Yavapai County Water Advisory Committee (WAC)

Information Series* 2009 #3
Water Budgets

*Informational Series Background: This is intended as an informational item for the Yavapai County Water Advisory Committee (WAC) and the public. This document is prepared by the WAC Coordinator in consultation with the Technical Committee of the WAC.

The Informational Reports Series is a result of the WAC's desire to systematically address questions raised by the WAC member representatives. This document does not fully explore the complexities and implications of any given question. Thus it is not necessarily intended to "stand alone". This is intended to provide fundamental information to aid in understanding this regions water resource.

The question is interpreted as: What are our best estimates of water budgets for the major basins in Yavapai County? This is a high priority question for the WAC and much of the work that the WAC has funded has resulted in information relevant to water budgets.

Water Budgets:
A water budget is a measure of the amount of water entering and the amount of water leaving a system. It is a way to evaluate all the sources of supply and the corresponding discharges with respect to a basin or aquifer. In hydrology, a water balance equation can be used to describe the water budget by mathematically accounting for the water budget components. A system can be one of several hydrological domains, such as a drainage basin, an aquifer, or localized parcel of land. A water budget is fundamental to understanding and assessing inputs, outputs, and changes to a particular water resource system.

Ideally, for a water balance equation, all input and output components are directly measurable and sufficient amounts of data are available; however, in reality some components are calculated based on other information, estimated, or not calculated due to insufficient information. While data in the Verde basin are not complete, enough data exists to make representative estimates of most components of the subbasin water budgets on an average annual basis.

This document reports water budget information for the subbasins of the Upper Verde Watershed from Blasch *et al,* 2006. A summary of the water balance is found on page 80-88 of Blasch *et al*, 2006 (the "Blasch Report" http://pubs.usgs.gov/sir/2005/5198/pdf/sir20055198.pdf)). The Blasch Report utilizes and cites several sources of water budget data and water budget calculations (such as the WAC and ADWR, 2000).

Figure 1, below, shows the location of the three Verde River subbasins for which the average annual water budgets were calculated by Blasch *et al*, 2006. Figure 2 shows the water balance equations and conceptual diagrams for a basin water budget and aquifer water budget components. The Table on page 3, below, shows the calculated average annual water budgets for three Verde River subbasins (Table 22, Blasch *et al*, 2006).

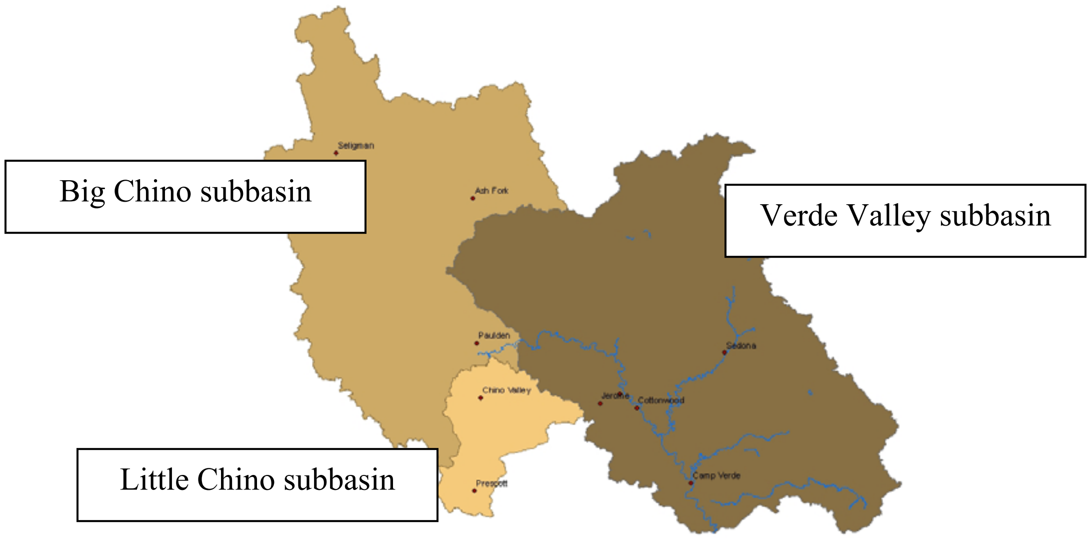


Figure 1: Upper Verde Watershed showing subbasin boundaries for Big Chino, Little Chino, and Verde Valley (modified from USGS presentation to WAC February 2007).

Table 22 from the Blasch *et al*, 2006 report (below, on page 3 of this report) (from page 82 of the Blasch Report) is a summary of the **regional aquifer** water budgets for the Big Chino, Little Chino, and Verde Valley subbasins. Appendix 9 of the report contains annual information.

