Water Above, Water Below
In Arizona's Big Bug Creek Area

By Clifford Hersted
for the
Upper Agua Fria Watershed Partnership © 2006
Preface

This study introduces many of the basic topics necessary for understanding water issues in the Big Bug Creek area. Some information is specific to the Big Bug Creek Area, but much of the information is available only for Yavapai County or the entire state of Arizona. Current information often changes, such as drought conditions, and interested readers are encouraged to do further monitoring and research through the online resources provided, listed either on the charts or in the Online Resources Guide on the back cover.

This booklet discusses drought conditions because the area seems to be experiencing a relatively dry period, of unknown duration, that began in 1998. It also discusses development in the area because people are uncertain about how much development can be supported by the natural water supply, especially during a possible long-term drought. Most of the development in the Southwest occurred during the relatively wet period from 1977 to 1998.

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Water Cycle in the Big Bug Area

During an average year, 16 inches of precipitation falls into the Big Bug Creek Corridor: 56% falls in the winter and 44% in the summer (McPhee et al. 2004:15).

Rain, snow and hail saturate the landscape throughout the year nurturing the soils, vegetation, animals and humans.

About 90% eventually returns to the sky as water vapor through evaporation and transpiration (evaporation from plants) throughout the year and then moves out of the region.

Approximately 3% runs as stream flow out of the Big Bug Creek into the Agua Fria River.

About 2% is consumed by residents and visitors.

The other 5% remains in the soils throughout the year, and an unknown portion of this percolates into groundwater storage below the watertable.

This is an AVERAGE water-cycle profile for the area based on over 100 years of instrumental record, but precipitation varies greatly from year to year, especially during the winter season. The percentages in Figure 1 will also change yearly.

In summary, we only get to use precipitation throughout the year, and precious little is naturally saved as groundwater for the following year.

Figure 1. Annual Water Cycle
Arizona’s Annual Precipitation: Yearly & Multi-Decade Trends

Figure 2 demonstrates that precipitation in Arizona varies greatly from year to year, from a low of about 6 inches to a high of over 24 inches. The instrumental record also shows periods of 20-30 year cycles of below average and above average precipitation. However, even during wet cycles there are drier years and wetter years during drier cycles. A water year is measured from October to September.

The 10-year running mean (yellow line) is calculated for each year by adding each year to the prior nine years and dividing by ten. This flattens the curve in order to show trends more clearly. This curve will also be used in other charts.
Winter Storms from the Pacific

Large winter storms blow in from the Pacific Ocean, usually over the Northwest states of Oregon and Washington from October through April. A persistent subtropical high-pressure ridge over Arizona keeps most of the storms north of this area, resulting in higher winds and cloudy skies rather than rain or snow.

Winter storms that do arrive over Arizona tend to be regional and may drop gentle, soaking rain for several days over several states.

Rain Shadow Effect

Additionally, winter storms on their way to Arizona pass over large mountain ranges to the west and drop most of the water on the ‘windward side’ of the mountains and much less on the ‘leeward side’. This is called the “rain shadow effect,” which results in less moisture reaching Arizona. As the westerly winds push warm, moist clouds up the ‘windward side’ of the mountain, they cool as they rise, creating condensation and precipitation. This is called the ‘orographic effect’. This cooler, drier air then falls on the ‘leeward side’ of the mountain range and warms, releasing little or no rain until it rises again.

Figure 3. Elevation Profile of the landscape from Los Angeles to The Upper Agua Fria Watershed, the Orographic Effect and the Rain Shadow Effect are shown.
El Nino & La Nina

Precipitation in the Big Bug area varies greatly from year to year. Most variation occurs during the winter season and seems to be related to changes in surface water temperatures in the equatorial Pacific. Surface water temperatures off the Pacific Coast of South America occasionally get either warmer or cooler than normal.

Warmer ocean temperatures modify Pacific winds and pressure systems to drive more winter storms into the Southwest rather than the Northwest, and Arizona winters tend to be cooler and wetter. This is called El Nino (boy child). The winter of 2004-05 was an El Nino year that dropped much more water in Arizona than usual.

