Subject: Summary of US Geological Survey (USGS) Report – Geologic Framework of Aquifer Units and Ground-Water Flowpaths, Verde River Headwaters, North-Central Arizona (Open File Report 2004-1411 by Laurie Wirt, Ed Dewitt, and V.E. Langenheim)

From: TAC - February 21, 2007

In accordance with a Yavapai County Water Advisory Committee (WAC) directive, the Technical Administrative Committee (TAC) has prepared this summary document as an interpretive aid for the WAC. As such, this document is the TAC's perspective[1] regarding the subject report and the relevance of the information to water management objectives. References to specific pages in the subject report are provided throughout this document. All figures are from the report.

Executive Summary:

Subject report: "Geologic Framework of Aquifer Units and Ground-Water Flowpaths, Verde River Headwaters, North-Central Arizona" (U.S. Geological Survey Open File Report 2004-1411 by Laurie Wirt, Ed Dewitt, and V.E. Langenheim (Wirt Report)).

Purpose and Key Findings:

- The stated purpose of the report is to provide a "more detailed understanding of the hydrogeologic framework of the Verde River headwaters, especially the relation between major aquifers and the upper Verde River." (p. A4 of Wirt Report)
- Flow entering the upper Verde River originates from three major aquifers: the Big Chino basin-fill aquifer, Little Chino basin-fill aquifer, and the "Carbonate Aquifer", which underlies the Big Chino Valley and Big Black Mesa.
- The report concludes that most of the baseflow measured at the Paulden gage is from the Big Chino Valley area. The combined Big Chino basin-fill and carbonate aquifer underlying the Big Chino basin contributes between 80 and 86% of the baseflow at the Paulden gage, or 13,600 to 14,650 acre feet per year (p. G9). Geochemical modeling indicates that approximately 10 to 15% of this amount comes from the carbonate aquifer that underlies the Big Chino Valley basin-fill (p. G10 and Fig. G1).
- The Little Chino basin-fill aquifer contributes about 14% (p. G10 and Fig. G1) of the baseflow at the Paulden gage.
- Between 0 and 6% of the baseflow measured at the Paulden gage is estimated from geochemical modeling to come from the carbonate aquifer north of the Verde River (p. G10 and Fig. G1.)
- The conclusions are supported by several lines of evidence including geological, geophysical, and geochemical analyses.

[1] Because of his involvement with the subject report, TAC member Dr. Abe Springer of NAU is not an author of this document.

Summary:

The following technical information provides a brief summary of the recent USGS report "Geologic Framework of Aquifer Units and Ground-Water Flowpaths, Verde River Headwaters, North-Central Arizona" (Open File Report 2004-1411 by Laurie Wirt, Ed Dewitt, and V.E. Langenheim (Wirt Report)).

The Wirt Report combines the results of geophysical, geologic, and geochemical investigations to present an understanding of the relation between major aquifers ("Carbonate", Big and Little Chino) and the upper Verde River. It provides an overview of the regional geologic and topographic setting, describes the major aquifers, and uses various data sets to create a conceptual understanding of the groundwater system. Groundwater source areas, flow paths, and the sources of groundwater inflow to the upper Verde River are characterized in the report using water chemistry of selected wells and springs (pp. A4-A6). Data were modeled and interpreted to identify trends and form conclusions; some are reported in this summary document.

The Wirt Report is divided into seven chapters which present the results of different geologic disciplines or approaches. Chapter A serves as an introduction and defines the scope and purpose. Chapters B through F are geology, geophysics, hydrogeology, chemistry, and sources of baseflow, respectively. Chapter G is a synthesis and summary of the previous discipline-specific chapters. The report also contains a glossary and appended data.

Information from previous studies is included together with new data collected specifically for aspects of the study. Databases used for the study are available from the USGS upon request. A number of other relatively recent reports were instrumental in the creation of the document; a number of of these are listed in this summary document.

The Wirt Report offers a conceptual understanding of the groundwater flow system and relationship between water in the major aquifers and water in the upper Verde River. Many of the reports insights can be incorporated into water management by way of tool development, strategies, and scenarios. The information in the report will assist modeling efforts such as the USGS Northern Arizona Regional Groundwater Flow Model.

The purpose of this summary document is to concisely report the hydrogeologic methods and technical findings of the Wirt Report to the Water Advisory Committee. As such, this white paper forms a partial basis for interpretation of the Wirt Report with regards to various management questions. This document is not a peer review of the report and it does not attempt to verify the methods and results.

Study Uses, Limitations and Implications:

The information in the report is a valuable contribution to basic data and the knowledge base. The conceptual understanding of the groundwater system presented in the report can be used to inform water management planning. It is a framework that can inform some of the key planning questions of the WAC. Additionally, much of the information will be utilized for on-going and future scientific investigations.

As with most studies, unanswered questions remain and data gaps are evident. The certainty of conclusions is associated with the type and availability of data. Where data are sufficient and precise, certainty is likely to be high; and certainty is lowered where data are sparse or inexact. A detailed review of the data and methods is required to fully understand the conclusions and the evidence upon which the conclusions are based. The Wirt study applies standard methodologies, basic theory, judicious interpretation and professional judgment.

Some central questions are directly addressed by the report. For instance, the most significant contribution to Upper Verde River base flows is shown to be derived through groundwater discharge from the Big Chino Sub-basin. This conclusion is consistent with the previously reviewed Blasch Report (Blasch *et al* 2006). Other key questions addressed in the study relate to potential recharge areas, groundwater divides, and sub-irrigated grasslands.

Some important questions are outside the scope of the report. For example, the report does not examine potential hydrologic impacts related to future groundwater pumping scenarios. Also, mitigation requirements for groundwater pumping scenarios are beyond the scope of the report. It does not attempt to define specific aquifer properties and does not report or predict results of aquifer pump tests.

The report underwent internal U.S. Geological Survey and external peer review prior to publication. The report is currently being reviewed by an independent party under contract with the City of Prescott, Town of Prescott Valley and Town of Chino Valley. The product of that review is expected to be available in late March, 2007.

The report provides a significant amount of hydrologic information useful to scientists and water resource managers. The report provides a general basis for the WAC communities to continue moving forward on water management planning. Concerns about the interaction between the natural system and human needs can be addressed in general terms.

