Laurie Wirt's Presentation to the WAC 5/17/2006

The Big and Little Chino Aquifers
and the
Upper Verde River

USGS
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Semiarid Big and Little Chino valleys are undergoing rapid growth, their populations solely dependent solely on ground water. Although the basins contain considerable amounts of ground water, from a historical perspective, ground-water overpumping in excess of safe yield inevitably leads to reduction or loss of perennial streams. The source of base flow to the Upper Verde River is the discharge from two basin-fill aquifers---the Big Chino basin-fill aquifer and the Little Chino basin-fill aquifer. Maintaining this discharge is critical toward maintaining base flow in the upper Verde River which is in turn critical for to maintain base flow for grandfathered downstream surface-water users in Verde Valley and Phoenix as well as for the maintenance of fish and game in some of the best remaining wildlife habitat in the State.

The goal of my talk today is to summarize some of the results of a recent USGS study[1] on the geologic framework of the Verde River headwaters in the hope that a better understanding of the hydrologic system will help to clarify the science and lead to more informed decision making by stakeholders and the voting public regarding water resources.

This talk is abridged from a USGS report that was released in December by myself and two co-authors, Ed DeWitt and Victoria Langenheim. The report compiles the results of a multi-disciplinary study on the Verde Headwaters region that was initially funded in 1999 by the largest competitive research grant ever received from the Arizona Water Protection Fund; this study also received internal support from other USGS sources.

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[1] Geologic Framework of Aquifer Units and Ground-Water Flowpaths, Verde River Headwaters, North-Central Arizona. Open File Report 2004-1411 available at http://www.usgs.pubs/of/2004/1411

Geologic Framework of Aquifer Units and Ground-Water Flowpaths, Verde River Headwaters, North-Central Arizona

Edited by Laurie Wirt, Ed DeWitt, and V.E. Langenheim

- Introduction, environmental setting, and predevelopment conditions
- Geologic Framework
- Geophysical Framework
- Hydrogeological Framework
- Geochemistry of Major Aquifers and Springs
- Tracer study and Geochemical model
- Synthesis

Each chapter in the report presents the results of a different discipline or approach, with the final chapter serving as a synthesis and summary of all the results. As much as possible, chapters in the report are arranged in a logical sequence so that earlier chapters provide a basis for subsequent interpretations made in following chapters.

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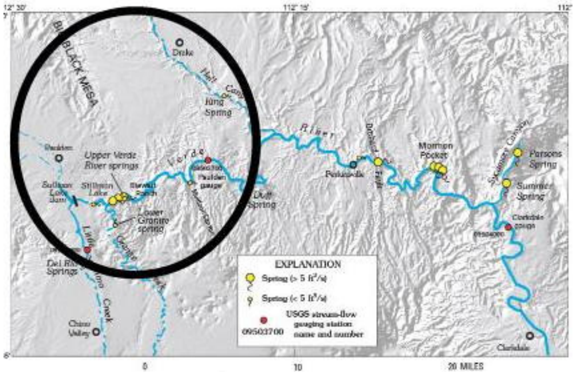
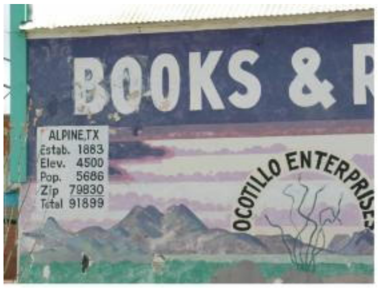


The upper Verde River begins below the confluence of BC and LC basins, and drains the eroded margin of the Colorado Plateau, south of Big Black Mesa and the Mogollon Rim. The brown box illustrates the scale of the geological, geophysical, and geochemical investigations conducted as separate chapters within the report. The uppermost perennial reach of the Verde River lies within the smaller box (dashed lines).

Predevelopment Conditions

Basin	Recharge (ac-ft/yr)	Data Source
Big Chino	21,600 21,500	Ewing and others, BOR, 1994 Freethey and Anderson, USGS, 1986
Little Chino	5,000 4,000 4,500	Schwalen, UA, 1967 Matlock and others, UA, 1973 Freethey and Anderson, USGS, 1986
Big Black Mesa	1,250	Ford, Leonard Rice Associates, 2002
Headwaters Total	**27,300**	Using above data sources
Baseflow for Verde River near Paulden	**18,000*** **16,000***	Wirt and Hjalmarson, USGS, 2000 Freethey and Anderson, USGS, 1986

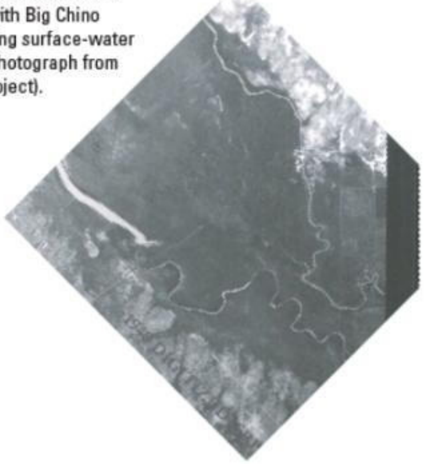
Last row, asterisk indicates discharge from combined aquifers and not recharge.

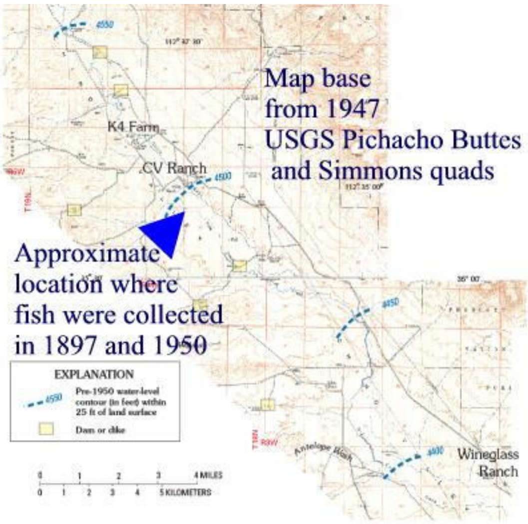


This mural was painted on the side of a rock shop in Texas, and offers some important insights on things to watch for when evaluating water budgets.

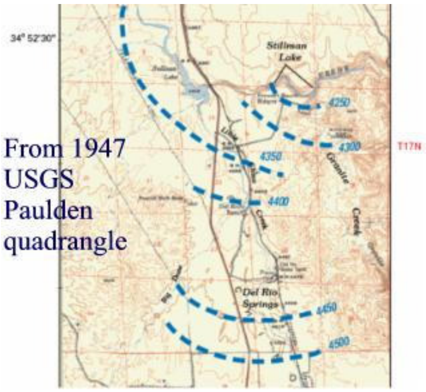
In addition to technical publications, other data sources such as historical photos and maps were used.

1940 oblique aerial photograph upstream from confluence of Pine Creek with Big Chino Wash, showing surface-water diversions (photograph from Salt River Project).