Cooler ocean temperatures in the eastern equatorial Pacific, on the other hand, drive winter storms into the Northwest and much less into the Southwest. This results in warmer and drier Arizona winters. This is La Nina (girl child). La Nina winters are associated with drought in the South-west.
Pacific Decadal Oscillation (PDO)

In addition to wet and dry years, there seem to be wetter and drier periods lasting two or three decades. According to the PDO record there was a dry period in the Southwest from 1890-1924, followed by a wet period from 1925-1946, then another dry period from 1947-1976, and a wet period from 1977-1998 (when much of the development occurred in the Southwest). Since 1998, the Southwest has shifted into another dry period that may last into the 2020’s, despite the occasional wet winter (Lenart 2005).

These shifts appear to be related to multi-decade long oscillations in surface-water temperature in the Northern Pacific. Positive (warmer) phases of PDO enhance El Nino and dampen La Nina events, resulting in wetter Arizona winters. Negative (cooler) PDO phases strengthen La Nina and weaken El Nino, resulting in drier Arizona winters (Maxwell & Holbrook 2002).

Curiously, the PDO index seems to correlate with Arizona precipitation better after 1925. Before about1925 the trends seem to be opposite.

Summer Monsoon Storms

“Monsoon” refers to a shift of winds from westerly to southerly, usually from July to September.
Summer moisture blows northward from Mexican waters into Arizona and is warmed by the landscape and summer sun. This moisture, fueled with local evaporation, rises rapidly over the central mountains, cools and condenses into convective thunderstorms. These storms are characterized by frequent lightning, thunder, hail, intense rain and an occasional tornado.

Summer storms tend to be short-lived and localized, and much of the precipitation evaporates in the summer heat. Sometimes the precipitation evaporates before it hits the ground (called “virga”).

On average, 44% of the annual precipitation in this area falls in the summer.

Winter and summer storm patterns seem to be independent of each other, and one season cannot be used reliably to predict the other season’s wetness or dryness.

**Arizona’s Average Temperature**

Figure 7 indicates that Arizona’s average annual temperature has increased 2.5 °F over the last 100 years, or 0.25 °F each decade. Globally, 2005 may have been the hottest year on record.

This warming trend in Arizona will accelerate the effects of drought by increasing evaporation and transpiration.

Vegetation communities may migrate up hill as higher elevations become warmer. Higher elevation vegetation might disappear.

Increased wildfires will occur because of warmer, drier and windier conditions.
Evaporation & Transpiration (ET)

Evaporation and transpiration (evaporation from plants) occurs when solar energy transforms surface water and moisture in the soils and plants into water vapor. These vapors then rise, cool and condense into clouds that typically blow out of the area. ET is the opposite of precipitation.

The surface water evaporation rate is 62-64 inches per year, as measured on the Cordes Ranch south of Spring Valley, four times the 16 inches of annual precipitation. Rates of transpiration from plants are difficult to measure because plants differ greatly.

Rates of ET generally follow the annual temperature curve and are higher during daylight, clear days, dry days and summer months when the sun is hotter.
Winter precipitation may last 5 or 6 months when temperatures and evaporation rates are lowest. This situation allows the surface water more time to soak into the soils.

Persistent springtime winds increase the rate of ET. A 15 mile-per-hour wind increases ET by 50%.

During a hot year or drought, ET eventually returns ALL the precipitation to the sky and continues to vaporize the moisture out of the soils and plants, along with the groundwater that naturally flows into streambeds, springs, and is pumped out of wells onto the landscape.

**Figure 8. Evaporation (E), Temperature (T) and Rainfall (R)**

Average monthly percent distribution of Annual Temperature (T), Precipitation (P), and Evaporation rates in Central Arizona.

**Portrait of a Drought**

Drought is a period of drier conditions resulting in water-related problems. Drought (short and long-term) is a result of the natural climatic cycles that have dominated the Southwest for thousands of years.

Less precipitation falls, soil moisture decreases, plants experience water stress or die, trees become vulnerable to insect infestations like bark beetles, wildfires increase, stream flow dries up, water tables drop and wells go dry.
Despite the occasional wet winter (e.g., 04-05), some climate scientists believe we have entered another multi-decade dry period beginning in 1998, and that this dry period may persist into the 2020’s. This belief is based on past long-term cycles and current climatic data. No one knows how intense this dry period will be, but precipitation during 1999-2005 was well below average, with 2002 as one of the driest years on record.