Other Recent USGS Reports that contribute to our understanding of the Verde watershed system:

- Geophysical Framework Based on Analysis of Aeromagnetic and Gravity Data, Upper and Middle Verde River Watershed, Yavapai County, Arizona" (U.S. Geological Survey Scientific Investigations Report 2005-5278, V.E. Langenheim, Ed DeWitt, and L. Wirt) - This report uses the aeromagnetic data commissioned by the WAC and the Arizona Water Protection Fund, along with a wide variety of other information to detail the surface and sub-surface geology of the watershed. The USGS, Arizona Department of Water Resource, and the WAC funded this project.
- Blasch, K.W., Hoffman, J.P., Graser, L.F., Bryson, J.R., and Flint, A.L., 2006, Hydrogeology of the Upper and Middle Verde River Watersheds, Central Arizona: U.S. Geological Survey Scientific Investigations Report 2005-51989, 101p., 3 plates.
- "Hydrogeology of the Mogollon Highlands, Central Arizona" (U.S. Geological Survey Scientific Investigations Report 2004-5294 Prepared in cooperation with the Arizona Department of Water Resources, By John T.C. Parker, William C. Steinkampf, and Marilyn E. Flynn
- "Hydrogeologic Data for the Coconino Plateau and Adjacent Areas, Coconino and Yavapai Counties, Arizona" (U.S. Geological Survey Open-File Report 02-265). Prepared in cooperation with the City of Williams. By Donald J. Bills and Marilyn E. Flynn
- Water-Resources Investigations Report 02-4026 "Generalized Hydrogeology and Ground-Water Budget for the C Aquifer, Little Colorado River Basin and Parts of the Verde and Salt River Basins, Arizona and New Mexico" (U.S. Geological Survey Water-Resources Investigations Report 02-4026) Prepared in cooperation with the National Park Service. By R.J. Hart, J.J. Ward, D.J. Bills, and M.E. Flynn

Definitions used in Wirt Report:

Upper Verde River: The 10 mile reach upstream from the USGS gage station number 09503700 ("Paulden gage"). That is, the stretch of river between Sullivan Dam and the Paulden gage (p. A4)

Study Area: Mogollon Rim and Big Black Mesa on North, Sycamore canyon on the east, Black Hills and Agua Fria Water shed to south and southwest, and confluence of Partridge Creek and Big Chino Wash on west. Figure A1, below, is from the Wirt Report (p. A2) and shows the principle study area. Because each chapter is somewhat independent, the precise study area varies from chapter to chapter.

Flowpath (flow path): An underground route for groundwater movement, extending from a recharge zone to a discharge zone.

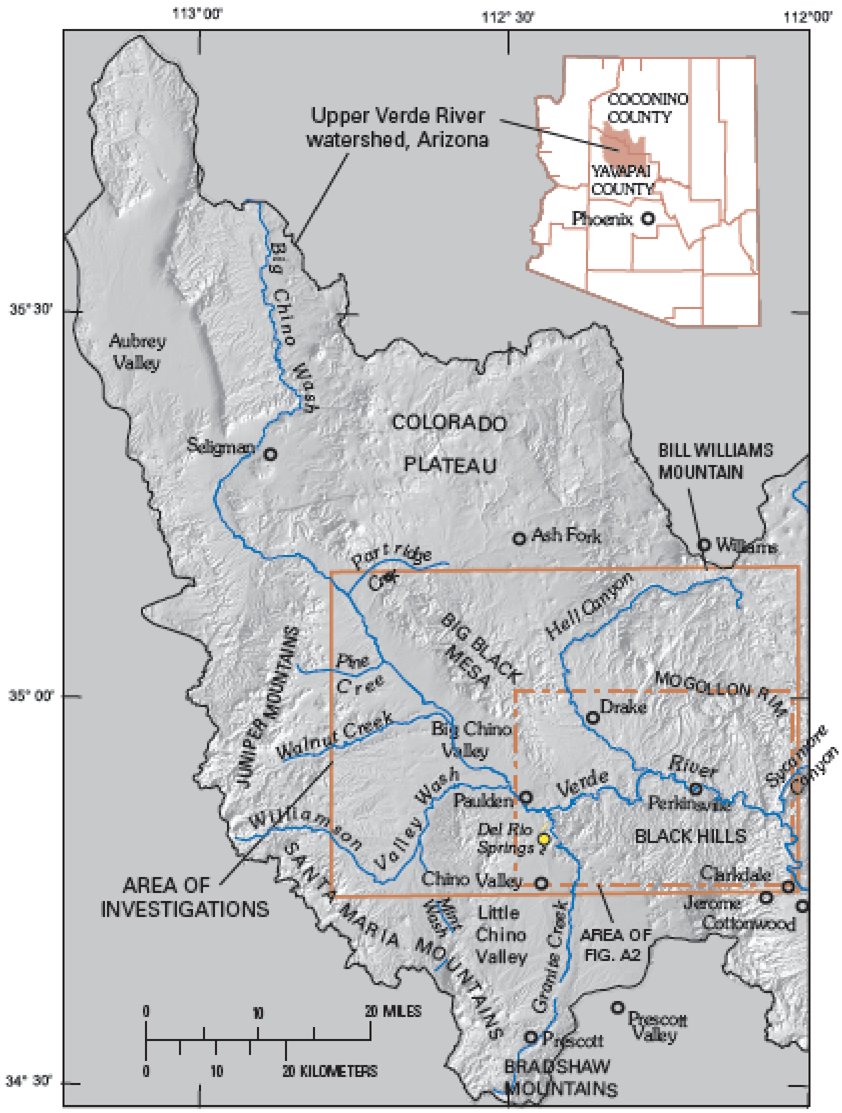

Figure A1. *Shaded relief map showing upper Verde River watershed, locations of major physiographic features, and principal area for study investigations in this report. Base is from U.S. Geological Survey digital data 1:100,000; sun angle elevation is 45 degrees from southeast; azimuth is 120 degrees.*

"Upper Verde River springs": Set of unnamed springs (see Figure A2 below) located between Stewart Ranch and the confluence of Granite Creek with the Verde River. Sometime these are given other names such as the "headwaters springs".