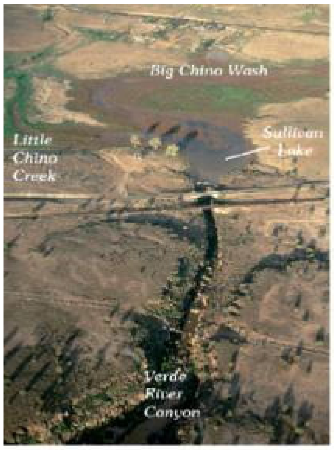


Native fish were collected by National Museum, a pre-cursor to the Smithsonian Institute in 1897 (five species), and again by the University of California in 1950 (two species). These references are accepted and have been cited in modern publications by AGF. So biologists are aware of these studies and hydrologists should take note.



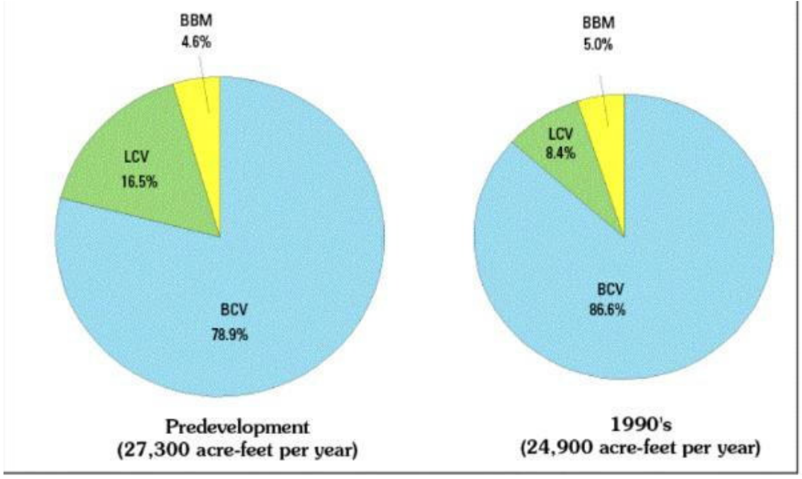
Del Rio Creek is shown as perennial south of the T5 Road, and possibly as far as the T4 Road. Sullivan Lake extends northward towards the confluence of WVW and BCW (formerly BC Creek).

In the area shown, at least 6 mi are shown as perennial that no longer flow.



This is what Sullivan Lake looks like today, following a small runoff event, much more like a pasture than a lake.

Initial Conceptual Model for Sources of Recharge to the Upper Verde River upstream from USGS Paulden Gauge



Major Findings, Chapter A:

- More than 6 miles of perennial stream segments have been lost since ~1950
- Segments of Big Chino Wash had native fish until ~1950

- Water levels near Sullivan Lake have declined by >80 feet since 1947*
- Data gaps identified include Big Black Mesa and different carbonate aquifers
- Available water-budget data is far better for Little Chino Valley than Big Chino Valley

Multiple Lines of Evidence

- Introduction, environmental setting, and predevelopment conditions
- **Geologic Framework***
- **Geophysical Framework***
- Hydrogeological Framework
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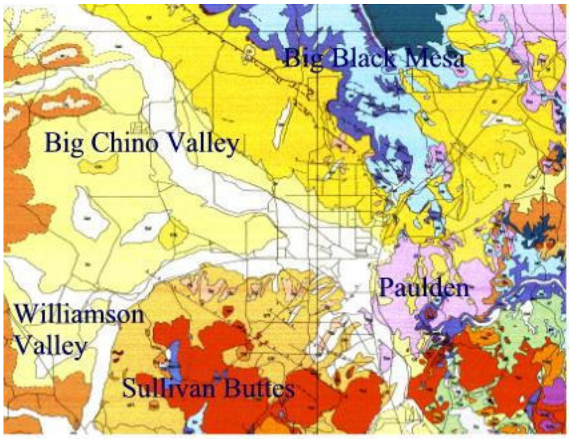
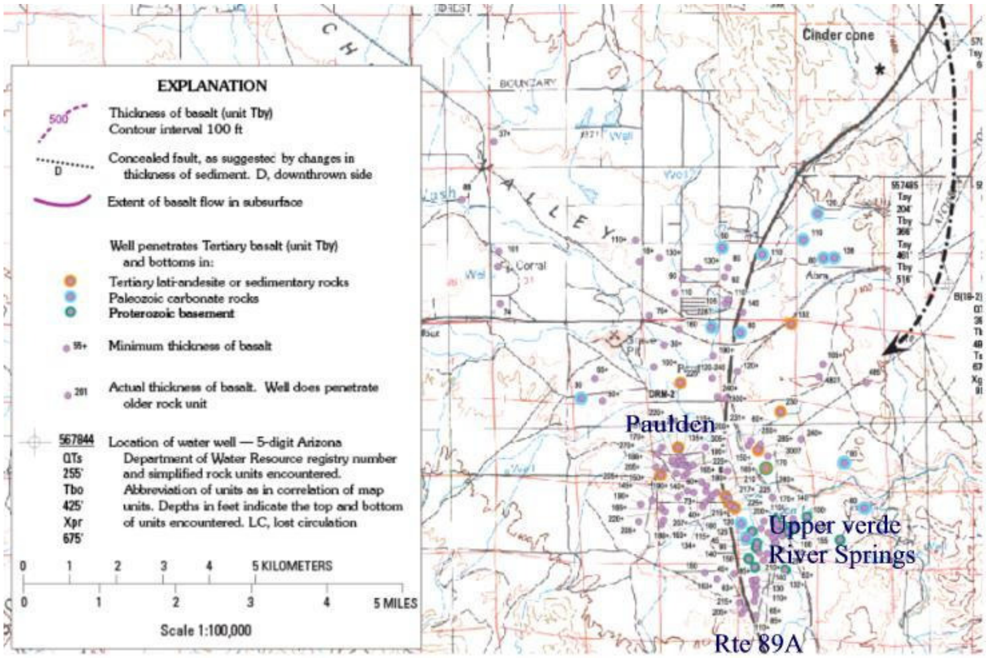
*These two chapters dovetail and will be discussed together.

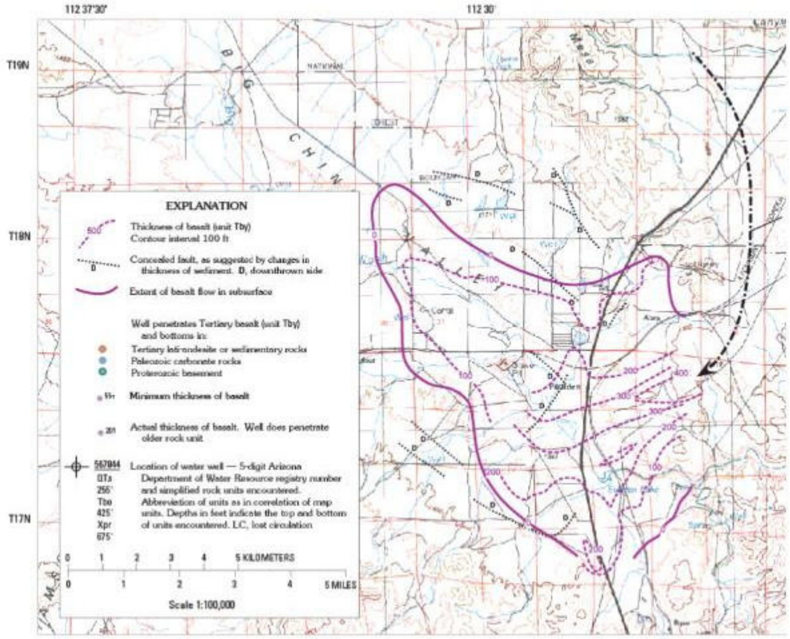


When people think of geology, they think of geologic maps, which are two dimensional. In a geologic framework study, we utilize geologic maps, but we try to extend our view of the environmental setting to the third dimension. What I will try to do in the next few slides is illustrate some of the approaches used to develop our 3-D conceptual model of GW movement through the basin-fill aquifers.

