related, as exotic fish prey directly on native fish, and can out-compete natives for available resources. The proportion of native fish is higher in the upper portion of the Verde River (Sullivan Lake to Tapco), possibly due to differences in flood regime and human impact. The more pristine, upstream portion of the river experiences annual floods, which tend to flush out nonnative fish, while native fish can quickly recolonize the river following a flood event. Downstream areas of the Verde River have more water diversions, channel restrictions such as road crossings and bank armoring, and greater sources of nonnative species. Recently, stakeholders identified several strategies to improve ecological conditions on the Verde. Some of these strategies show limited preliminary success, while others are still in the conceptual stage. Selective removal of exotic fish through netting and electroshocking shows promise as a means of improving conditions for native fish. Other potential strategies include managing the upper Verde River exclusively as a native fishery, including the installation of a fish barrier near Tapco, and educating anglers against introducing new populations of nonnative fish via bait buckets, and other education measures. Riparian and aquatic habitat degradation can be slowed by wise development that leaves greenbelts and floodplains connected to the river channel so the natural flooding regime damages less property. Most importantly, water pumping and development plans need to ensure that adequate flows are left in the river to provide habitat for fish. However, complicated negotiations among a wide variety of stakeholders are required for successful implementation of habitat improvement projects on a scale broad enough to ensure success. A comprehensive approach that includes management of water resources, habitat, and non-native fishes will be needed over the next few years to ensure the long-term survival of Arizona's diverse native fish heritage in the Verde River.

Wildlife and Fisheries Inventory and Monitoring along the middle Verde River

Bill Burger, Nongame Specialist, Arizona Game and Fish Department, Region VI, Mesa.

Although relatively close to the Phoenix metropolitan area, much of the Verde River that flows within the boundaries of Arizona Game and Fish Department's (AGFD) Region VI, i.e. that below Camp Verde, receives limited human use. Between Childs and approximately Sycamore Creek the river is within the Mazatzal Wilderness area, and between Childs and Red Creek it is designated as a Wild River. On 14-17 June 1999 and 21-25 August 2000 I conducted wildlife surveys along the Verde from Childs to Sheep Bridge (near Sycamore Creek). Major objectives of the trips were to document the level of river otter use and to search for riparian herpetofauna, particularly leopard frogs, along the river and in proximate portions of tributary drainages. Otters used the entire portion of river surveyed, with documented scat locations averaging 3.2 locations per mile along a 26 mile stretch in 1999, and 1.7 locations per mile along a 32 mile stretch in 2000 (annual numbers are not comparable because of different flow regimes prior to and during surveys). Crayfish appear to be among the otter's major prey based on observation of otter scat. No leopard frogs were found during the June 1999 trip. In 2000, lowland leopard frogs were found in two tributary drainages (Squaw Creek and Tangle Creek) but none were found along the Verde itself. The absence, or low densities, of leopard frogs along the river is speculated to be a result of adverse impacts from introduced fish and crayfish. During 2000 surveys, crayfish and exotic fish were documented in the Verde, Fossil Creek, Wet Bottom Creek, and in a pool in Red Creek near its confluence with the Verde. Along with the leopard frogs, only native fish were seen in Houston/Squaw Creek and Tangle Creek. One night bat netting in each 1999 and 2000 resulted in captures of 4 species (pallid, big brown, Yuma myotis, and Mexican free-tailed), and another free-tailed bat species (*Nyctinomops*) was audibly detected. Several small caves showed evidence of bat use. Limited small mammal trapping in 2000 resulted in poor capture success but documentation of two species, *Peromyscus leucopus* and *Perognathus pencillatus*. Six black bears were documented along the river in 2000 by sightings and tracks. Other wildlife work being conducted along the Verde within AGFD Region VI includes surveys for southwestern willow flycatchers (transients and one possible breeding pair have been documented) and management activities related to the several pairs of nesting bald eagles along the river. Fisheries management and research activities center on reintroduction of two big-river native fish, the Colorado pikeminnow and razorback sucker.

