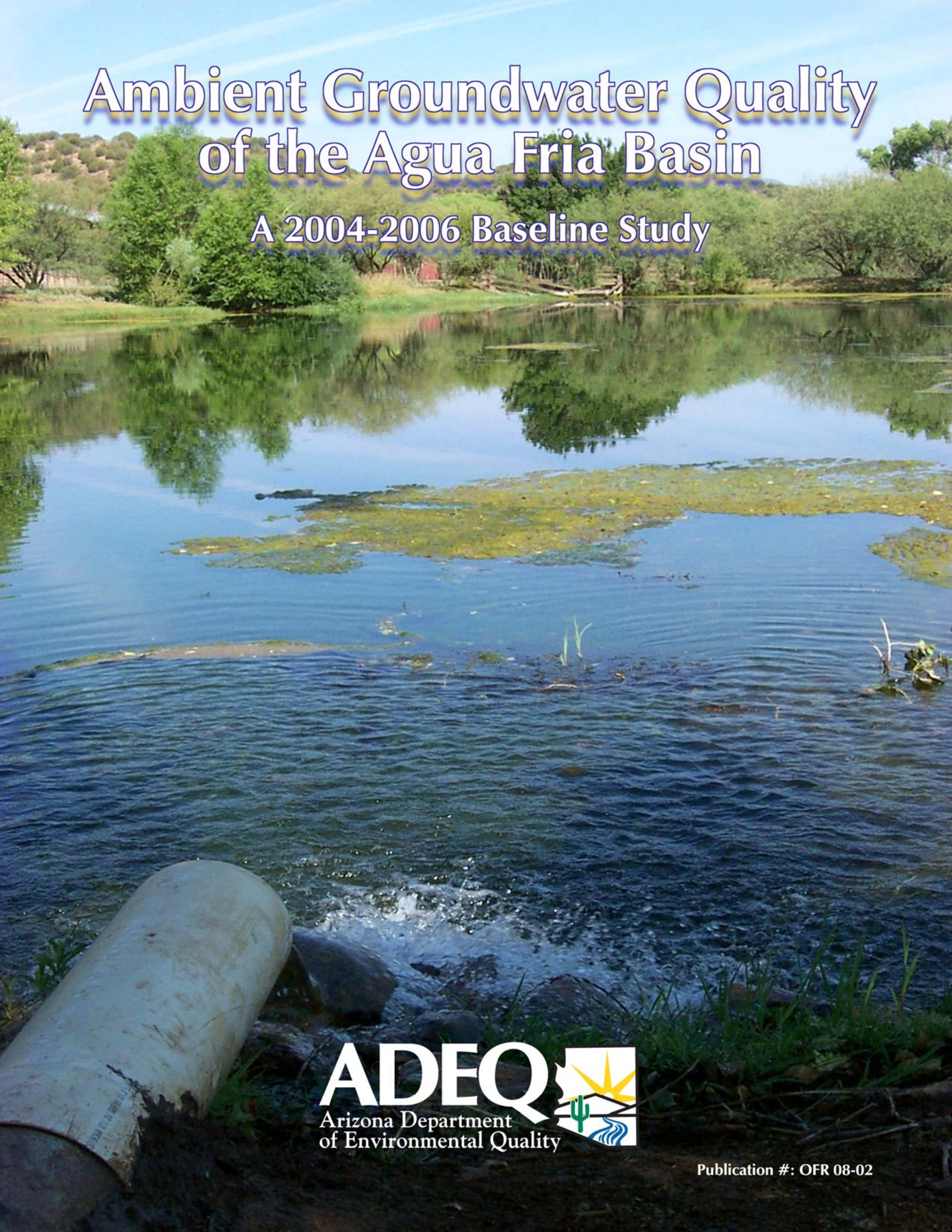
Ambient Groundwater Quality of the Agua Fria Basin

A 2004-2006 Baseline Study



ADEQ
Arizona Department of Environmental Quality

Publication #: OFR 08-02

Ambient Groundwater Quality of the Agua Fria Basin: A 2004-2006 Baseline Study

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Arizona Department of Environmental Quality
Open File Report 08-02