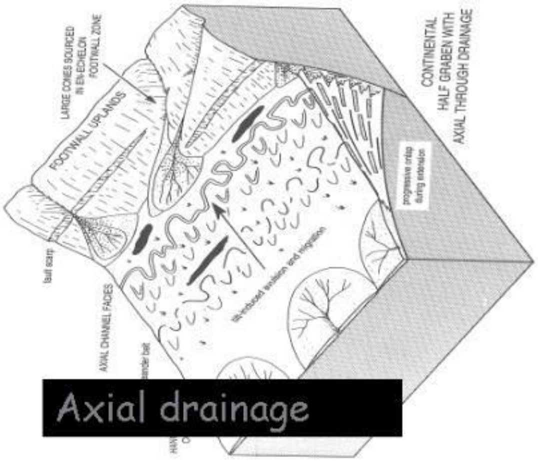
This is the geologic map for Big Chino Valley, which is characterized by dense plugs of lati-andesite to the south (orange) and permeable Paleozoic rocks to the north (blue). Paleozoic are underlain by Proterozoic rocks which prevent water from moving across the Big Chino Fault (base of BBM), except where there is no displacement (north of Paulden). Again, SW and GW follow separate paths out of the basin, with SW outlet located south of Paulden (Sullivan Lake). What is not shown in this surficial map, however, are the buried basalts and igneous intrusive rocks that are concealed by basin sediment.



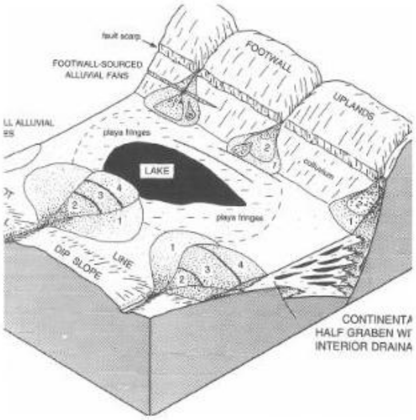
This map shows locations of reinterpreted drillers logs. Dashed arrow indicates basalt-filled paleochannel.



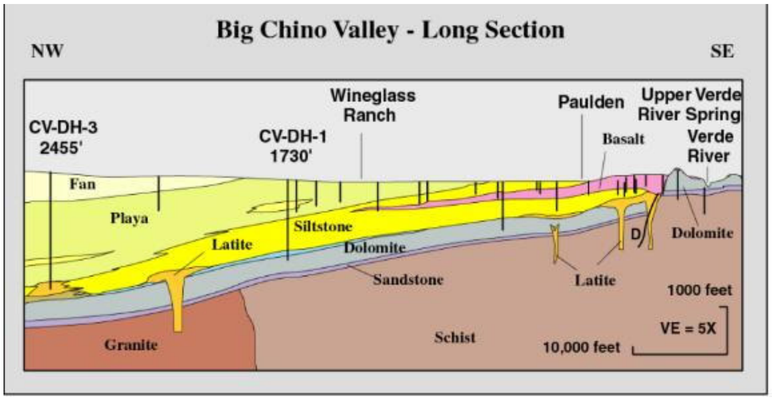
Open and Closed Basin
Drainage Models

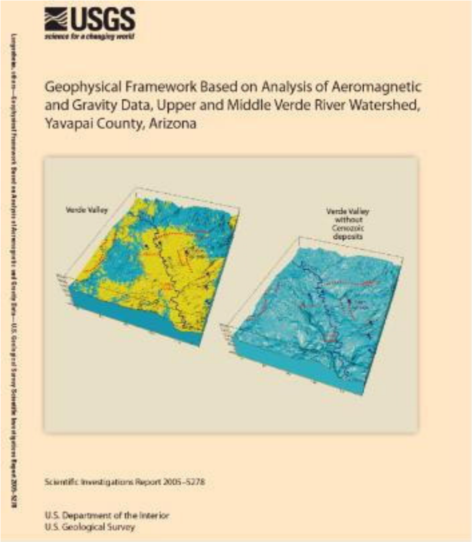


Axial drainage



Closed basin with Playa
Leeder and Gawthorne 1987





USGS
science for a changing world

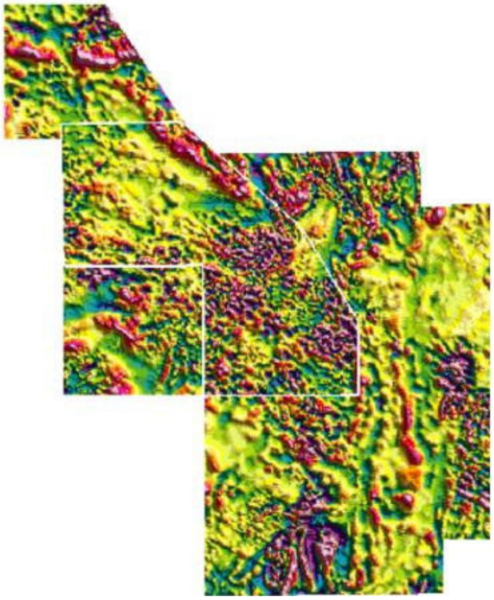
Geophysical Framework Based on Analysis of Aeromagnetic and Gravity Data, Upper and Middle Verde River Watershed, Yavapai County, Arizona

Scientific Investigations Report 2005–5278

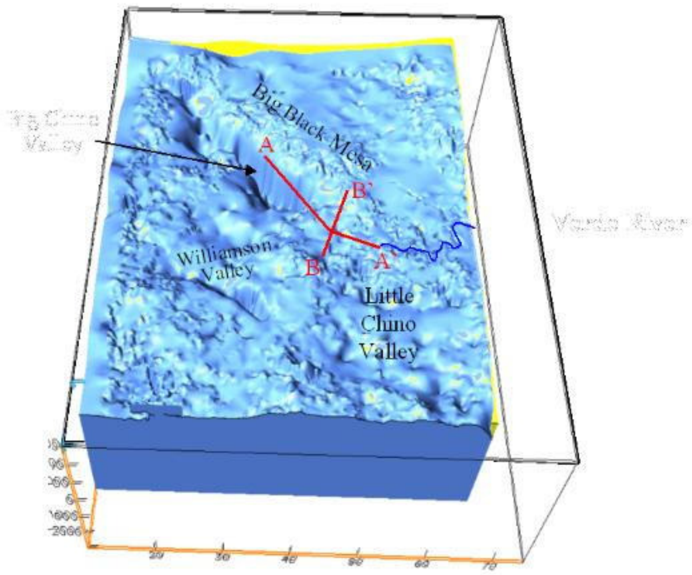
U.S. Department of the Interior
U.S. Geological Survey

Another way that we look at what is going on with depth is with geophysics.