U.S. government agencies have developed a drought monitor that provides a weekly profile of the extent and intensity of drought in the United States. Readers may monitor drought conditions at [www.drought.unl.edu/dm/monitor.html](http://www.drought.unl.edu/dm/monitor.html)

![Figure 9. U.S. Drought Monitor](image)

### Wildfires

Wildfires are one of Arizona’s few recurring disasters. They are caused by both humans and nature. Summer lightning storms follow the dry, windy spring season and ignite numerous wildfires throughout the state. Some of the largest wildfires occur in June when temperatures increase, humidity is extremely low, and there is little, if any rainfall to suppress the flames.

Wildfires often begin on difficult terrain, making firefighter access difficult.
Figure 10 shows the satellite traces of wildfires in our region during 2005. The winter of 2004-2005 was very wet and produced a lot of new vegetation growth that dried out and became fuel by June.

Vegetation Communities

The Big Bug Creek originates in the Ponderosa Pine Forest on Mount Union in the Bradshaw Mountains and descends through Interior Chaparral on Big Bug Mesa into the Semidesert Grassland along State Route 69 (See figure 11).
Many species of vegetation and wildlife depend on moisture in the soil zone where plant root systems hold soil from water runoff erosion. While most of the moisture held in the soil zone will eventually yield to ET, the capacity of the soils to absorb, hold and use water throughout the year is what sustains life.

Figure 11 shows the vegetation communities in the Upper Agua Fria Watershed (after Barnett 2000:Figure 9), the two local stream gages, and the pueblo settlement pattern. Notice how pueblo dwellers, who did not have the benefit of deep wells, settled near the streams and river as well as near the grasslands. Wildfires have occurred in all vegetation communities during 2005. The Ponderosa Pine Forest is especially vulnerable to fire because of the bark beetle infestation that has weakened or killed many trees.
Surface Water

Once precipitation falls, gravity moves water downhill over the landscape into the many washes and creeks that flow into the Agua Fria River. The river eventually delivers an average of 83,000 acre-feet of water per year to Lake Pleasant on the southern tip of the watershed (from a high of 481,000 acre-feet in 1916 to a low of 1700 acre-feet in 1977).

Ephemeral and intermittent streams flow only after precipitation and during periods of melting snow. They are usually dry.

Interrupted streams flow on the surface in some stretches, often over impermeable bedrock, and disappear to flow underground in others stretches. The Agua Fria River and some of its tributaries are interrupted streams that have perennial stretches. Water often infiltrates into the soils in washes and creeks, which are major areas of groundwater recharge in this area.

Perennial stretches often support year-round vegetation. Ash Creek has 2 perennial reaches totaling 10 miles, the Big Bug Creek has 2 reaches totaling 6 miles, and the Agua Fria River has 4 reaches totaling 21 miles. Stream flow varies greatly by season and rainfall, as well as by the movement of groundwater into or out of the streambeds.

12a. A rapidly flowing Agua Fria moves tons of soil down river.

Stream flow rates in the Agua Fria at the confluence of Big Bug Creek varies from less than 1 cubic foot per second (CFS) to over 9,000 CFS as measured by the stream gage after a big winter storm (see Figure12b).
Riparian Areas

Riparian areas are narrow strips of lush vegetation along perennial stretches of the Agua Fria River and some of its tributary creeks. Washes fed by springs may also support riparian areas. These “ribbons of green” provide critical habitat for many wildlife species, including waterfowl and other birds, frogs, native fish, insects and mammals, including deer and pronghorn antelope.

Riparian habitats host hundreds of migrating bird species and are popular with wildlife watchers. Many of the early ranchers settled in or near riparian areas.
Instead of healthy hiking, more people are now driving their ATV’s in riparian areas. This may disrupt the delicate, natural balance of species in the perennial stretches, and ATV’s may cause serious erosion of stream banks.

**Groundwater Dynamics**

Some people visualize aquifers as underground lakes or streams, as if in a big cave. This is misleading. Gravity forces surface water to infiltrate or percolate into the soils. The water seeps through the pores, cracks, and fractures of rocks, and in the small spaces between sand and gravel (See Figure 14).

When these spaces are filled or saturated with water, that water is called a zone of saturation, or simply, groundwater. If there is enough groundwater to yield significant quantities of water to a well or spring, the zone of saturation is considered an aquifer. To tap groundwater, a well must be drilled deep enough in the soil to penetrate the surface of the groundwater, called the water table.

![Figure 14. Groundwater Dynamics](image)

With well pumping, the water table near the well drops, creating a cone of depression that then draws groundwater horizontally from surrounding areas. Many wells may draw water from the same aquifer creating a lower water table in a larger area, like many straws sucking from the same punch bowl. Not all wells
in the same aquifer or aquifer basin (as shown in Figure 15) will have the same yield.