Baseflow: The sustained low-flow condition of a stream derived from groundwater inflow to the stream channel, in contrast to runoff from rainfall or snowmelt.

Playa: A flat area at lowest part of undrained desert basin. A playa typically contains evaporative deposits and other fine grained materials such as clay and silt. These materials have low hydraulic conductivity (water typically moves slowly through fine grained materials.)

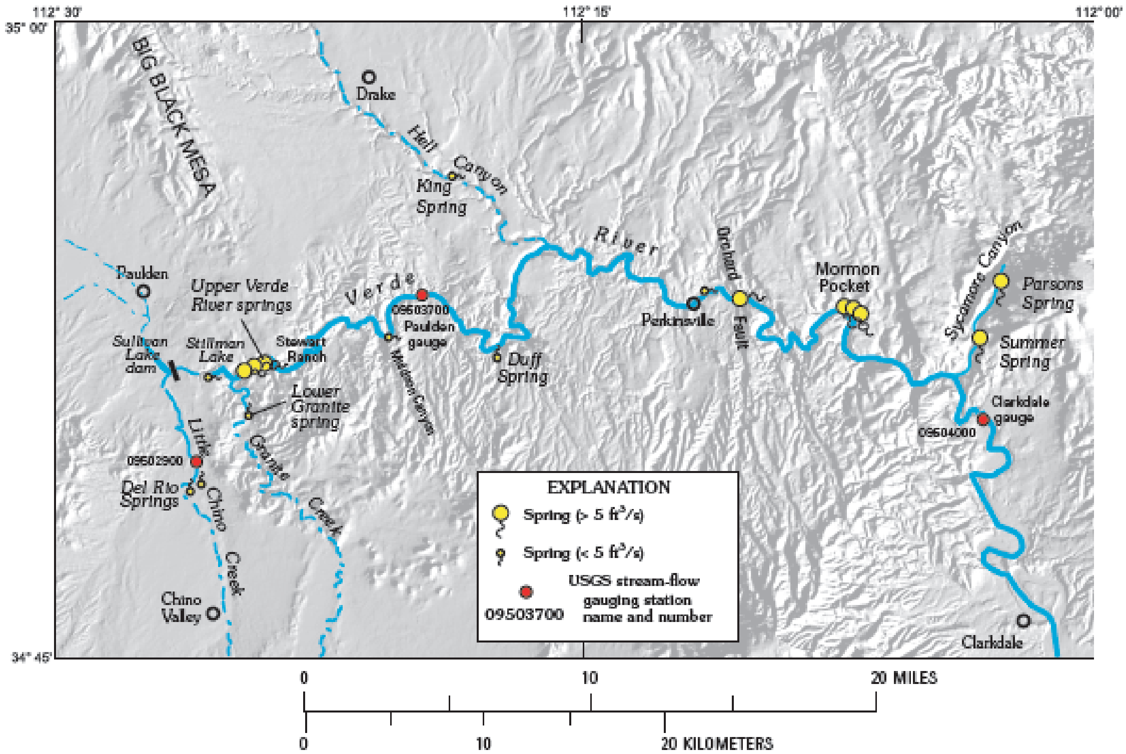

Figure A2. Locations of known springs along the upper Verde River from Sullivan Lake to Sycamore Creek. Base is from U.S. Geological Survey digital data 1:100,000; sun angle elevation is 45 degrees from southeast; azimuth is 120 degrees.

Major areas of study in the report:

The basic approach taken in the study is to characterize the geology (rock types and structure of the aquifers), and characterize the chemistry of waters known to be from a particular aquifer source (such as the carbonate aquifer or the sediments beneath Chino Valley). Then, examine the chemistry of the water at the springs entering into the upper Verde River. Then, through comparison of analytical results and examination of data trends, the nature of the groundwater flow system can be elucidated and chemistry can be modeled. The geochemical model leads to conclusions about the sources of water in the upper Verde River. In order to reduce uncertainty of conclusions based on any single result or analysis, different kinds of tests are used and conclusions are based on multiple lines of evidence.

The major topics presented in the report include: Predevelopment conditions; Water use trends; Conceptual water budget; Groundwater levels; Contours and gradients (flow direction); Geologic history and rock types; Major aquifers that contribute to Verde River at headwaters; Geophysical modeling to describe the shape of alluvial basins including structural features, such as buried faults and buried volcanic rocks that may affect movement of groundwater; Groundwater flow paths; Water chemistry sampling to characterize aquifers and springs; and Water chemistry sampling and modeling to determine the source of base flow in springs in the Verde River headwaters region.

Key Findings:

<u>Source of base flow in Upper Verde River</u>: Perennial base flow in the Upper Verde River begins down gradient from the three aquifers defined in the report: the Big Chino, Little Chino, and the carbonate aquifer. Base flow emerges in three places near the confluence of Granite Creek and the Verde River including (a) Stillman Lake, (b) “Lower Granite spring”, and the gaining reach of the River downstream of mile 2.2 referred to as the “upper Verde River springs” (see Figure A-2 above)

Based on chemistry modeling and tracer dilution studies, the report concludes that most of the base-flow in the River upstream of Stewart Ranch is predominantly derived from the upper Verde River Springs (about 85% of 20 cfs)(p F31). The report presents water chemistry and inverse modeling results that indicate the majority of the water entering the upper river *via* the upper Verde River springs is from the Big Chino aquifer and has traveled a short distance through the carbonate aquifer prior to emerging in the upper Verde canyon. About 14% of the baseflow is estimated to come from the Little Chino aquifer.

Figure G1 in the report (and below) contain pie charts showing the report’s conclusions regarding sources of base flow in the Upper Verde River. The primary purpose of the figure is to reconcile the current work with previous work by illustrating data and demonstrating that different approaches provide the same general conclusion. The pie chart on the left shows predicted predevelopment conditions based on previous work using a water budget approach, and the middle chart shows predicted 1990’s (contemporary) conditions also using a water budget approach and based on previous work (Chapter A, Table A4, Figure A16). The pie chart on the right is based on the geochemical modeling results of the Wirt Report (Chapter F). The values on the left and middle pie charts are linked to less specific geographical areas (Big Black Mesa, Little Chino and Big Chino Valley); the pie chart on the right is in accordance with the conceptual model and major aquifers described in the Wirt Report.

