BASE FLOW TRENDS IN THE UPPER VERDE RIVER REVISITED

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The native fish populations in Arizona's rivers are affected by various intrinsic and extrinsic factors that are characteristic of the arid environment of the Southwest and the activities of its human inhabitants (Table 1). Concerns have been raised about nearly all of these factors. However, climatic events of the past decade have focused questions on the potentially negative effects of reduced stream flows. Principal among these concerns are the effects of drought, consumptive water use for municipalities, water diversion for irrigation, and water quality deterioration on native fish. Minimum base flows are the most critical for fish survival. Significantly reduced base flows could put native fish populations, especially threatened and endangered species, 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, characteristic to the Southwest, and its aridity, patterns of stream flow are highly variable (Jaeger 1957; Green and Sellers 1964; Nations and Stump 1981). An alternating pattern of episodic floods and drought are the norm in the basin. The interactions of these factors result in the 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 last 3 decades of the twentieth century (1963 to 1995; Neary and Rinne 1997). At the USGS Paulden gage, near the beginning of perennial flow on the Verde River, Neary and Rinne (1997) found that mean daily minimums ranged from 0.42 to 0.71 m^3/sec (15 to 25 ft^3/sec). The annual minimum mean daily flows at this gage exhibited an increasing trend through this period. At the Clarkdale gaging station above Cottonwood, mean daily minimums varied from 1.70 to 2.32 m^3/sec (60 to 82 ft^3/sec). Similar to Paulden, the trend at Clarkdale since 1965 was toward increasing annual minimum mean daily flows. At the time of our initial analysis, we concluded that the increases in minimum base flows on the upper Verde River appeared to indicate that adequate flows would be available in the near future to sustain the Verde's fish population (Neary and Rinne 1997). However, we cautioned that the base flow trend would require future evaluation and monitoring to determine if rapid urbanization of the Prescott and Chino Valley areas in future years could impact the base flow of the upper Verde River.

Because of recent droughts and the extensive, rapidly increasing urban development in Chino Valley, which is the headwater of the Verde River drainage system, concerns have arisen again over the ability of the river to sustain its native fish population. An understanding of this trend is very

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Table 1. Ecosystem influences on native fish in the Upper Verde River watershed.

Uplands Extrinsic – Natural	River Intrinsic	Uplands Extrinsic – Human Related
1. Climate	1. Stream flow	1. Grazing
2. Geology	2. Nonnative fish	2. Mining
3. Soils	3. Other nonnative fauna	3. Roads
4. Vegetation	4. Water quality	4. Forestry
5. Groundwater	5. Geomorphology	5. Urban development
6. Runoff	6. Sediment regime	6. Agriculture
7. Natural sediment	7. Macro-invertebrates	7. Recreation
8. Wildlife	8. Riparian vegetation	8. Water engineering

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. This paper deals only with data from the Paulden stream gage in the uppermost portion of the Verde River.

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 percent 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 gage.

Results and Discussion

Base Flow Trends

Mean monthly discharges at Paulden from 1964 to 1999 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 an 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 rose 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 percent 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 3 decades has affected the annual minimum daily flow.

Long-Term Trends

Stream flow gaging at Paulden did not start until 1963, so 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. A reconstruction of climate over the past 2200 years by Grissino-Mayer (1996) indicates that