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Thanks:

Field Assistance:	Elizabeth Boettcher, Aiko Condon, Karyn Hanson, Jason Jones, Angela Lucci, Meghan Smart, John Woods and Wang Yu. Special recognition is extended to the many well owners who were kind enough to give permission to collect groundwater data on their property.
Photo Credits:	Douglas Towne

Report Cover: Groundwater pumped by a shallow well flows into a pond creating a bucolic scene on the U-Cross Ranch located north of the Town of Mayer. Situated in the floodplain of the Agua Fria River, the 52-foot-deep well produces 300 gallons per minute for irrigation, domestic and wildlife uses.

Other Publications of the ADEQ Ambient Groundwater Monitoring Program

ADEQ Ambient Groundwater Quality Open-File Reports (OFR):

Pinal Active Management Area	OFR 08-01, June 2007, 97 p.
Hualapai Valley Basin	OFR 07-05, March 2007, 53 p.
Big Sandy Basin	OFR 06-09, October 2006, 66 p.
Lake Mohave Basin	OFR 05-08, October 2005, 66 p.
Meadview Basin	OFR 05-01, January 2005, 29 p.
San Simon Sub-Basin	OFR 04-02, October 2004, 78 p.
Detrital Valley Basin	OFR 03-03, November 2003, 65 p.
San Rafael Basin	OFR 03-01, February 2003, 42 p.
Lower San Pedro Basin	OFR 02-01, July 2002, 74 p.
Willcox Basin	OFR 01-09, November 2001, 55 p.
Sacramento Valley Basin	OFR 01-04, June 2001, 77 p.
Upper Santa Cruz Basin	OFR 00-06, Sept. 2000, 55 p. (With the U.S. Geological Survey)
Prescott Active Management Area	OFR 00-01, May 2000, 77 p.
Upper San Pedro Basin	OFR 99-12, July 1999, 50 p. (With the U.S. Geological Survey)
Douglas Basin	OFR 99-11, June 1999, 155 p.
Virgin River Basin	OFR 99-04, March 1999, 98 p.
Yuma Basin	OFR 98-07, September, 1997, 121 p.

ADEQ Ambient Groundwater Quality Fact sheets (FS):