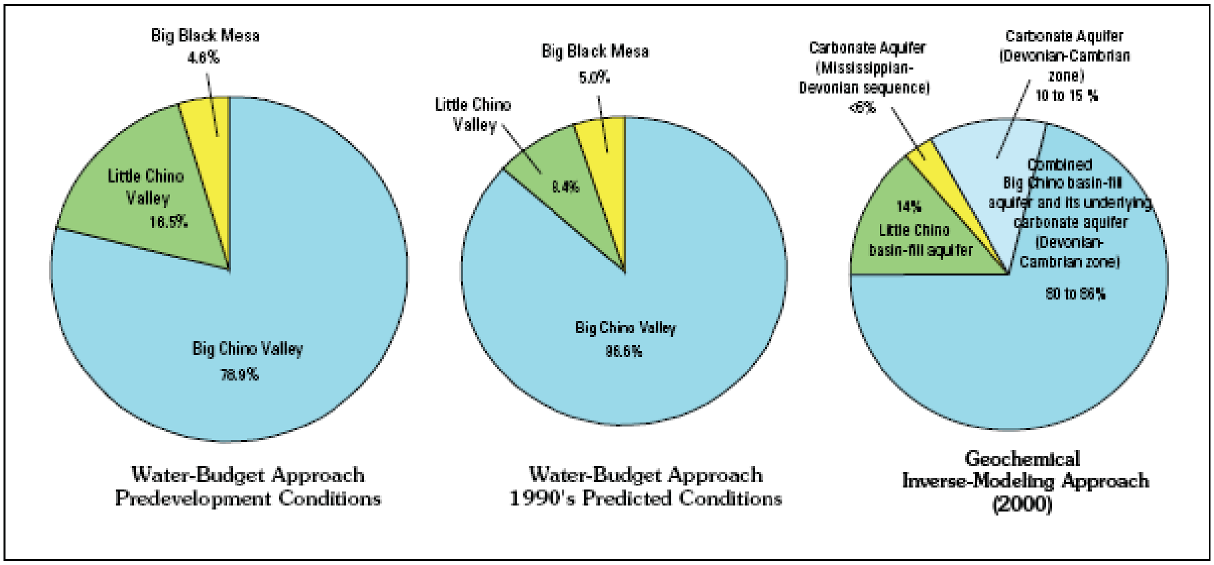

Figure G1. Pie charts showing sources of base flow to the upper Verde River, comparing water-budget estimates with those based on inverse modeling using geochemistry and tracer-study data. Data from previous studies is provided in table A4 and figure A16 (Chapter A, this volume). Note that the predevelopment pie diagram on the left is proportionately larger than those on the center and right.

Major Aquifers and their Water-Bearing Characteristics: The Big Chino, Little Chino and Carbonate aquifers are recognized as the major aquifer units in the Upper Verde watershed study area of this report. The report states that an aquifer may consist of one or more water bearing units (p.D10). The following Figure D-2 (from the report), shows the approximate horizontal boundaries of the aquifers and some of the geology discussed in the report. Also see the geologic map that is Figure D3 in the report and below in the geologic setting section.

Big and Little Chino Aquifers: The Big and Little Chino aquifers consist of relatively permeable sand and gravel, less permeable silt and clay, and interlayered volcanic rocks. These so-called basin-fill aquifer deposits fill fault bounded basins that formed during the past 10 million years (p. B1). The layers of basin fill material inter-finger in a complex pattern that creates uncertainty in determining precise flow paths and flow rates through the basins. Thus, these aquifer units have highly variable water bearing and transport properties (page D7 table D1). However, despite the inherent uncertainties, the report does support some general statements about groundwater storage and flow in these aquifers.