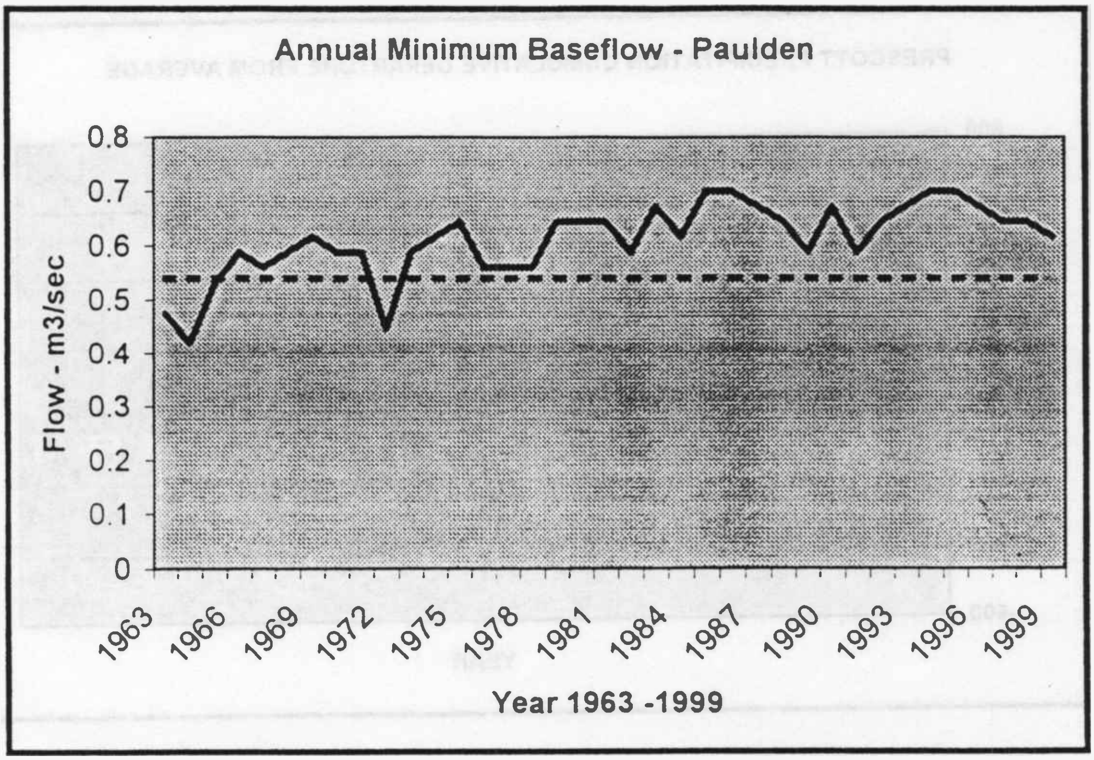

Figure 1. Annual minimum base flows, Paulden gage, upper Verde River, 1964–1999.

the current conditions are the wettest since 600 A.D.

Mechanisms

The trend 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 3 decades that would reduce transpirational losses of water. Photo comparisons show that the opposite trend may be occurring due to increasing pinyon-juniper density and biomass. The remaining mechanisms that might explain the increases in minimum daily base flows are reduced groundwater pumping for agriculture in the Chino Valley and increased precipitation.

Agriculture Groundwater Pumping

Wirt and Hjalmarson (2000) reported a decline in agricultural usage of groundwater in Big Chino Valley from a peak of just over 14.8 million m^3/yr (12,000 ac-ft/yr) in the mid 1970s to 2.5 million m^3/yr (2,000 ac-ft/yr). This reduction coincided with an increase in the mean annual base flow of the Verde River and an increase in winter groundwater levels in Big Chino Valley. Wirt and Hjalmarson (2000) concluded that this is additional evidence of the direct linkage between Big Chino Valley groundwater and base flows in the Upper Verde River.

Rainfall

Although Wirt and Hjalmarson (2000) discounted precipitation as the cause of increased base flow in the Verde, during the 1932 to 1999 time frame there have been wetter and drier periods. These are 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). In Figure 2, 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 be-