Table 23 (below) also from the Blasch Report highlights **recharge** for the subbasin water budgets and the regional aquifer water budgets. The difference between the regional aquifer and the subbasin types of water budgets is illustrated in Figure 2 on page 5 of this report.

Table 23 shows the natural recharge to the Little Chino subbasin is about 5,000 acre feet per year (does not include artificial recharge). The Big Chino has on the order of 23,000 acre feet of natural recharge per year; and the Verde Valley subbasin has on the order of 130,000 acre feet of recharge to the groundwater aquifer per year.

Table 23. Estimated recharge in the Big Chino, Little Chino, and Verde Valley subbasins

	Subbasin water budget		Regional aquifer water budget	
Subbasin	Average annual recharge (acre-feet per year)[1]	Recharge from precipitation (percent)[2]	Average annual recharge (acre-feet per year)[3]	Recharge from precipitation (percent)[2]
Big Chino[4]	22,980	1.3	23,300	1.3
Little Chino[4]	5,130	1.6	5,100	1.6
Verde Valley[4]	146,300	4.4	130,300	3.9

[1]Recharge derived from subbasin budgets as rainfall + snowfall + runoff in - runoff out - evapotranspiration calculated at the land surface.

[2]Average annual rainfall from 1971–2000 and average annual snowfall from 1981–2002.

[3]Recharge is calculated as a residual in table 22 and is a combination of channel, basin, mountain-front, and mountain-block recharge.

[4]Changes in storage are not considered.

Table 22. Average annual water budgets for **regional aquifers** in the upper and middle Verde River watersheds, central Arizona, 1990–2003

[Values are in acre-feet per year. Negative values indicate water is removed from or leaves the subbasin. Terms in parentheses refer to terms in water-budget equations. Terms in brackets are estimated error as ± percent. Detailed annual water budgets are included in appendix 9]

Water-budget component	Big Chino subbasin	Little Chino subbasin[1]	Verde Valley subbasin
Total inflow	**30,300**	**12,620**	**167,470**
Base flow in[2] (BF_{in})	[2a]180	0	17,900
Natural recharge[3] (R)	23,420	5,070	130,270
Incidental and artificial recharge[4] (IR)	4,300	7,550	[4a]19,300
Ground water in[5] (GW_{in})	[5a]2,400	0	Not Calculated[5b]
Total outflow	**-30,300**	**-16,720**	**-167,470**
Agricultural irrigation[6] (WU)	-7,900	-4,900	-120
Agricultural subirrigation (WU)	[7]-3,400[25]	0	0
Domestic (WU)	-300	-1,300	-1,900
Water providers (WU)	-200	-6,600	-7,800
Golf course irrigation (WU)	-30	0	-1,500
Industrial use (WU)	-10	-140	-1,150
Base flow out[8] (BF_{out})	-17,900	[8a]-1,800[1]	[8b]-144,100
Vegetation evapotranspiration[9] (ET)	-560	[9a]0	[9b]-10,800
Ground water out[10] (GW_{out})	Not Calculated[10a]	[10b]-1,980	[10c]-100
Change in storage (ΔS)	**Not Calculated**[11a]	[11b]**-4,100**	**Not Calculated**[11a]

[1]The Little Chino subbasin is considered a tributary subbasin to the Big Chino subbasin.
[2]Base-flow separation calculated by using HYSEP; 14-year average values (1990–2003).
[2a]Base flow from Del Rio Springs minus diversions, channel infiltration, and evapotranspiration.
[3]Natural recharge is estimated as a residual in this equation. Includes components such as mountain-block, mountain-front, basin, and channel recharge. This value does not consider storage losses in the system.
[4]Calculated on the basis of incidental recharge factors and water use; 14-year average values (1990–2003).
[4a]Includes recharge from diverted surface water applied as irrigation.
[5]14-year average values (1990–2003).
[5a]Nelson (2002) simulated 1,800 acre-ft/yr of ground-water flow from the Little Chino subbasin to the Big Chino Subbasin. About 600 acre-ft/yr is derived from recharge of base flow downstream from the streamflow-gaging station at Del Rio Springs. This value was applied to the conceptual budget for 1990–2003. Possible ground-water inflow on thenorthern boundary of the subbasin not calculated.
[5b]Ground-water inflow that may occur along the Mogollon escarpment not calculated.
[6]Ground-water use values detailed in appendix 9; 14-year average values (1990–2003).
[7]Includes approximately 3,400 acre-ft of water evapotranspired from subirrigated agriculture.
[8]Base-flow separation calculated by using HYSEP; 14-year average values (1990–2003).
[8a]Base flow from Del Rio Springs including diversions, channel infiltration, and evapotranspiration.
[8b]Base-flow values based only on winter base-flow values.
[9]Calculated by using gaging-station data and HYSEP base-flow separation; 43-year average values (1961–2003).
[9a]Evapotranspiration near Del Rio springs is included in base flow out.
[9b]Sum of Wet Beaver Creek, West Clear Creek, Oak Creek, and Verde River near Camp Verde.
[10]14-year average values (1990–2003).
[10a]Ground-water flow out of the subbasin through the northern boundary not calculated.
[10b]Nelson (2002) simulated 1,800 acre-ft/yr of ground-water flow from the Little Chino subbasin to the Big Chino Subbasin. This GW_{out} value includes the water that leaves the Little Chino subbasin as base flow from Granite Creek. Wirt and others (2005) reported a base flow of 360 acre-ft/yr; however, the base flow can vary. In order to determine the flows across the subbasin boundary, the Arizona Department of Water Resources did a Zone Budget (Harbaugh, 1990) analysis of the 1998 model results (Frank Corkhill, hydrologist, Arizona Department of Water Resources, written commun., 2005).
[10c]Ground-water flow out of the southern boundary calculated. Ground-water flow out of the northern and eastern boundaries not calculated.
[11a]Changes in storage occuring; consult water level altitudes on pl. 3
[11b]Nelson (2002) simulated an average 4,000 acre-ft/yr of ground-water storage change from 1990 to 2003.