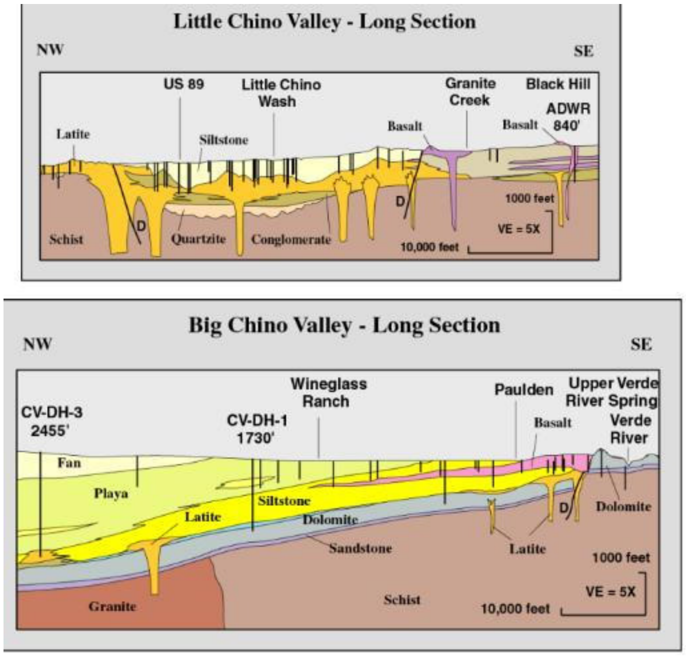
Aeromagnetic Map



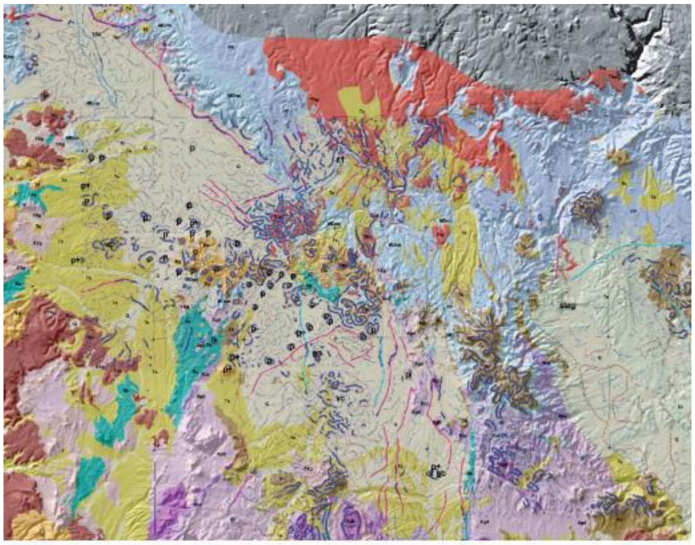
BASIN THICKNESS FROM GRAVITY DATA



O.K., let’s now take a look at what we can do with the gravity data. Here is a block diagram of our area. The blues are the old rocks-the Precambrian basement and the Paleozoic sedimentary rocks. The yellows are the sedimentary and volcanic rocks. Because of the big density contrast between the yellow and blue rocks, we can use the gravity data, the geology, and drill log information to map out the thickness of the yellow rocks. Here is what the area would look like if you can vacuum away all that dirt. Big Chino Valley is a big deep hole. The northeastern edge of this hole coincides with the Big Chino fault. This big basin filled with sediments and volcanic rocks formed as the Big Chino fault dropped down the valley floor relative to Big Black Mesa. Let’s now look at a couple of slices through Big Chino Valley….



Long Axis Geologic Cross Sections provided for reference.



And this newly released map shows a synthesis of the geology and geophysical data at the regional scale (Langenheim and others, 2006).

Major Findings of the Geology & Geophysics Investigations:

- Improved understanding of basin depth, geometry and structural features
- Improved understanding of the nature of the playa deposits ("clay plug") in BCV
- Improved understanding of the occurrence and location of buried volcanic rocks within and adjacent to the basin-fill aquifers, particularly near the GW outlets.

Multiple Lines of Evidence

- Introduction, environmental setting, and predevelopment conditions
- Geologic Framework
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- **Hydrogeological Framework**
- Geochemistry of Major Aquifers and Springs
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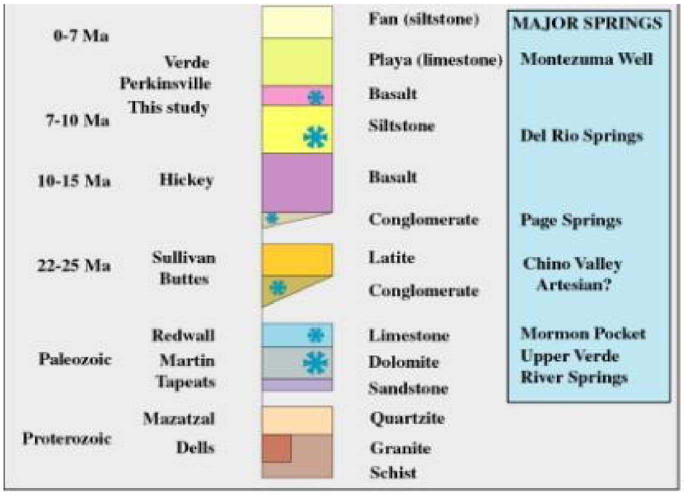
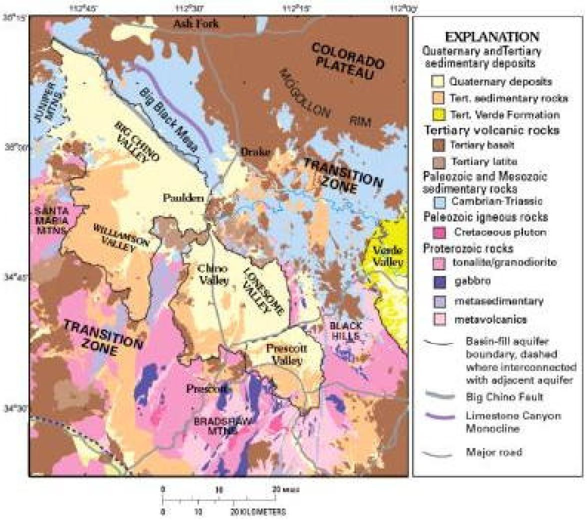
- Synthesis

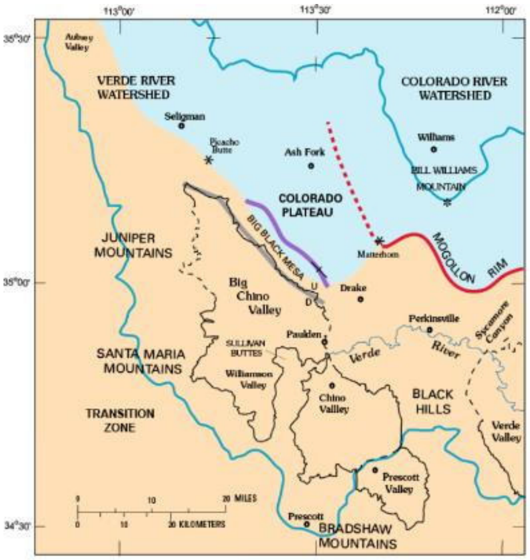


The next step is to identify the packets of water-bearing rocks that form aquifers. From oldest to youngest, the Paleozoic rocks form the carbonate aquifer (with two subgroups, the D-C zone and the M-D sequence).