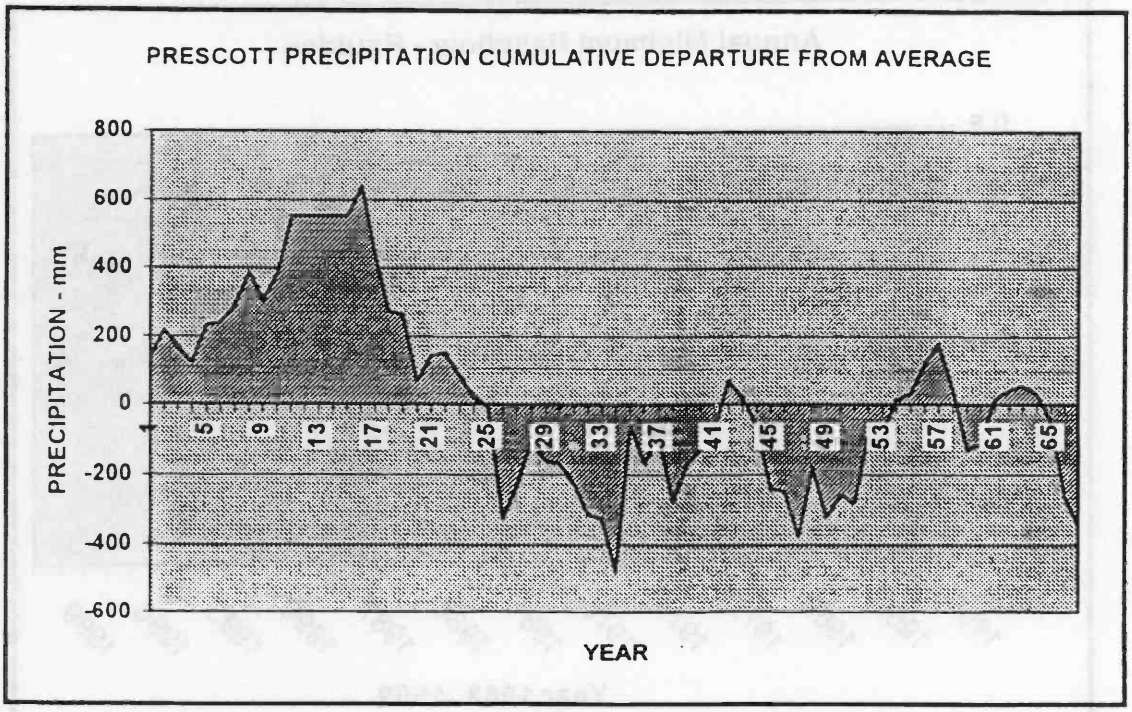

Figure 2. Prescott precipitation cumulative departure from average, 1932–1997.

come more positive since the low point in 1964. Another indication that there is a trend since 1964 toward wetter weather is shown in Figure 3. The number of days with base flows at or below the mean minimum flow has declined dramatically since the 1960s and 1970s. This trend could be attributed to the decline in agricultural groundwater pumping. However, the storm flow trend during this period supports the wetting trend hypothesis. This information suggests that annual minimum daily flows might 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 increased, not decreased. There is not enough evidence of vegetation cover expansion on upland areas in the past 3 decades to argue one way or the other, but vegetative cover since the early part of the twentieth century has definitely increased.

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 4). Because peak flows have a high degree of year-to-year variability, they are indicators of an increasingly wetter climate. Peak flows have definitely increased over the period of record, culminating in the high flows of February 1993, which were estimated to have a return period of 70 years.

Potential Urban 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 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 percent or more of the upper Verde's base flow comes from interconnected