Often groundwater flow discharges into, or draws water from, a surface body of water like a river, stream or lake. This natural process is called stream-aquifer flux that varies with the amount of precipitation, well pumping and stream flow.

Groundwater flows range in velocity from less than 1 inch to 800 feet per day. Highest velocities are found in sedimentary deposits (like gravel, conglomerate, or sandstone) because of their very high permeability. The least permeable ground type occurs in dense, crystalline rocks like granite or schist.

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Figure 15. Geology of the Big Bug Area. Notice how the lava flow shows up as blue.

**Geology & Groundwater**

Geological faulting formed the present-day, discrete groundwater basins that are separated by impermeable granite or schist basement units. As a result, there is little, if any, direct sub-surface water flow between the Lonesome Valley aquifer (in the Dewey-Humboldt area), the Mayer aquifer and the Black Hills Aquifer.
Rock units in the Big Bug Corridor can be divided into four broad units based on geologic character and their ability to yield water. The units are, from youngest to oldest:

- **Basin-fill sands and gravels** readily transmit recharge into the underlying units. However, basin-fill units are thin and do not store large quantities of groundwater.
- **Volcanic basalt** rocks provide small amounts of water to low-yield stock wells in the area and feed a number of seasonal springs. Well yields are best from cinder beds and fractured sections of the basalts.
- **Sedimentary sandstone** deposits occur widely throughout the basin and contain the largest volume of groundwater.
- **Basement units** are schist or granite and yield only small amounts of water from fractured, weathered or decomposed areas.

Groundwater occurs in all four units, but the main water-bearing units are the sands and gravels and the sandstone. (Wilson, 1988).

**Water Quality - Minerals**

Water has been called the ‘universal solvent’. Water dissolves many naturally occurring minerals, and water is a ready receptor of human-caused pollutants.

The mineral content of water, measured as total dissolved solids (TDS), progressively increases as rainfall moves into streams and rivers, and seeps beneath the surface. Common soluble minerals in the aquifer material in this area include sodium, calcium, magnesium, chloride, bicarbonate, and sulfate. These minerals make the water “hard.” Many areas have supplies exceeding the recommended aesthetic drinking water guideline of 500 parts per million, but they are not harmful. Layers of calcium-bicarbonate, or ‘caliche’, can be found in many areas.

Wilson (1988: Plate 3) shows the measured water hardness for Big Bug communities:

- **Arcosanti**: 748
- **Cordes Junction**: 336
- **Cordes Lakes**: 405
- **Mayer**: 699
- **Spring Valley**: 340, 380

The Arizona Department of Environmental Quality has reported that some mining operations in this area have polluted nearby water to harmful levels. Water in
wells and surface water near mine tailing piles has been found to contain a variety of metals exceeding drinking water standards: Very high concentrations have been found for zinc, cadmium, molybdenum, mercury, lead, nickel, and copper. Overall, however, water quality in the Big Bug Corridor is good (Wilson 1988).

Groundwater Use & Recharge

Everyone living in the Big Bug Corridor depends on groundwater pumped from wells. Water use in this area averages about 110 gallons per day, per capita, according to the Arizona Department of Water Resources. For 5000 people, this means 550,000 gallons per day (1.7 acre feet). This equals 200,750,000 gallons per year or 616 acre feet of water. One acre foot equals 325,851 gallons of water.

If more water is pumped from an aquifer than is recharged, overdraft occurs and the water table drops. If this continues, it is called groundwater mining. Eventually, wells will dry up if groundwater is not recharged.

Significant areas of likely recharge in this area occur in basin fill sand and gravel deposits in or near washes, creeks and the river.

Ironically, some people illegally dump their trash in likely recharge areas so that the rainwater washes over their trash before it enters the groundwater, carrying unknown pollutants with it.

Figure 16. A partially developed Cordes Lakes. Photo by Bruce Colbert.

Development & Groundwater Use

Communities depending on ground water from the Big Bug Creek include: Poland Junction, Mayer, Bensch Ranch Estates, Spring Valley, Cordes Junction and
Cordes Lakes. The 2000 Census Bureau statistics for Zip code 86333 listed a population of almost 5,000 with a median age of 45. The Mayer Post Office services 2860 postal boxes in ZIP 86333.