Any and all of the younger rocks can be found within the basin-fill aquifers.

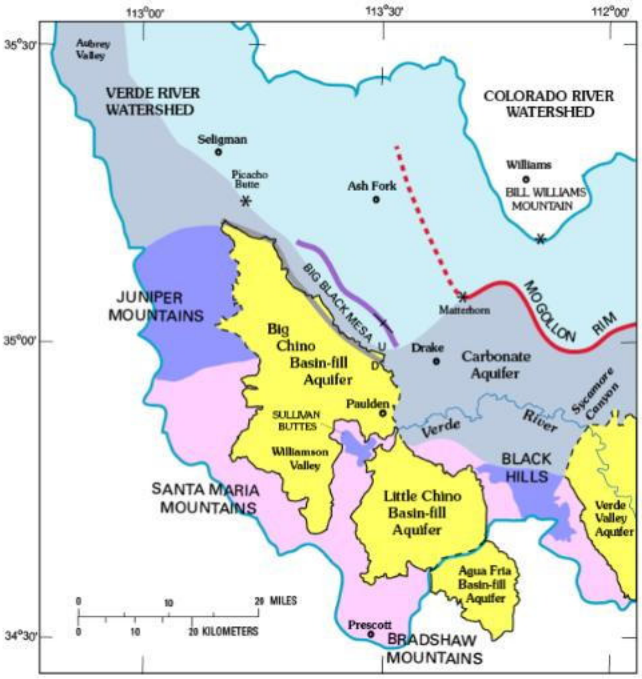


The generalized geologic map shows how the boundaries were defined between basin-fill aquifers and bedrock.

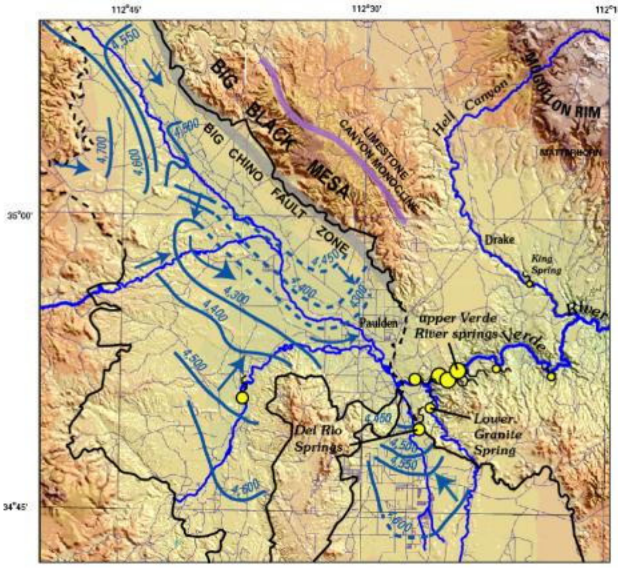


The next 2 slides are schematic diagrams (cartoons) showing the associations among the major aquifers. The Verde River watershed straddles the boundary and drains nearly equal parts of the two geologic provinces. Blue line is watershed boundary. Blue shaded area is Colorado Plateau. Tan shaded area is the Transition Zone.

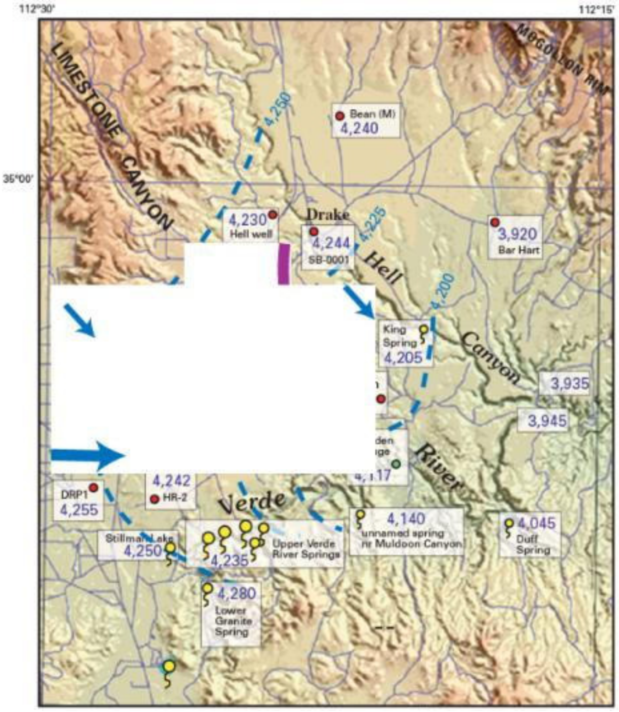
Big and Little Chino Valleys are part of the Transition Zone, a physiographic and tectonic transition between the relatively undeformed Colorado Plateau province to the northeast, and the severely faulted Basin and Range province to the southeast. Big and Little Chino Valleys (and Verde Valley to the east) are among the first in a series of alluvial basins extending outward from the eroded southwestern margin of the Colorado Plateau. Within the study area, the southern boundary of the Colorado Plateau is defined, in part, by the erosional scarp of the Mogollon Rim and, in part by the crest of Big Black Mesa.



This is a schematic diagram showing the relationship between the basin-fill aquifers (yellow) and subunits of the carbonate aquifer (shades of blue). Pink rocks are metamorphic and igneous rocks with low permeability. As before, light blue shows the expanse of relatively flat-lying carbonate rocks having high to moderate permeability beneath the Colorado Plateau. Medium blue shows carbonate rocks that are in the Transition Zone. These TZ rocks may be stratigraphically contiguous with those underlying the Colorado Plateau, but they are highly eroded and incised, and also may have undergone substantial faulting. The dark blue carbonate rocks are stratigraphically disconnected from rocks on the Colorado Plateau. Pink areas represent areas underlain by Proterozoic metamorphic and igneous rocks having low permeability. Dashed lines represent areas where two adjoining aquifers are likely interconnected (1 = LC and Agua Fria basin-fill aquifers; 2 = along the base of the Junipers; and 3 = BC aquifer outlet near Paulden where there is no longer displacement along the BC Fault). Note that displacement along BC fault results in a solid-line boundary between Big Black Mesa and the BC aquifer.