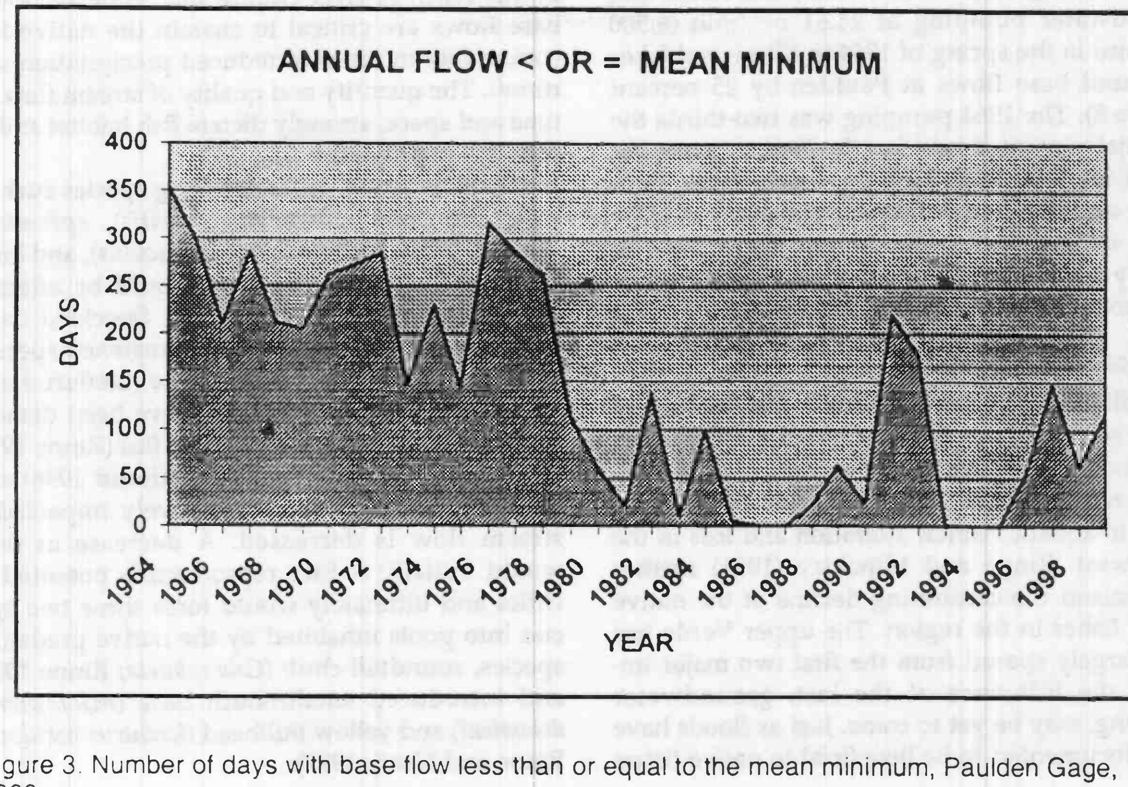

Figure 3. Number of days with base flow less than or equal to the mean minimum, Paulden Gage, 1964–1999.