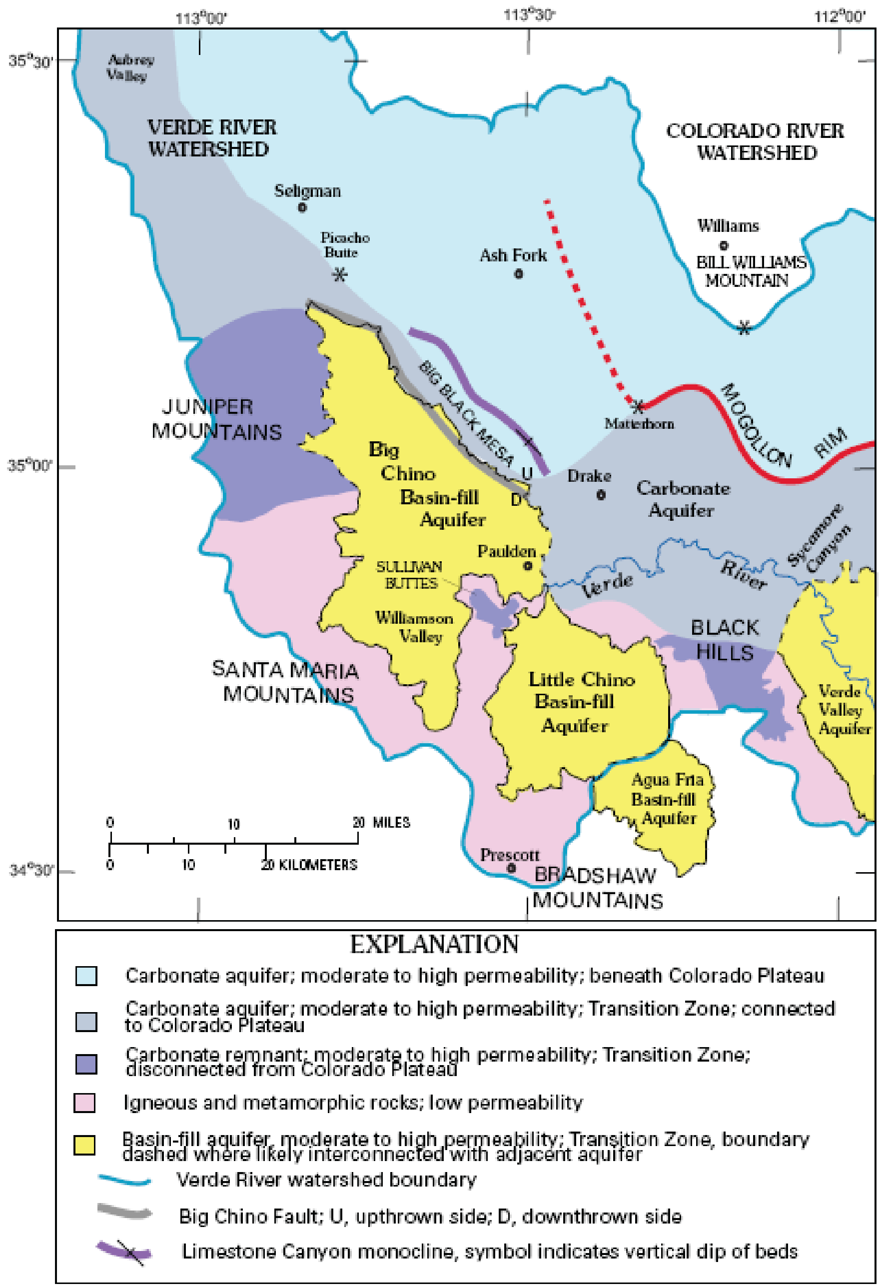

Figure D2. Schematic diagram of basin-fill aquifer boundaries in relation to geologic provinces and different parts of the regional carbonate aquifer, upper Verde River watershed. Base is from U.S. Geological Survey digital data 1:100,000.

The Big Chino basin is elongate, at least 2,300 feet deep in the center, and shallower around the edges (Chapter C and p. D17). The basin is filled with sediment of variable texture, as described above. The sediment is interlayered with buried basalt flows that entered the basin from the north, west, and southeast (p. B1) and flowed down slope toward and locally along the basin axis. A thick fine-grained playa deposit with relatively low hydraulic conductivity occurs in the basin center.

According to references cited in the report (p D18), drill hole data and groundwater contours, the fine grained playa does not extend far enough across the valley to create a barrier to groundwater movement. Due to lack of data, the extensive basin-fill deposits at depths below about 700 feet from the ground surface are not well understood, nor are the nature and extent of inter-fingering of the basin fill deposits (p. D19).

In general the Little Chino basin-fill aquifer is not as deep and narrow as the Big Chino basin-fill aquifer. The thickness of the Little Chino aquifer increases from southwest to the northeast (to about 700 feet near Del Rio Springs). The subsurface geology is complex (Chapter B). Depth to water ranges from the surface at Del Rio Springs to about 100 feet beneath the town of Chino Valley.

***Carbonate Aquifer*:** The report describes a regional carbonate aquifer as a sequence of several hydrologically connected rock units (e.g. Martin Formation and Redwall Limestone, p. D10). The geologic framework section of this document, below offers more detail. The report further divides the carbonate aquifer, and makes a distinction between a "carbonate aquifer underlying basin-fill deposits" and "carbonate aquifer north of the upper Verde River" (p. D13).

In the geochemistry sections of the report, the two carbonate sequences are discussed as zones: the Devonian-Cambrian age rocks, or D-C zone, and the Mississippian-Devonian age rocks, or M-D zone. The D-C zone is the carbonate aquifer beneath the Big Chino Basin-fill aquifer (this is the "carbonate aquifer underlying basin-fill deposits"). The M-D zone is the part of the carbonate aquifer located north of the Big Chino Valley and the upper Verde River ("carbonate aquifer north of the upper Verde River"). This distinction is significant in the report's discussion of water sample groups, and geochemistry and isotopic study results (Chapter E).

Typically, water in the carbonate aquifer (either "zone") moves through fractures and solution features (karst). Groundwater potentially can move quickly through the fractures and karst features. The large springs at Mormon Pocket and Summers Spring in Sycamore Canyon originate from the carbonate aquifer as does upper Verde River springs and spring-fed Stillman Lake.

The report concludes that the D-C zone and the basin fill aquifers are strongly connected in the basin outlet region (p. D13)

Recharge areas and spring locations: Natural recharge arrives in the form of rain run-off and snowmelt. It moves by gravity and pressure gradients into and through the aquifers towards outlets (such as springs, p. D4).   The report states that "infiltration is greatest in the study area for Paleozoic carbonate rocks and Tertiary volcanic rocks". It also states that recharge is "expected to be high for low gradient run-off flowing over alluvium" (p. D10). Losing reaches of major tributaries produce recharge through seepage losses.

According to the report, high-altitude surface-water runoff from the Colorado Plateau typically reaches the Big Chino only a few times in any given decade. Therefore, the author concludes that little if any groundwater recharge to the Big Chino Valley or the upper Verde River is contributed from the area north of the Big Black Mesa and the Mogollon Rim (Chapter D).