This contour map is a compilation of 1990’s water-level conditions from previous USGS and ADWR studies on the Big and Little Chino basin-fill aquifers. Note that data outside of the basin boundaries are lacking. Important pathways of GW movement are indicated by blue arrows. Note large influence of tributary inflows from Walnut Creek and Williamson Valley Wash which have perennial reaches. Main axis of flow is essentially down length of BC Valley and also from WV but curving around a buried playa unit in the deepest part of the basin along the BC Fault. Click. Brown rectangle indicates region of Transition Zone carbonate aquifer where water-level data are lacking and is the area for the inset map in the next slide.



This is an enlargement of the area north of the upper Verde River east of Paulden showing availability of new and existing water level data for part of the regional carbonate aquifer. The regional direction of ground-water movement in the carbonate aquifer is east or southeast. Basin-fill aquifer and carbonate aquifer are strongly interconnected north of the Verde River. This is evidenced by a gently sloping water-level gradient east of Paulden that extends north of Drake, and east as far as Hell Canyon. Gradient and flow direction are entirely consistent with the Big Chino aquifer providing the major source of discharge to upper Verde River springs, although it is possible that a minor fraction of inflow could be derived from the carbonate aquifer. Click. Permeability along the basin outlet may be enhanced, in part, by the presence of a basalt-filled paleochannel (purple arrow).

Major Findings of the Hydrogeologic Framework

- A ground-water divide separates the Colorado Plateau and Transition Zone carbonate aquifer units
- The CP part of the carbonate aquifer contributes little if any recharge to the BC aquifer or to UVR
- Recharge from Big Black Mesa contributes directly to BCBF aquifer or entrs along BC basin-outlet flowpath

Multiple Lines of Evidence

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- Geologic Framework
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- **Geochemistry of Major Aquifers and Springs**
- Tracer study and Geochemical model
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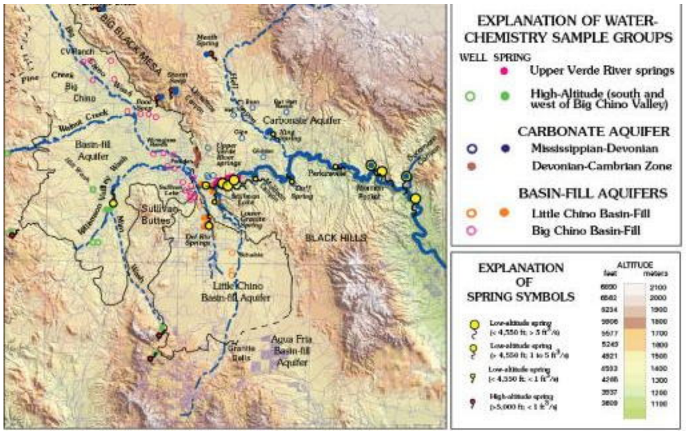
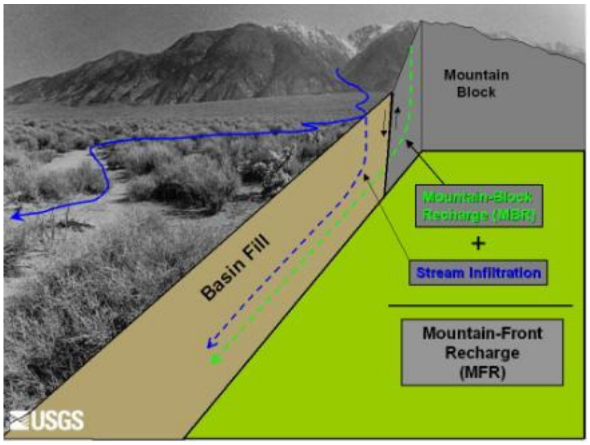
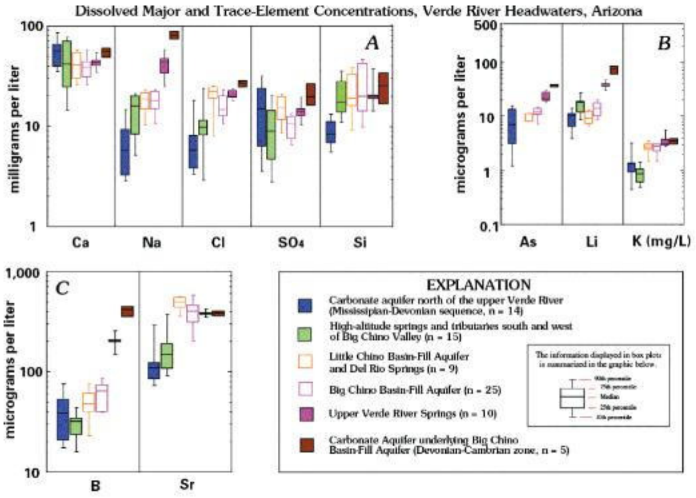


Geochemical and isotope methods are used (1) to characterize the water chemistry of major aquifers, recharge areas, and springs in the upper Verde River, (2) to identify water-rock interactions along flowpaths through fractured rock near the outlets of Big and Little Chino Valleys, (3) to delineate areas where recharge is occurring, and (4) to help determine whether ground water discharging to upper Verde River springs is derived from a single source (e.g. the Big Chino basin-fill aquifer) or is comprised of a mixture of ground water from the Big Chino aquifer with the adjacent carbonate aquifer. Water-chemistry samples were collected from major basin-outlet springs, from high-altitude springs and tributaries of the Bradshaw, Santa Maria, and Juniper Mountains, from the carbonate aquifer north of Big Chino Valley and the upper Verde River, and from the Big and Little Chino basin-fill aquifers. Geochemical approaches used in this study include major- and trace-element concentrations, stable (or nonradioactive) isotopes of oxygen, hydrogen, and carbon, and radioactive tritium and carbon-14.

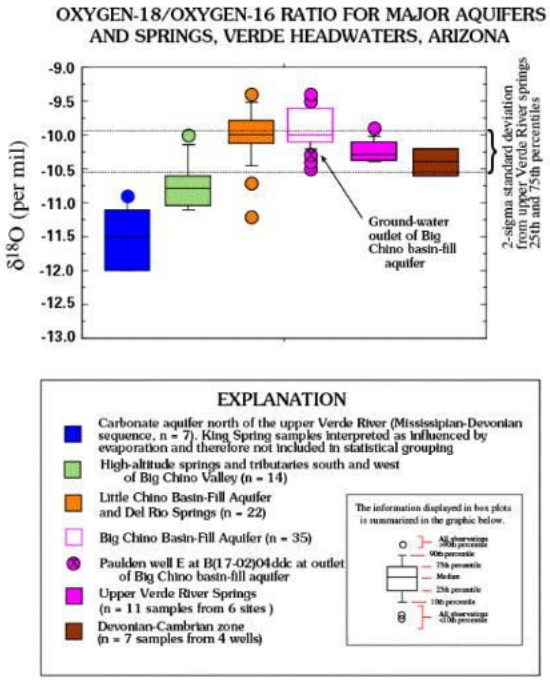


Conceptual illustration of mountain block recharge.