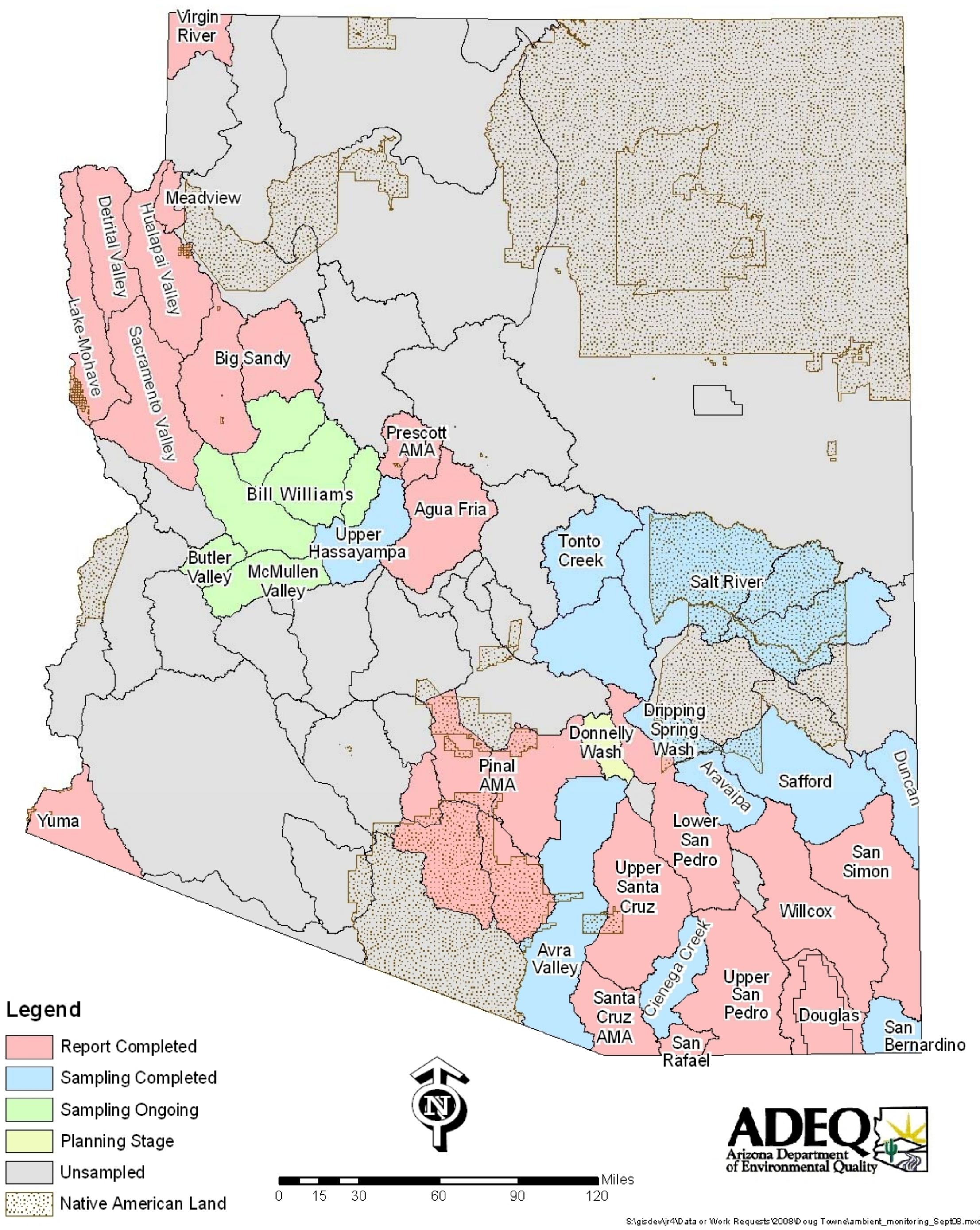
Agua Fria Basin	FS 08-02, July 2008, 4 p.
Pinal Active Management Area	FS 07-27, June 2007, 7 p.
Hualapai Valley Basin	FS 07-10, March 2007, 4 p.
Big Sandy Basin	FS 06-24, October, 2006, 4 p.
Lake Mohave Basin	FS 05-21, October 2005, 4 p.
Meadview Basin	FS 05-01, January 2005, 4 p.
San Simon Sub-basin	FS 04-06, October 2004, 4 p.
Detrital Valley Basin	FS 03-07, November 2003, 4 p.
San Rafael Basin	FS 03-03, February 2003, 4 p.
Lower San Pedro Basin	FS 02-09, August 2002, 4 p.
Willcox Basin	FS 01-13, October 2001, 4 p.
Sacramento Valley Basin	FS 01-10, June 2001, 4 p.
Yuma Basin	FS 01-03, April 2001, 4 p.
Virgin River Basin	FS 01-02, March 2001 4 p.
Prescott Active Management Area	FS 00-13, December 2000, 4 p.
Douglas Basin	FS 00-08, September 2000, 4 p.
Upper San Pedro Basin	FS 97-08, August 1997, 2 p. (With the U.S. Geological Survey)

These publications are available on-line.
Visit the ADEQ Ambient Groundwater Monitoring Program at:

www.azdeq.gov/environ/water/assessment/ambient.html

ADEQ Ambient Groundwater Monitoring Program Studies

September 2008



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Abbreviations

amsl	above mean sea level
ac-ft	acre-feet
AGF/yr	acre-feet per year
AGF	Agua Fria Groundwater Basin
ADEQ	Arizona Department of Environmental Quality
ADHS	Arizona Department of Health Services
ADWR	Arizona Department of Water Resources
ARRA	Arizona Radiation Regulatory Agency
AZGS	Arizona Geological Survey
As	arsenic
bls	below land surface
BLM	U.S. Department of the Interior Bureau of Land Management
^{o}C	degrees Celsius
$CI_{0.95}$	95 percent Confidence Interval
Cl	chloride
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
gpm	gallons per minute
hard-cal	hardness concentration calculated from calcium and magnesium concentrations
HCl	hydrochloric acid
HUC	Hydrologic Unit Code
LLD	Lower Limit of Detection
Mn	manganese
MCL	Maximum Contaminant Level
ml	milliliter
msl	mean sea level
ug/L	micrograms per liter
um	micron
uS/cm	microsiemens per centimeter at 25° Celsius
mg/L	milligrams per liter
MRL	Minimum Reporting Level
MTBE	Methyl tertiary-Butyl Ether
ns	not significant
ntu	nephelometric turbidity unit
pCi/L	picocuries per liter
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
SAR	Sodium Adsorption Ratio
SDW	Safe Drinking Water
SC	Specific Conductivity
su	standard pH units
SO_4	sulfate
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound
*	significant at $p \leq 0.05$ or 95% confidence level
**	significant at $p \leq 0.01$ or 99% confidence level
***	for information only, statistical test for this constituent invalid because detections fewer than 50 percent

Ambient Groundwater Quality of the Agua Fria Basin: A 2004-2006 Baseline Study

Abstract - In 2004-2006, the Arizona Department of Environmental Quality (ADEQ) conducted a baseline groundwater quality study of the Agua Fria basin that is located between Phoenix and Prescott in central Arizona. This groundwater basin encompasses the drainage of the Agua Fria River from below the Prescott Active Management Area to Lake Pleasant and includes the Bradshaw Mountains to the west and Bloody Basin to the east. This lightly populated basin consists primarily of federal lands (U.S. Forest Service and Bureau of Land Management), State Trust and private land. [5, 21] Minimal water development has occurred except around the communities of Mayer in the Bradshaw Mountains and Cordes Junction and Black Canyon City along Interstate 17.

To characterize regional groundwater quality, samples were collected from 46 sites located throughout the basin. Most sample sites consisted of shallow wells used for domestic uses and wells and springs used for stock watering. All sites were sampled for inorganic constituents and, at selected sites, for oxygen and deuterium isotopes (44 sites), radon (40 sites), and radiochemistry (33 sites). Nine isotope samples were also collected from surface water sources.

Analytical results indicate that of the 46 sites sampled, 14 sites (30 percent) had concentrations of at least one constituent that exceeded a health-based, federal or State water-quality standard. These enforceable standards define the maximum concentrations of constituents allowed in water supplied for drinking water purposes by a public water system and are based on a lifetime daily consumption of two liters per person.[3, 33, 36] Health-based exceedances included arsenic (12 sites), fluoride (5 sites), gross alpha (1 site), and nitrate (1 site). Elevated concentrations of arsenic, fluoride and gross alpha appear to be the result of natural sources; the nitrate exceedance appears to be impacted by septic systems. [23] At 31 sites (67 percent), concentrations of at least one constituent exceeded an aesthetics-based, federal water-quality guideline. These are unenforceable guidelines that define the maximum concentration of a constituent that can be present in drinking water without an unpleasant taste, color, odor, or other effect.[33, 36] Aesthetics-based exceedances included chloride (4 sites), fluoride (7 sites), iron (2 sites), manganese (9 sites), pH-field (1 site), sulfate (3 sites), and total dissolved solids or TDS (26 sites).

Groundwater quality in the Agua Fria basin is remarkably homogeneous in many aspects. The majority of sample sites are of *calcium-bicarbonate* or *mixed-bicarbonate* chemistry, have concentrations of TDS that typically vary between 450 to 625 milligrams per Liter (mg/L) range, have *hard*-to-*very hard* water, have low concentrations of nutrients including nitrate, and have few occurrences of trace elements other than fluoride and arsenic. [14, 18]

The exception to the uniformity of the basin's groundwater quality involves a limited subgroup of sample sites that have sodium as their major cation and are almost devoid of calcium and magnesium. The sodium chemistry sites tended to occur, interspersed with calcium or mixed chemistry sites, in the southern portion of the basin along the flanks of the Bradshaw Mountains stretching to the floodplain of the Agua Fria River. Besides very different water chemistry, the sodium chemistry sites tend to have significantly higher TDS, chloride, sulfate, fluoride and arsenic concentrations than the calcium or mixed chemistry sites (Kruskal-Wallis test, $p \leq 0.05$). The arsenic and fluoride concentrations at these sodium chemistry sites are frequently above health-based, water quality standards, often by several orders of magnitude. A sample from a well near Black Canyon City had an arsenic concentration of 2.25 mg/L, one of the highest arsenic concentrations ever found in groundwater in Arizona.