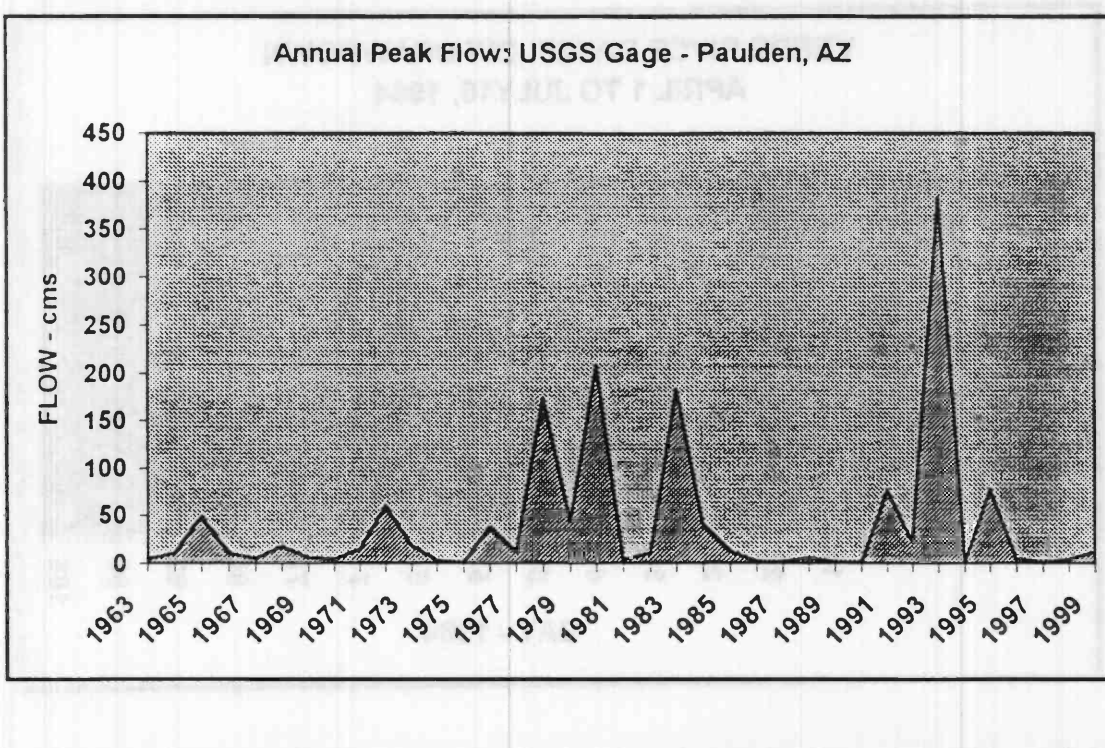

Figure 4. Annual peak flow at the upper Verde River stream gage at Paulden, 1964–1999.

aquifers in Big Chino Valley. They also noted that groundwater pumping at 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 percent (Figure 5). 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.

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 that result 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 stream flow 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. A decrease in flow would initially 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).

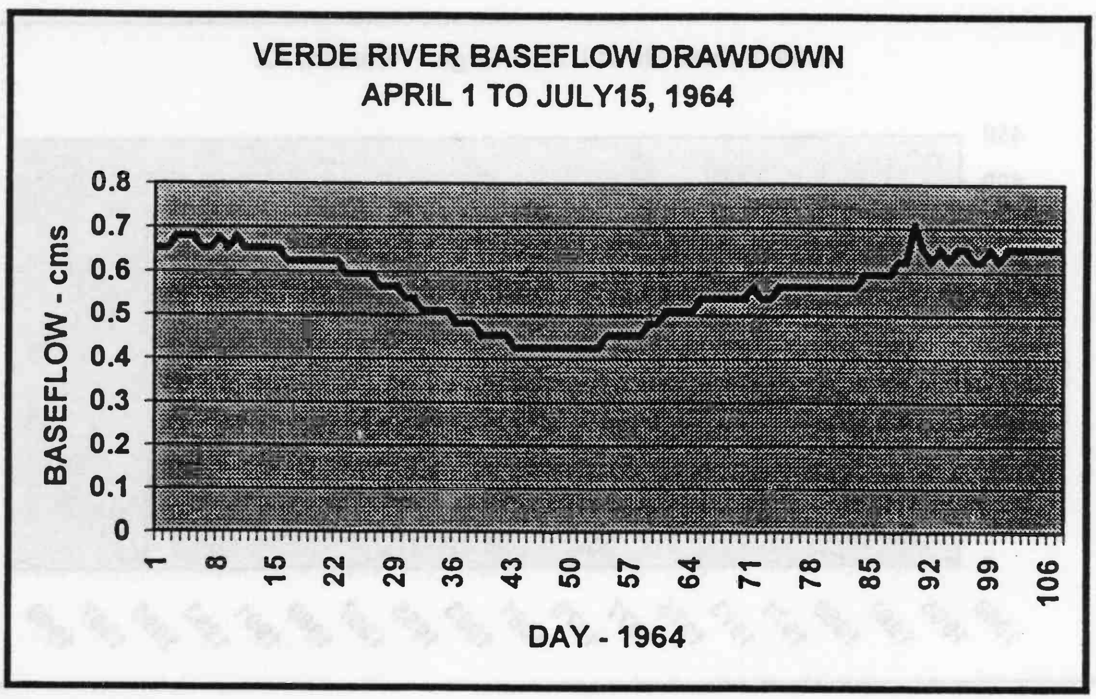

Figure 5. Base flow drawdown from groundwater pumping in the Chino Valley, Paulden Gage, April 1–July 15, 1964.

Conclusions and Recommendations

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 have exhibited an increasing trend over the past 3 decades. At the present time, these increases in minimum base flows on the upper Verde River appear to indicate that current flows are adequate to sustain the Verde's native fish population. It is evident from new information developed by the U.S. Geological Survey that base flows in the upper Verde River depend heavily on groundwater in the Big Chino aquifer. The current trend in minimum base flows will require close evaluation and monitoring in the future. Preliminary information on potential groundwater withdrawals by the city of Prescott and the rapidly urbanizing Chino Valley indicate that these actions could begin to impact the base flow of the upper Verde River.

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