There are no comprehensive estimates of growth in the study area; however, the 1996 “Cordes Lakes/ Spring Valley/Highway 69 Corridor Plan” projected a potential for a total of 6,000 residential units (an increase of about 3,000) with the current zoning pattern, and a population of 12,000-15,000. No one knows for sure how much development can be supported by existing underground water supplies. Most potential for growth is in the Black Hills Aquifer basin. 15,000 people in the corridor will require over 5 acre feet of water a day and 1850 acre feet a year. Cordes Lakes is only partially developed, as seen above.

Additionally, an unknown number of winter residents flock to the area from colder climates, and millions of visitors pass through the Big Bug Corridor each year in vehicles. Many travelers stop at retail stores, visit relatives and friends, and enjoy outdoor recreation, all of which increase water use.

**Non-Point Source Pollution (NPS)**

Everyday activities also pollute surface and groundwater, especially with increased development. As rain moves over various landscapes, such as agricultural fields, roadways, parking lots, corrals, construction sites and residential backyards, it picks up soil particles, fertilizers, pesticides, weed killers, animal wastes, road salt, motor oil, and other land-borne pollutants.

This type of pollution is called non-point source pollution because it is widely disbursed. People are beginning to understand that medicines and antibiotics are also finding their way into groundwater. Improper ranching practices have contributed to fecal coliform in the water in some areas.

Solutions to landscape pollution include properly disposing of trash, cleaning up spills, using non-toxic products when possible, and keeping yards, driveways and roadways clean.

Some people foolishly and illegally dispose of their household trash in or near washes and creeks where surface water soaks into groundwater (water that eventually gets pumped up for drinking). With the help of ADEQ grant money, volunteers of the Upper Agua Fria Watershed Partnership have removed over 100 tons of trash from the Big Bug Creek area.
Figure 17a. Just one of too many illegally trashed sites in the Big Bug Area.

Figure 17b. A sign produced by the Upper Agua Fria Watershed Partnership that will soon be found in areas that have been cleaned up.
Water Conservation

Water conservation in the semi-arid desert of the Big Bug Corridor makes sense whether or not drought conditions exist, for droughts will surely come and go. Many people now living in Arizona relocated from wetter climates during a wetter period of Southwestern climatic history, bringing their more opulent water-use habits and ideas of landscape with them. Changing personal behavior to plan for drought follows the wisdom of “waste not, want not.” Water conservation is not a punishment; it is the smart use of a necessary, but limited, natural resource.

Water managers need to prepare for dropping water tables, fix all existing leaks, and evaluate storage tank capacities consistent with a growing population during drought. Both Yavapai County and the State of Arizona have published water conservation guidelines for water managers.

Residents can also practice simple household water-management techniques appropriate to a semi-arid region and conserve water. Fix all leaks in the household, especially faucets and toilets. Use a broom instead of a hose to clean walkways and driveways. Wait until you have a full load before using washers and dishwashers. Irrigate in the early morning or night when there is less evaporation, and don’t over irrigate. Replace water-hungry plants with beautiful drought-resistant plants in your landscape (xeriscape).

Figure 18. An example of a beautiful, drought-resistant yard. Photo from Arizona Department of Water Resources.
All water within Arizona belongs to the state of Arizona, but people can own the right to use water. The main types of water rights are surface water rights and groundwater rights. Each is governed by different laws. Arizona law has been slow to recognize that surface water and groundwater are hydrologically connected and not easily distinguished.

The Maricopa Water District owns the surface water rights in the Upper Agua Fria Watershed. Water companies and individuals own the groundwater rights in the watershed.

Surface water is considered all water in streams, rivers, lakes, and ponds, as well as flood water and water flowing beneath the river. The Arizona Supreme Court is considering redefining surface water as water in the Holocene-deposited soils in a river or stream. The Holocene is a geological time period, beginning about 10,000 years ago after the last ice age. We are still in the Holocene Period. It is sometimes difficult to identify soils deposited during the Holocene.

A person who first puts surface water to beneficial use acquires a prior appropriation right to continue using that amount of water. In times of shortage, users with older water rights should get water, while more junior appropriators go without, but enforcement is difficult. Surface water rights may be forfeited if they are unused for five years or are not put to beneficial use. In-stream uses of water to support recreation, fish and wildlife have been recognized as beneficial use since 1976.

Figure 19. "Discussion Water Rights, A Western Pastime."
A popular postcard by Duckboy Cards, Inc.
Forest Service, BLM lands and Arizona State Trust lands, which together comprise 88% of the watershed, have federal reserved water rights. Many of these potentially enormous senior rights have yet to be quantified.