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Hydrogeologic Data Assessment for the Coconino Plateau

By Marilyn E. Flynn[1] and Donald J. Bills[1]

This project is a compilation and evaluation of existing data that can be used to describe the hydrogeology of the Coconino Plateau. The information assembled will be part of the database used to investigate the effects of natural and human-caused stresses on the sustainability of water resources of the region. The study is funded by an Arizona Water Protection Fund (AWPF) grant to the City of Williams and will determine preliminary boundaries of the hydrogeologic flow systems that supply the major springs of the Coconino Plateau in the greater Grand Canyon region and support riparian zones along the Little Colorado River, Havasu Creek, and streams of the South Rim of the Grand Canyon.

OBJECTIVES

The objectives of this study are to determine, on the basis of currently available information:

1. Preliminary boundaries of the ground-water flow systems in relation to natural recharge and discharge areas and current and proposed ground-water development.
2. Hydrogeologic controls on known discharge areas.
3. Additional data and analysis needed to describe and assess the sustainability of natural flows that support riparian areas.

PROJECT WORK PLAN

The following tasks describe activities to be performed for data compilation, inventory, and evaluation as part of this study:

Task 1: Develop a detailed work plan for collecting data, inventoring wells and springs, and monitoring ground-water levels and ground-water discharge.
Completed June 2000.

Task 2: Inventory and compile available water-resources data.
Completed December 2000.

Task 3: Identify preliminary boundaries of the ground-water flow systems and physical aspects that control the occurrence and movement of water resources of the Coconino Plateau.
In progress.

Task 4: Identify limitations of analyses and indicate types and areas of additional data needs.
In progress.

Task 5: AWPF Information Transfer Meetings and outreach.
In progress.

Task 6: Annual progress reports and final report.

CURRENT STATUS

- Computer database contains data on wells, springs, topography, and geography.
- Geology, soil, vegetation, climate, and remotely sensed data will be added.

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4 MAY 2001

POSTER ABSTRACT for Verde Watershed Symposium - State of the Watershed, 2001

PRIVATE WELL WATER TESTING - YAVAPAI COUNTY
"Almost Free" Private Well Water Testing During National Drinking Water Week.

The **University of Arizona Cooperative Extension** has been providing an annual *Private Well Water Testing Program* to Yavapai County residents for the past four years, during **National Drinking Water Week.** This program has been dedicated to raising public awareness of drinking water issues. We have encouraged all well owners to develop a stewardship of their local watershed and aquifers by participating in this years program.

During the year 2000program, the Cooperative Extension provided participants with a **Seven-Parameter "Shirt Pocket" Laboratory**. *This kit tested for pH, nitrates, nitrites, total hardness, alkalinity, copper and iron*. This on-site, easy-to-use, accurate, test-strip-type, kit provided well owners with instant and immediate results about their well water. All testing was done on-site, at home. As results were returned_ follow-up analysis and recommendations, from the Cooperative Extension, were promptly provided.

For the past four years, we have been testing privately owned wells within Yavapai County and ALL Reaches of the Verde River for water quality. . . . . specifically, for pH, nitrates, total dissolved solids and conductivity. Gradual increases in the occurrences of nitrate-enriched water has been identified in several areas of Yavapai County that may be impacting the groundwater quality of the Verde Watershed. Nitrates and nitrites can enter ground water supplies from poorly designed septic systems, excessive fertilization of crops and/or landscapes, or concentrated animal waste sources. Excessive levels of nitrates (and some of the other elements being tested for this year) can pose serious health risks. Other substances distract from the taste or domestic uses of water. This has been a good opportunity for well owners to get an idea of the condition and quality their well water. The Cooperative Extension continues to encourage previous participants to keep a close, annual, watch on well water quality. In Arizona, well owners have ***sole responsibility*** for determining and monitoring the quality of their wells.

In recent months, the water testing efforts of the University of Arizona Cooperative Extension of Yavapai County has played an important role in increasing public awareness and knowledge about water resource issues. Increasing nitrate levels of ground water in the Little Chino Aquifer, which were initially discovered as a result this program, have resulted in the City of Chino Valley determining the source of nitrate pollutants and the future potential impact of land development and use in the area. There is currently an effort being made by that municipality to move to a municipal wastewater treatment operations for the residents in that area.

An increased interest in drinking water quality is being demonstrated throughout Yavapai County.

The poster presentation reflects the efforts, data and findings of this four year program. Supportive information and/or handouts will compliment the display.

A collaborative, formal paper regarding this five year program is in progress and will be released later this year, after 2001 data is processed and included.

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