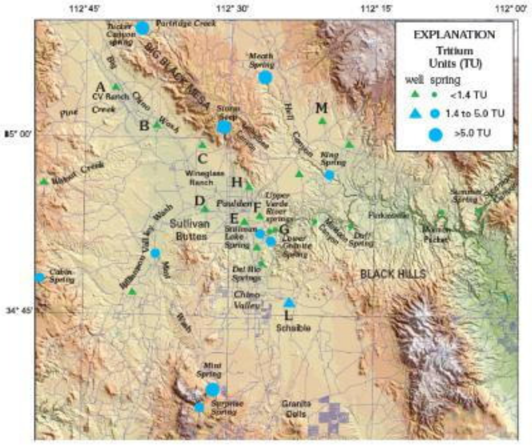
Characterization of recharge areas and aquifers employed the use of boxplots to illustrate broad water-quality trends. In these plots, the boxplot groupings are arranged from upgradient or recharge areas on the left (blue and green boxplots) to downgradient areas on the right (pink and brown boxplots).

One of the most prominent trends in the study area is that ground water tends to increase in Na, Cl, As, Li, and B as a consequence of water-rock interaction with Devonian-Cambrian sedimentary rocks present along the basin outlet. A secondary trend is that the highest Sr concentrations are associated with the occurrence of volcanic rocks (particularly Sr-rich lati-andesites in northern LC Valley) but may also be associated with buried basalts and playa sediment in the BC basin-fill aquifer. Characterization of water-quality trends, interpreted in conjunction with water-level gradients, was important in identifying major conduits of flow.

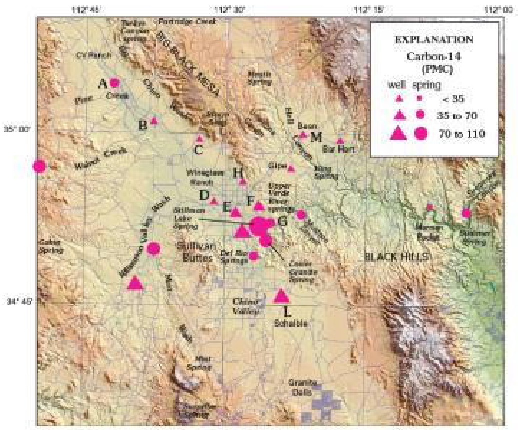


Boxplots were also used to summarize the range in δ18O among the different aquifer groups. On average, the carbonate aquifer north of the Verde River (M-D sequence) typically is 1.3‰ more depleted in δ18O than upper Verde River springs, and thus cannot be a major source (although even a small amount of mixing cannot be precluded on the basis of stable isotope data alone). The Big Chino aquifer has a large range in δ18O, however, the GW near the basin outlet is isotopically indistinguishable from upper Verde River springs. GW chemistry near the BC outlet at Paulden was used in the geochemical model to represent a volumetric composite of the wide range of water within the BC basin. The use of stable-isotope data alone can result in non-unique interpretations, and thus multiple lines of geochemical evidence were needed to improve confidence in any source interpretations.

Tritium (TU)



Carbon-14 (PMC)



Major Findings Spatial Geochemical Trends:

- Distinctive trends were linked to recharge areas or water-rock interactions
- Higher concentrations of trace elements were found in the carbonate aquifer beneath the BC basin-fill aquifer
- Higher strontium concentrations were spatially associated with volcanic rocks
- Tritium and C-14 indicate modern recharge has occurred beneath ephemeral streams

Multiple Lines of Evidence

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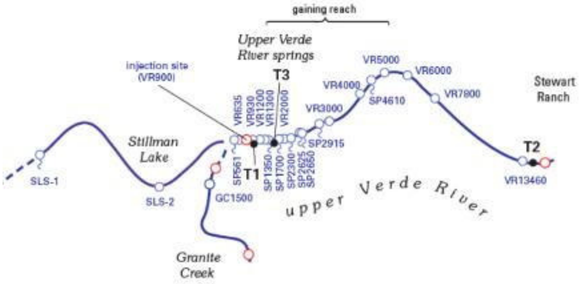
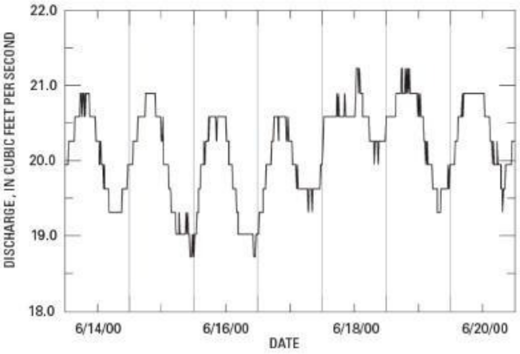
Tracer Dilution Study
Synoptic Sample Locations

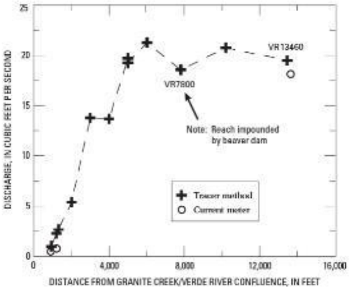


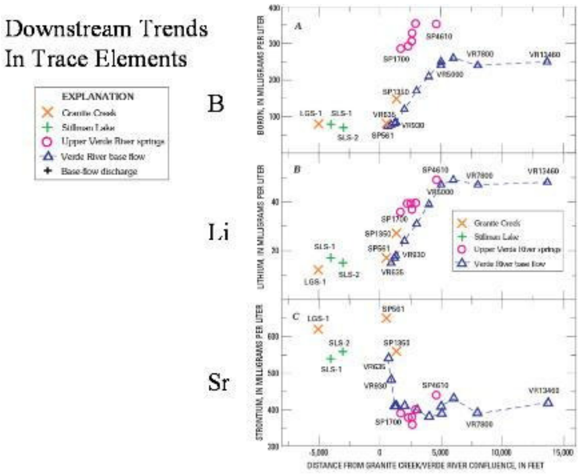
The relative contribution of inflow from each of the three aquifer sources was difficult to directly measure because most of the inflows occur diffusely through the streambed. Thus, a tracer-dilution study and synoptic water-chemistry sampling were conducted during low-flow conditions to identify locations of inflows and to determine the relative contribution from major aquifers. Discharge was determined using the analytical concentration of chloride tracer to calculate dilution. This map shows sample locations collected within the uppermost 2-mi reach of perennial flow in the Verde River.