Groundwater is all water under the surface except for water immediately underneath a river or shown to be in connection with a river or stream. Historically, the right to use groundwater belonged to whoever owned the overlying land. Because wells often draw water from beneath neighboring lands and can pump aquifers dry, conflicts arise.

The 1980 Groundwater Management Act established the Department of Water Resources, which regulates groundwater use in the Phoenix, Pinal, Prescott, Santa Cruz and Tucson Active Management Areas (AMA's), where groundwater levels were dropping significantly due to rapid development. In these areas, existing pumpers were granted rights to continue pumping, and now are required to conform to management practices to attain the goals of their AMA.

**Upper Agua Fria Watershed Partnership**

The Upper Agua Fria Watershed Partnership (UAFWP) grew out of the Water Committee of the Big Bug Economic Development Alliance, Inc. The UAFWP holds monthly open meetings every first Tuesday, 10 am, at Arcosanti. The UAFWP consists of area stakeholders: Residents of the various communities, ranchers, members of community groups and public service agencies in the study area. These groups include:

- Agua Fria National Monument-BLM,
- Arcosanti-Cosanti Foundation,
- Audubon Society,
- AZ Dept. of Environmental Quality,
- AZ Dept. of Water Resources,
- AZ Fish & Game Dept.,
- AZ State Land Department,
- Big Bug-Canyon Country News,
- Big Bug Economic Dev. Alliance,
- Black Canyon City Chamber,
- Dewey-Humboldt Community Assn.,
- Mayer Area Chamber,
- Mayer Water District,
- Natural Resource Conservation Service,
- Orme School & Ranch,
- Sonoran Audubon Society,
- Southwest Strategy,
- Spring Valley Property Owners Assn.,
- U of A Cooperative Extension,
- U of A NEMO Program,
- U of A School of Renewable Resources,
- US Corps of Engineers,
- US Bureau of Land Management,
- US Bureau of Reclamation,
- US Fish & Wildlife,
- USDA Prescott National Forest,
- USDA Tonto National Forest,
- US Corps of Engineers,
- US Geological Survey,
- Yavapai County Water Resources,
- Yavapai County Flood Control District.
Mission & Goals: The UAFWP conducted a stakeholder workshop on October 16, 2000 and identified four focus areas for study and clarification: Water Quantity, Water Budget, Water Quality & Water Rights.

Activities & Accomplishments: The UAFWP was awarded $25,000 in 2000 and $25,000 in 2001 by the AZ Department of Water Resources to research watershed issues in our area. Two studies contracted with the University of Arizona have been completed:

- Additionally, the University of Arizona, under contract to the Arizona Department of Environmental Quality, is currently writing the Upper Agua Fria Watershed-Based Plan to support future Clean Water Act, 319-funded watershed restoration projects. Completion is scheduled for November of 2006, and it will be available online at the NEMO web site

Water Quality: The UAFWP is also active in dealing with water quality issues such as illegal chemical dumping and “junk” dumping (people dumping their personal trash in or near the washes & creeks). The Arizona Department of Environmental Quality has been particularly helpful in water quality issues, education, and support. The UAFWP has received $15,000 in matching grants over the last few years from the USEPA through ADEQ to help remove over 100 tons of trash from the Big Bug Creek and the Aqua Fria River with the help of dozens of volunteers.
 References

Barnett, Lloyd O., Richard H. Hawkins, and D. Phillip Guertin
2002 Reconnaissance Watershed and Hydrologic Analysis on the Upper Agua Fria Watershed, School of Renewable Resources, University of Arizona, Tucson. Available online as a PDF at the Arizona Dept. of Water Resources.

León, Elizabeth

Lenart, Melanie

Maxwell, Karen D. and Vincent P. Holbrook

McPhee, Jenna, Andrew Coomrie and Gregg Garfin

Wilson, Richard P.

 Online Resources

Important links to Arizona climate research and to the Big Bug Creek in Upper Agua Fria River Watershed.


CLIMAS: Climate Assessment for the Southwest, University of Arizona. Find informative articles and data concerning Arizona weather. 
http://www.ispe.arizona.edu/climas/

NEMO stands for Non-point Education for Municipal Officials. Find links to the Upper Agua Fria. Great maps. 
http://www.srnr.arizona.edu/nemo/index.php?page=links