The data for the regional aquifer water budgets for each year used in the average annual value in Table 22 (1990-2003) are shown in Appendix 9 of Blasch *et al*, 2006 (http://pubs.usgs.gov/sir/2005/5198/).

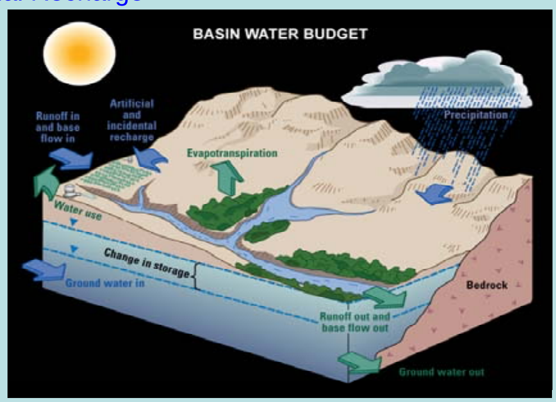
Basin water balance equation (Hydrologic Equation)

$$\underbrace{P + IR + GW_{in} + BF_{in} + RO_{in}}_{\text{Inflow}} - \underbrace{ET - GW_{out} - BF_{out} - RO_{out} - WU}_{\text{Outflow}} = \Delta S$$

P Precipitation (rainfall + snowfall)
IR Incidental and Artificial Recharge
GW_{in} Ground-water in
BF_{in} Base-flow in
RO_{in} Run-off in

ET Evapotranspiration
GW_{out} Ground-water out
BF_{out} Base-flow out
RO_{out} Run-off out
WU Water use

ΔS Change in storage
Specified area is a basin



Regional aquifer water balance equation

$$\underbrace{R + IR + GW_{in} + BF_{in}}_{\text{Inflow}} - \underbrace{ET - GW_{out} - BF_{out} - WU}_{\text{Outflow}} = \Delta S$$

R Recharge
IR Incidental and Artificial Recharge
GW_{in} Ground-water in
BF_{in} Base-flow in

ET Evapotranspiration
GW_{out} Ground-water out
BF_{out} Base-flow out
WU Water use

ΔS Change in storage

Specified area is an aquifer

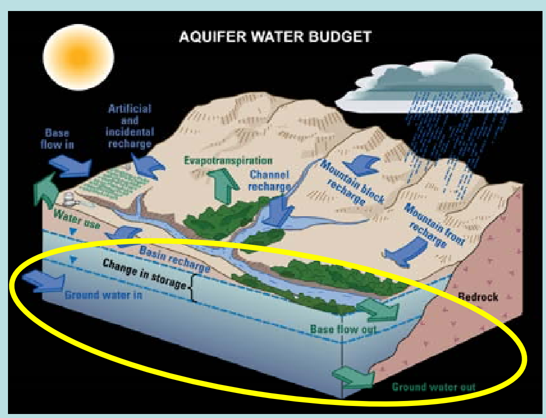


Figure 2: Basin (top figure) and **Regional Aquifer** (bottom figure) Water Budget Equations (and components) and conceptual diagrams (modified from USGS presentation to WAC February 2006). These figures illustrate different ways of computing water budgets (from USGS).

Conclusions, Caveats and Potential Implications

Water budgets are a way to account for the components of a water system (inflows, outflows and changes in storage). Management decisions are improved with an accurate accounting of the water budget components. A water budget can be utilized to understand the movement of water in a system, and comprehend effects of changes to the system (and the system components).