Water chemistry differences appear to be influenced by a 100-to-200 feet thick confining layer of clay and silica-rich caliche that separates the unconsolidated deposits of the Agua Fria River in the Black Canyon City area from the underlying, water-bearing schist that is also present in places north of Lake Pleasant. [21] Water produced from the schist contains elevated concentrations of TDS, fluoride and arsenic while water produced from shallower wells that only penetrate the overlying gravel, sand and silt have significantly lower concentrations of these constituents. [21]

The elevated fluoride samples all occur at sites with sodium as the dominant cation. The main control on fluoride concentrations are calcium concentrations through precipitation or dissolution of the mineral fluorite. If a source of fluoride ions is available for dissolution, large concentrations of dissolved fluoride may occur if the groundwater is depleted in calcium. [26] The elevated arsenic samples, all located in the Bradshaw Mountains, are less predictable in occurrence. Although sites with sodium as the dominant cation had the highest concentrations, health-based water quality standards were also exceeded at sites at which the dominant cation was calcium or mixed. The cause of the elevated arsenic concentrations is uncertain, although in Arizona such conditions are often associated with clay-rich sediments, volcanic rocks, geothermal environments and/or areas with gold deposits. [28]

INTRODUCTION

Purpose and Scope

The Agua Fria groundwater basin encompasses approximately 1,200 square miles north of Phoenix in central Arizona. Although most of the basin is located within Yavapai County, a small portion in the south is within Maricopa County. The basin's main drainage, the Agua Fria River, flows north to south through the basin until debouching in Lake Pleasant. Groundwater is the primary source for municipal, domestic and agricultural water supply within the basin. [6]

The Agua Fria basin was selected for study by the Arizona Department of Environmental Quality (ADEQ) Ambient Groundwater Monitoring program to characterize current (2004-2006) groundwater quality conditions because of the rapid development and population increases within the basin.

Sampling by the ADEQ Ambient Groundwater Monitoring program is authorized by legislative mandate in the Arizona Revised Statutes §49-225, specifically:

"*...ongoing monitoring of waters of the state, including...aquifers to detect the presence of new and existing pollutants, determine compliance with applicable water quality standards, determine the effectiveness of best management practices, evaluate the effects of pollutants on public health or the environment, and determine water quality trends*." [3]

Benefits of ADEQ Study – This study, which utilizes accepted sampling techniques and quantitative analyses, is designed to provide the following benefits:

- A general characterization of regional groundwater quality conditions in the Agua Fria basin identifying areas with impaired conditions. This statistically-based study is a valid and cost-effective alternative to testing all private wells in the basin for a wide variety of groundwater quality concerns.[19]

- A process for evaluating potential groundwater quality impacts arising from a variety of sources including mineralization, mining, agriculture, livestock, septic tanks, and poor well construction.

- A guide for identifying future locations of public supply wells.

- A guide for determining areas where further groundwater quality research is needed.