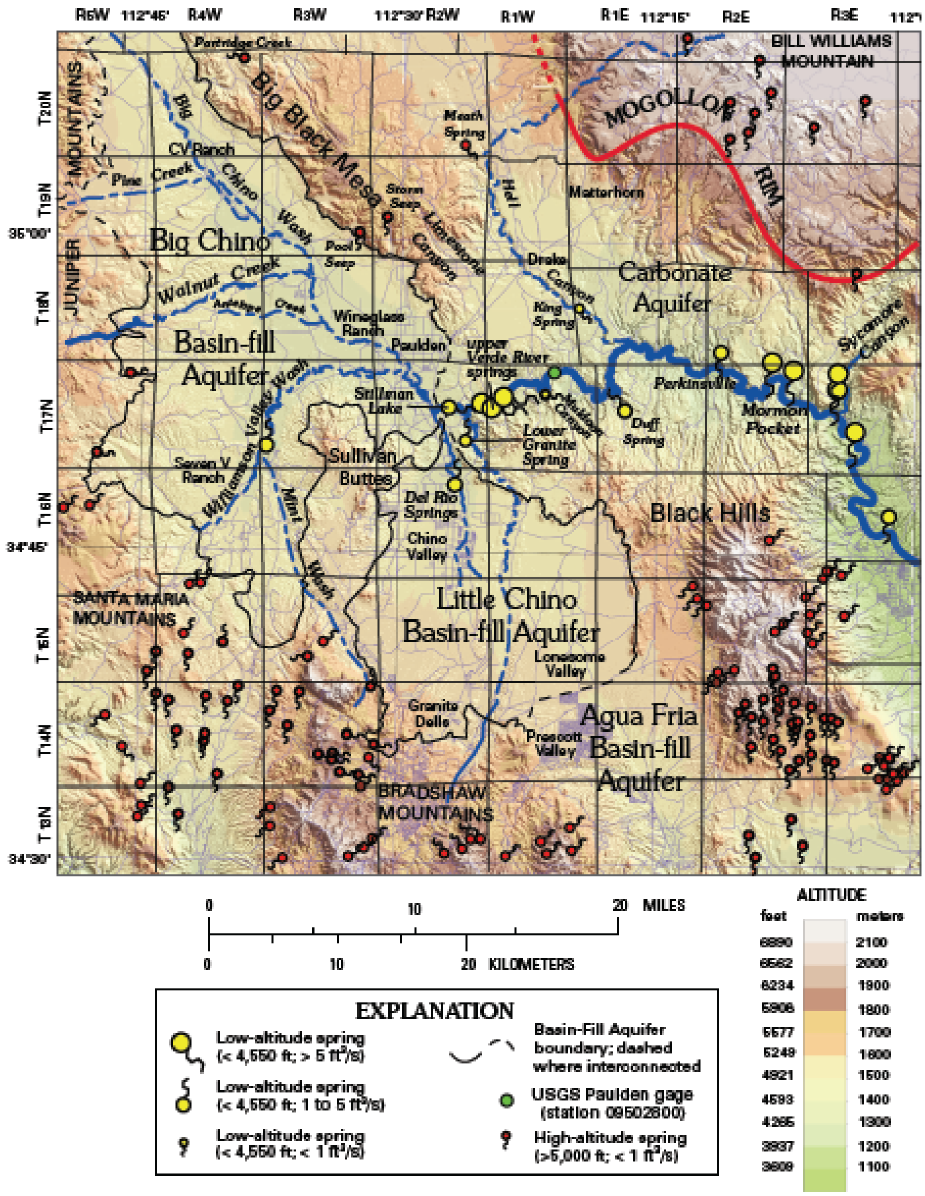

Figure D4, Shaded elevation map showing basin-fill aquifer boundaries and the location of high-altitude (red) and low-altitude (yellow) springs. Aquifer boundaries are dashed where likely interconnected with adjacent aquifers. Base is from 1:100,000 U.S. Geological Survey digital data.

Spring size and location depend on many factors such as climate, geology, and water level gradient. For purposes of discussing water chemistry, the report divides springs into high altitude (above 5,000 feet in elevation) and low altitude (below 4,550 feet) (figure D4 of report, reproduced below). The high altitude springs are typically in bedrock areas, have low flow, and are fed from small areas. The low altitude springs are typically near the topographic outlets of the valleys. Del Rio Spring is the largest low altitude spring in Little Chino Valley. The upper Verde River springs network lies below the topographic outlets of both the Little and Big Chino Valleys.

Flow paths: Groundwater flow direction in basin-fill aquifers is generally from the basin margins and tributaries towards the center and down the axis of the basin (Figure D8, below). The groundwater in Big and Little Chino Valleys drains by gravity toward large springs near their outlets. Variations of grain size in the basin fill aquifers affect flow paths and rates of flow (Coarse grained sand and gravel materials are more permeable than fine grained clay and silt). The report states that in the center of the Big Chino basin, groundwater flows above, around, and possibly beneath the fine-grained playa deposit (p. D21).

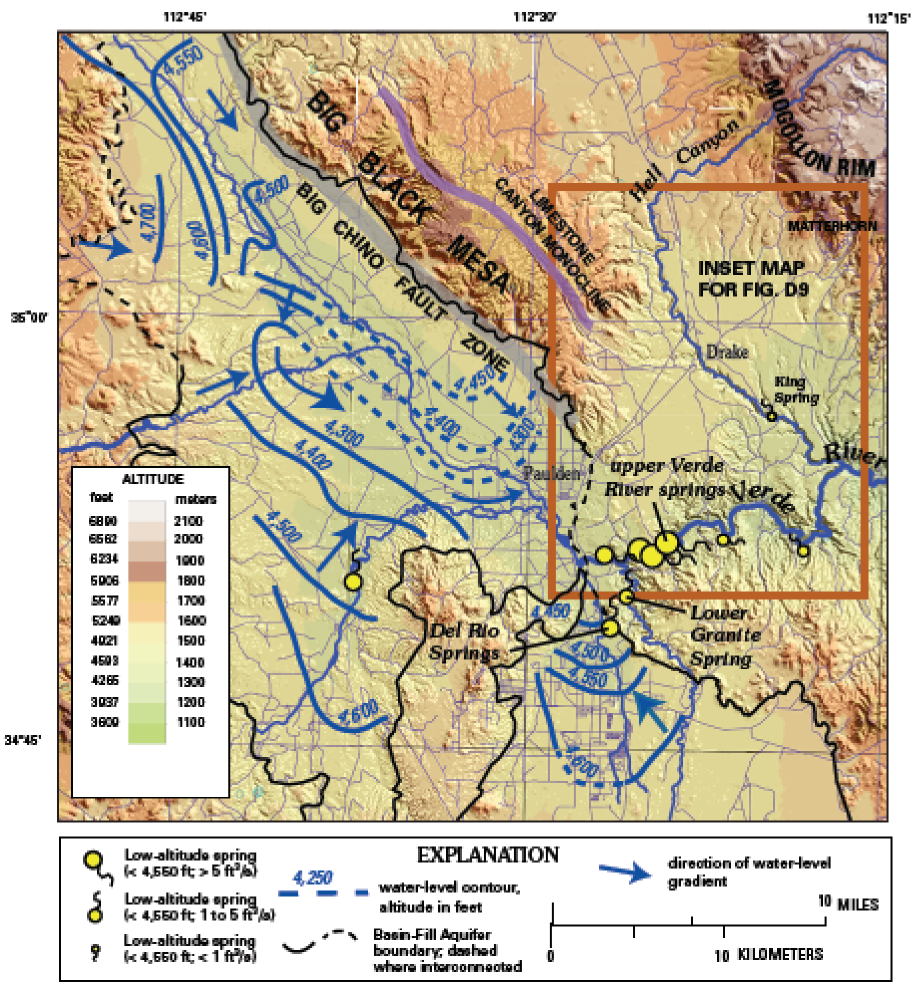

Figure D8. Compilation of water-level contours in the Verde River headwaters area (after Schwab, 1995; Corkhill and Mason, 1995). Dashed contours and arrows are the author's interpretation. Low-altitude springs shown as yellow circles, water-level contour elevations given in feet.