Daily Variation in Baseflow Discharge
(June 2000)

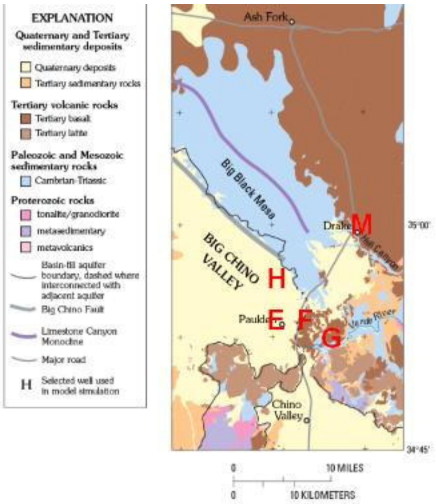


Tracer-dilution Calculated Discharge
Upper Verde River



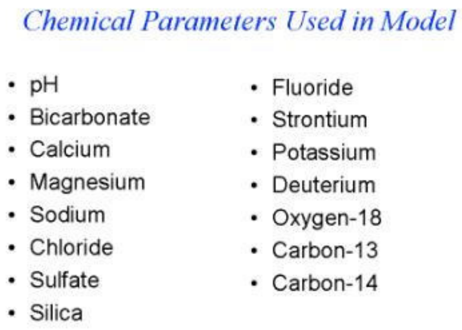


Again, different trace elements illustrate the relative contributions from different source areas. In the two upper graphs, boron and lithium are elevated in inflows from upper Verde River springs, associated with water-rock interaction with marine sedimentary rocks in the Devonian-Cambrian zone. In the bottom graph, GW inflow from the Little Chino aquifer is high in strontium, owing to contact with volcanic rocks (lati-andesite). These different trends provide evidence for GW flowpaths from the basin-fill aquifers to springs discharging in the Verde River canyon.



Finally, the hypothesis that upper Verde River springs is a mixture of ground water from the Big Chino basin-fill aquifer and the carbonate aquifer was tested by inverse geochemical modeling using the computer program PHREEQC (Parkhurst and Apello, 1999). Inverse modeling uses existing geochemical analyses to account for chemical changes occurring as water evolves along a flowpath. Given two water analyses representing the starting and ending water composition along a flow path, inverse modeling will calculate the moles of minerals and gases that must enter or leave solution to account for differences in composition.

In this exercise, the inverse model evaluated potential contributions of 4 initial waters from (A) the Big Chino aquifer, (B) the carbonate aquifer underlying the Big Chino aquifer, (C) the carbonate aquifer north of the Verde River, (D) the outlet flowpath through the carbonate aquifer, to produce (E) the water chemistry at upper Verde River springs.



Chemical Parameters Used in Model

- pH
- Bicarbonate
- Calcium
- Magnesium
- Sodium
- Chloride
- Sulfate
- Silica
- Fluoride
- Strontium
- Potassium
- Deuterium
- Oxygen-18
- Carbon-13
- Carbon-14

PHREEQCI (Parkhurst and others) Mole Phase Transfers for UVRS

Model	SiO2	CO2	NaCl	Talc	CaCO3	Gypsum	SrSO4
1		E-04				E-05	
2			E-05	E-05			E-07
3	E-04	E-04	E-05				E-07
4						E-05	E-07
5				E-05		E-05	
6	E-04		E-05				E-07
7		E-04				E-05	
8			E-05			E-05	
9				E-05		E-05	E-07
10				E-05	E-05	E-05	
11			E-05	E-05		E-05	
12		E-04				E-05	E-07
13			E-05			E-05	E-07

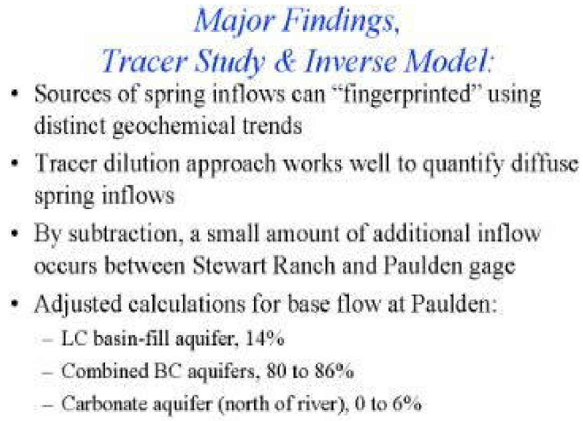
PHREEQCI (Parkhurst and others) Model Mixing Fractions for UVRS

	Big Chino Waters			Sum of BC	Drake	
Model	H	E	F	H+E+F	M	Final
1	.14	.00	.79	.94	.06	1.00
2	.1	.25	.66	1.00	.00	1.00
3	.1	.25	.66	1.00	.00	1.00
4	.12	.12	.76	1.00	.00	1.00
5	.13	.16	.67	.96	.04	1.00
6	.1	.25	.66	1.00	.00	1.00
7	.13	.23	.61	.97	.03	1.00

8	.1	.00	.83	.93	.07	1.00
9	.13	.00	.87	1.00	.00	1.00
10	.13	.00	.81	.94	.06	1.00
11	.12	.00	.82	.94	.06	1.00
12	.14	.00	.86	1.00	.00	1.00
13	.1	.00	.9	1.00	.00	1.00

The model exercise produced 13 plausible models that were quite similar. Mixing fractions for the total discharge from the combined BC aquifers and the carbonate aquifer north of the river varied within a narrow range. Any of the models are plausible, none is considered better than any of the others, and so I report the results as a range.

About half the models required no inflow from the carbonate aquifer north of the river; the other half required between 3 and 7 percent.



Major Findings,
Tracer Study & Inverse Model:

- Sources of spring inflows can "fingerprinted" using distinct geochemical trends
- Tracer dilution approach works well to quantify diffuse spring inflows
- By subtraction, a small amount of additional inflow occurs between Stewart Ranch and Paulden gage
- Adjusted calculations for base flow at Paulden:
  - LC basin-fill aquifer, 14%
  - Combined BC aquifers, 80 to 86%
  - Carbonate aquifer (north of river), 0 to 6%

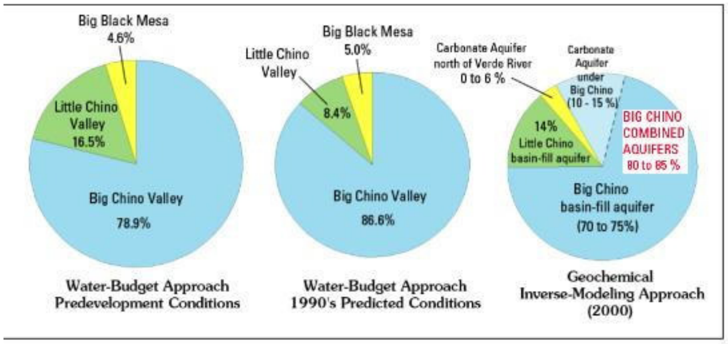
Multiple Lines of Evidence

- Introduction, environmental setting, and predevelopment conditions
- Geologic Framework
- Geophysical Framework
- Hydrogeological Framework
- Geochemistry of Major Aquifers and Springs
- Tracer study and Geochemical model
- **Synthesis**

Summary of Approach

- Determine geologic framework of major aquifers, including geometry, structure, and stratigraphy
- Evaluate regional ground-water gradients and build conceptual model of outlet flowpath(s)
- Characterize water quality of subgroups (large springs and parts of major aquifers)
- Apply tracer approach to quantify GW inflows from each aquifer to VR base flow
- Use geochemical modeling to integrate multiple lines of chemical and isotopic evidence along selected flowpath and calculate mixing fractions

Synthesis and Summary:



Important Note: All 3 pie charts represent base flow at USGS Streamflow-Gaging Station near Paulden

Questions?