Physical Characteristics

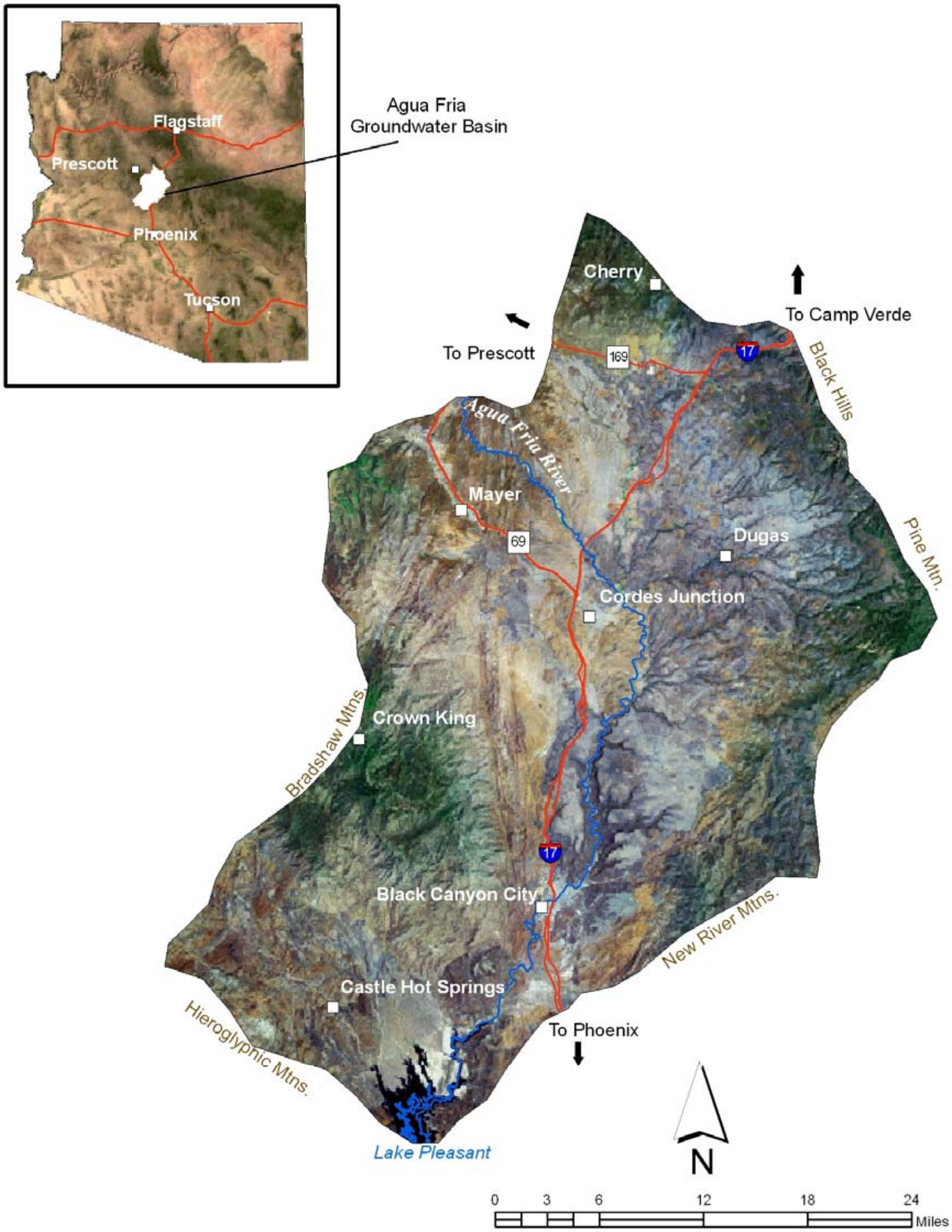
Geography – The Agua Fria basin is located within two major physiographic provinces in Arizona. The northern portion of the basin is in the Central highlands physiographic province which is characterized by a relatively narrow band of rugged mountains composed of igneous, metamorphic and sedimentary rocks. Due to the high elevations, steep gradients and predominance of hard rock, the Central highlands province has minimal water storage capabilities and high runoff as compared to most of the alluvial basins in Arizona.[6] The southern portion of the basin is located within the Basin and Range physiographic province which is characterized by broad alluvial filled basins separated by elongated, northwest-southeast trending fault-block mountain ranges.[6]

The Agua Fria basin is bounded to the north by Hickey Mountain, on the west by the Bradshaw Mountains, on the south by the Hieroglyphic Mountains and Lake Pleasant, and on the east by the Black Hills, Pine Mountain, and the New River Mountains.[6] Land surface elevations in the basin vary from 7,979 feet above mean sea level (amsl) at Union Peak in the Bradshaw Mountains to 1,570 feet amsl at Lake Pleasant. [6]