Groundwater flow paths within the carbonate aquifer are through cracks and solution features, and are inferred in part from the topography, geology, wells, and the location of springs (p. D23). Based on water level data and geochemistry, the carbonate aquifer in the area near Paulden is interpreted to be a conduit between the Big Chino Valley and the Verde River. The crest of Big Black mesa is inferred to be a groundwater divide between the Colorado Plateau to the north and the transition zone to the south. This implies that a large potion of the carbonate aquifer in the watershed contributes little groundwater to the Big Chino Valley or Verde River (p. D25). To the north of the Upper Verde River (e.g. Drake area), groundwater in the carbonate aquifer generally flows to the east or southeast.

<u>Geologic Framework</u>: Chapters C and D of the report provide diagrams and a detailed description of the geologic setting (Figure D3 reproduced from the report below and Figure D2 above on p. 9). Geologic maps in the report are based on earlier studies and reconnaissance mapping. Interpretations of subsurface geology are based on geophysical modeling and interpretation of well logs and borehole data.

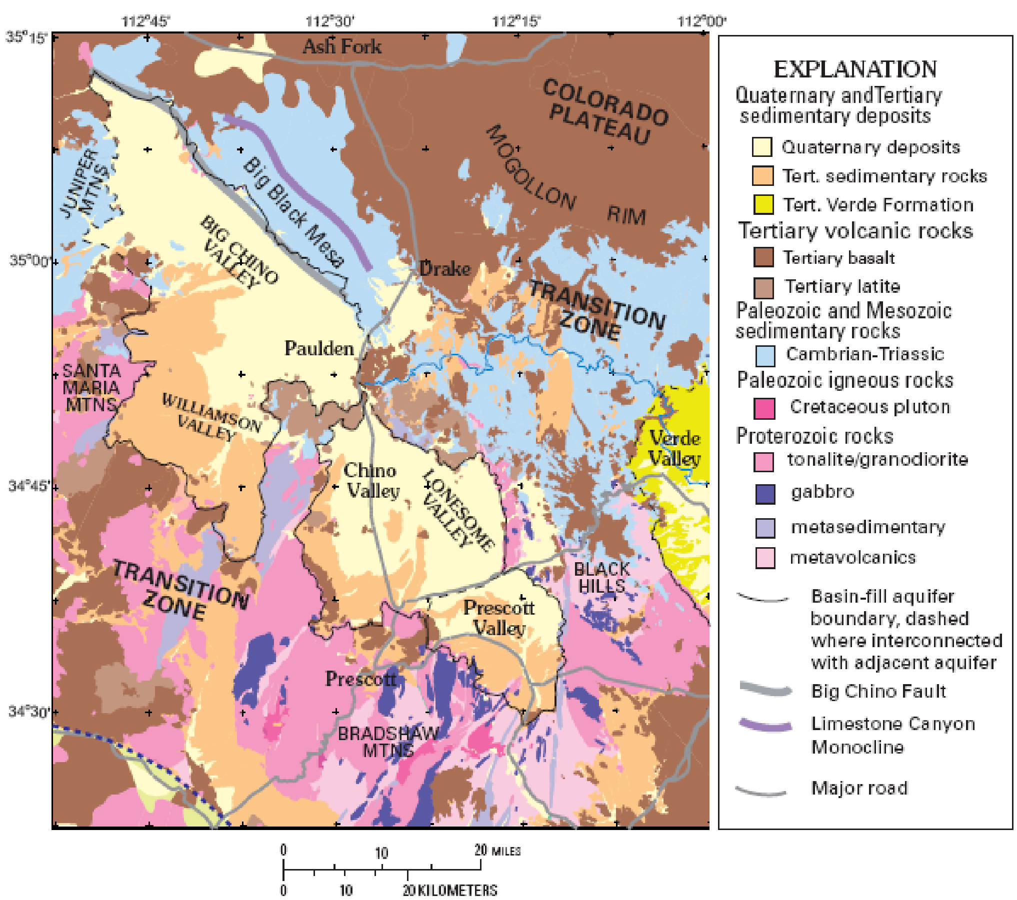

Figure D3. Geologic map of the Verde River headwaters study area (simplified from DeWitt and others, in press). Geology outside of thick dotted blue line is abridged from Reynolds (1988) and Richard and Kneale (1993). Base is from U.S. Geological Survey digital data 1:100,000.

Geophysical data and well log data help define the extent of Big and Little Chino Basins. The basins contain a mixture of sedimentary and volcanic materials. These materials have filled structural depressions (basins) created by large scale movement along faults such as the Big Chino fault adjacent to Big Black Mesa. The materials that filled the basins comprise the basin-fill aquifers (e.g. gravel, sand, clay, volcanic rocks, etc). The basin fill materials interlayer with each other in complex patterns.

Ancient (Proterozoic) basement rocks of low permeability (low ability to transmit water) constitute the "basement" that lies beneath the mountains and valleys of the region. The basement and other "old" rocks define the basin shape and aerial extent of the basin-fill aquifers.

Paleozoic age rocks comprise a "carbonate aquifer" north and east of the Big Chino Basin Fill aquifers that is connected to the Verde River and the Colorado Plateau. These rocks are younger than the basement and older than the basins and the basin-fill materials. The carbonate aquifer also underlies the Big Chino basins. The carbonate aquifer is composed of several hydraulically connected rock layers (including in ascending order the Tapeats sandstone and Bright Angel Shale of Cambrian age (older); the Martin Formation of Devonian age; Redwall Limestone of Mississippian age; and the Supai Formation of Pennsylvanian and Permian age (younger)). As discussed in the geochemistry section of the report, the carbonate aquifer is divided into two zones. The D-C (Devonian-Cambrian) zone is strongly connected to the Big Chino basin-fill aquifer at the Big Chino outlet, and the two function together as a single aquifer source (Chapter D). The report concludes the M-D (Mississippian – Devonian) zone north of the Big Chino Valley and upper Verde River mixes little with the basin-fill aquifer.