Alley, et al, 1999 ("Sustainability of Ground-Water Resources USGS Circular 1186) is a good reference for general information on water budgets. (http://pubs.usgs.gov/circ/circ1186)

Published estimated average annual water budgets for regional aquifers in the three subbasins of the Upper Verde watershed are available (Tables above). While there are data gaps and the water budget will be improved with new information, these values are considered representative. For instance, the amount of annual natural recharge to the subbasins is on the order of 130,000 acre feet for the Verde subbasin; 5,000 for the Little Chino and 23,000 acre feet for the Big Chino (see Table 23; page 2 above). These values represent a long-term average. The amount of recharge, and amounts of other water budget components, will vary relative to climate (For instance, less recharge will occur in drought periods and more recharge will occur during wetter periods of time; or precipitation will vary between one location in a basin and another).

The values presented in this summary may be used by water resource managers to understand implications of ongoing or planned activities. For instance, the values can be compared to potential groundwater withdrawal rates. In applying these values, nuances and specific consideration will likely be required for each application due to geographic and aquifer variations (such as the limitations expressed in WAC Information Series #2) Therefore, it is difficult to draw complex predictive conclusions solely from the numbers in the tables. However, the numbers are meant to be representative, and the true value of water budget components is likely to be approximately equal to the values in the published tables.

Other Watersheds

Little or no information was found quantifying water budgets for the other watersheds in the County (Agua Fria, Hassayampa, and Bill Williams). Some information for the Upper Agua Fria is presented below. Additionally, some information about water use in the Kirkland Creek Watershed of the Bill Williams River basin is available but not reported in this document (Smith and Ritter, 2001 "Kirkland Creek Watershed Assessment"; and Upper Bill Williams Watershed Partnership, Unpublished Draft "Preliminary Water Use Estimates, Kirkland Creek Watershed")

Agua Fria Sub Basin:

Wilson, 1988, provides the only published information on water budget of the Agua Fria that was examined for this paper. The Wilson report contains a groundwater budget for the year 1981 for the groundwater basin above the Mayer gage (09512500) (Figure below) (from about Cordes Junction north).

Pages 23-31 describe the Groundwater Budget; Table 1 of the report (p 23) lists the components and estimated values. Table Agua Fria, below is modified from the report and contains all the information provided in the Wilson reports table.

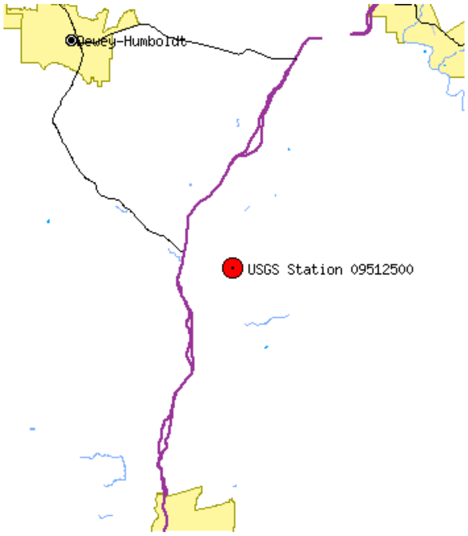


Figure – Location of Agua Fria near Mayer Gage on Agua Fria River (USGS Station 09512500) (Figure from http://waterdata.usgs.gov/nwis/uv?09512500)

Table Agua Fria: Ground-water budget for the study area excluding the Little Chino Valley ground-water basin for the 1981 water year (from Wilson, 1988) [Wilson notes: Components of this budget are estimated and indicate the magnitude of the transient hydrologic conditions]

Discharge		Acre feet	Acre feet
	Irrigation (Crop CU)	4,400	
	Domestic & Commercial Use	1,300	
	Evapotranspiration (riparian)	1,100	
	Base Flow past Agua Fria near Mayer Gage	2,900	
Total Discharge			9,700
Change in Storage			
	Upper Agua Fria Ground-water Basin	5,000	
	Black Hills Subarea(1)	0	
	Mayer Subarea(1)	0	
Total Change In Storage			5,000
Recharge			
	Upper Agua Fria ground-water basin	9,200	
	Black Hill & Mayer subareas	5,500	
Total Recharge			14,700 (2)

(1) Probably increase in storage but data were not adequate to make estimates.
(2) Minimum value for recharge; data were not adequate to estimate the increase in storage in the Black Hills and Mayer subareas.

References:

The primary reference for the Verde Basin is the USGS report by Blasch *et al*, 2006 (SIR 2005-5198) "Hydrogeology of the Upper and Middle Verde River Watersheds, Central Arizona". (This is the conceptual report; the WAC has received presentations and it serves as a basis for the Northern Arizona Regional Groundwater Flow Model in preparation by the USGS).

Alley, W.M., T.E. Reilly, and O.L. Franke, 1999, **Sustainability of Ground-Water Resources, US Geological Survey Circular 1186, http://pubs.water.usgs.gov/cir1186**

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