In places, relatively young volcanic flows (basalt) from volcanic activity centered on the Colorado Plateau formed layers of rock that influence groundwater movement in some parts of the study area. These are visible near Paulden and just downstream of Sullivan Lake.

<u>Geochemistry</u>: The report presents various geochemical data and methods used to identify groundwater flow paths and sources of springs discharging to the upper Verde River (Chapter E). To do this, geochemical methods were employed and trends examined to characterize the water chemistry of major aquifers, infer recharge sources, define groundwater flow paths, understand groundwater mixing, groundwater-rock interactions, and to show differences in the apparent ages of groundwater (p. E2). In general, the authors are trying to determine if chemistry trends are due to mixing of the waters from different aquifers, or water from a single aquifer interacting with rocks along a flow path (mixing or water-rock interactions).

The study concludes that lines of evidence indicate water-rock interactions dominate, not mixing of waters from different aquifers (e.g. carbonate aquifer water does not mix much with Big Chino basin-fill water). However, the Big Chino and underlying carbonate aquifer are strongly interconnected along the basin outlet flow path near Paulden and appear to function as a single source of groundwater to the upper Verde River springs.

Chemistry presented in the report indicates considerable vertical and horizontal heterogeneity of Big Chino basin-fill aquifer (p. E27).

Chemical analysis indicates similar or overlapping source areas for water in the Big Chino and carbonate aquifers (p. E27).

The water from the basin fill aquifers travels through fractures in the carbonate aquifer prior to discharging via springs to the Verde River. Groundwater leaving the Big Chino near Paulden either mixes with some water from the carbonate aquifer or travels through (and reacts with) about 1.5 miles of the carbonate aquifer before reaching upper Verde River springs (p E25). The report concludes the carbonate aquifer is mainly a flow-path at outlet zone, not source of new water (pp. E25-E27).

Predevelopment conditions: Present hydrologic conditions no longer reflect predevelopment conditions (Chapter A and summarized in Chapter G). For example, "Continuous perennial flow in the Verde River historically began at the confluence of Williamson Valley and Big Chino Wash and at Del Rio Springs in the Little Chino Valley…" (p. G2; also see p. A17 and p. A11). Predevelopment conditions are thought to have persisted in the Little Chino Valley until 1937 and until about 1950 in the Big Chino Valley (p. G2).

Figure A16 in the report and G1 in the report (reproduced above on page 8) show pie charts indicating relative contributions for sources of baseflow to the upper Verde River. The report notes the conceptual water budgets are estimates that are compiled to develop a conceptual understanding (the two pie charts on the left of the Figure G1). The conceptual framework serves as a basis for comparison with the new information presented in the other chapters of the report (i.e. the pie chart on the right of Figure G1). The predevelopment pie chart (on the left of the figure) is noted to be proportionately larger than the pies charts representing "current" conditions (p. A30). This reflects a slightly larger total budget during predevelopment times.

A summary of predevelopment base-flow discharge and calculated recharge for major areas in the headwaters is presented in Table A4 (p. A22) reproduced from the report below.

Table A4. Summary of predevelopment base-flow discharge and calculated recharge for major areas in the Verde River headwaters, Arizona.

[mi2, miles squared; acr-ft/yr, acre feet per year; bold indicates mean where n is total number of estimates]

Basin	Subbasin	Drainage area (mi²)	Base flow discharge[2] (acre-ft/yr)	Predevelopment calculated recharge (acre-ft/yr)	Recharge as percent of total calculated recharge[6]	Data source
Big Chino Valley		1,850		21,600[5]		Ewing and others (1994); Ford (2002)
				21,500		Freethey and Anderson (1986)[4]
				21,550	78.9	**Average of above (n = 2)**
	Williamson Valley Wash	255	11,583			Ewing and others (1994)
	Walnut Creek		1,500			Ewing and others (1994)
Little Chino Valley	Granite Creek and Little Chino Creek watersheds	300		5,000		Schwalen (1967)
				4,000		Matlock and others (1973)
				4,500		Freethey and Anderson (1986)[4]
				4,500	16.5	**Average of above (n = 3)**
	Del Rio Springs	41	2,849			Schwalen (1967)
	Willow Creek		1,420			Schwalen (1967)
	Granite Creek near Prescott (above Watson Lake)	36	4,830			Schwalen (1967)
Big Black Mesa		100		1,250	4.6	Ford (2002)
Verde River gage near Paulden		2,507[1]	18,000[3]	**27,300[6]**	100.0	Wirt and Hjalmarson (2000)
			16,000[3]			Freethey and Anderson (1986)[4]
			17,000			**Average of above (n = 2)**

[1]Includes 357 mi² of noncontributing area in Aubrey Valley.
[2]Base-flow discharge is same as mean annual discharge, except as noted.
[3]Base-flow discharge determined by hydrograph separation for period of record at time of study.
[4]Data from Freethey and Anderson (1986) are the raw values used to construct the pie charts in their report.
[5]Value of 23,700 acre-ft/yr of recharge for upper Verde River watershed (Ewing and others, 1994) minus 2,100 acre-ft/year of inflow in 1990 from Little Chino Valley (ADWR, 2000) equals 21,600 acre-ft/year (Ford, 2002).
[6]Sum of average calculated recharge for Big and Little Chino Valleys and Big Black Mesa.

Water Use: Preexisting water-use data for Big and Little Chino basins are inconsistent and inaccurate; however, some general observations are reported. For example agricultural use is decreasing and residential use is increasing. In the Little Chino Basin, 1997 water use was split "50-50" between agriculture and everything else.

The Big Chino Basin is less well understood because it is outside of the AMA and thus the AMA reporting requirements. However, indirect measurements of water use lead to estimates of a peak of 9,000 to 15,000 acre feet of irrigated agricultural use from the 1950s through the 1970s.