The Agua Fria basin consists of, in descending order of extent, federal land managed by the U.S. Forest Service (USFS) or the Bureau of Land Management (BLM), State Trust land, and private land.[5]

Climate – The climate of the Agua Fria basin is semiarid, characterized by hot summers and mild winters. Precipitation occurs predominantly as rain in either late summer, localized monsoon thunderstorms or widespread, low intensity winter rain that sometimes includes snow especially at higher elevations of the Bradshaw Mountains and the Black Hills. Annual precipitation near the center of the basin at the community of Cordes averages 13.5 inches. [38]

Map 1 - Agua Fria Groundwater Basin



HYDROGEOLOGY

Surface Water

The basin's main drainage is the Agua Fria River, which flows north to south before debouching into Lake Pleasant. Major tributaries to the Agua Fria River are Big Bug Creek, Silver Creek, Sycamore Creek, and Yellow Jacket Creek; all these watercourses are generally intermittent streams except for some perennial stretches where submerged bedrock forces groundwater to the surface. Nearly 80 percent of the perennial stream mileage is within the Agua Fria National Monument compared to only 6 percent in the Bradshaw Mountains. [6]

The only impaired surface water in the basin cited in the 2004 205(b) assessment is Turkey Creek for copper and lead. [4] Within the Agua Fria watershed, there are five watersheds as defined by U.S. Geological Survey Hydrologic Unit Codes (HUCs): Sycamore Creek, Big Bug Creek, Black Canyon Creek, Bishop Creek and Lake Pleasant.

The Agua Fria River was originally impounded in 1927 behind Waddell Dam; the only local water facility successfully constructed by private interests and the largest multiple arch dam in the world at the time.[32] The historic dam's functions of storing flow from the Agua Fria River and providing flood protection have been accommodated by the new Waddell Dam.[32] The historic Waddell Dam was partially dismantled and breached before it was covered with water from the enlarged Lake Pleasant.

The new Waddell Dam, located one-half mile downstream of the original impoundment, was constructed between 1985 and 1994 to increase the reservoir size to accommodate the storage of Colorado River water supplied via the Central Arizona Project. The new Waddell Dam, operated by the U.S. Bureau of Reclamation, has Colorado River water pumped into it via the Hayden-Rhodes Aqueduct during the winter months. Water will then be released from the dam for power generation and delivery to customers during the summer months. [6]

Groundwater

Rock units in the Agua Fria basin can be divided into four broad categories based on their general geologic character and their ability to yield water. [6] From youngest to oldest, the units (Map 2) include:

- basin-fill sands and gravels
- volcanic rocks
- conglomerates
- crystalline (igneous and metamorphic) rocks

Although groundwater occurs in all four rock units, the main water-bearing units are the basin-fill and conglomerates; volcanic and crystalline rocks yield only small amounts of water. [6]

Basin-fill – consisting of poorly sorted sand, silt and gravel form terraces along the Agua Fria River and its major tributaries.[21] Although well yields range from 10 to 600 gallons per minute (gpm), the basin-fill unit is thin and does not contain large quantities of groundwater in storage.[6] This unit readily transmits recharge into the underlying conglomerate.[38]

Volcanic Rocks – these provide small amounts of water to low-yield stock wells in the northeastern sections of the basin. Well yields are best from cinder beds and fractured sections of the volcanic rocks. [6] A number of seasonal springs flow form volcanic rocks in response to precipitation or snowmelt. [38]

Conglomerates – boulder-to-pebble sized conglomerate occurs from the community of Bumble Bee northward and is considered the main water-bearing unit on the basis of aerial extent. Well yields range from 10 to 50 gpm. [38]

Igneous and Metamorphic Rocks – the water bearing ability of the igneous and metamorphic rocks depends on their degree of fracturing. Most wells completed in this unit have low yields, however wells drilled into the Precambrian schist near Black Canyon City can produce up to 20 gallons per minute. Springs in the basin issue mainly from crystalline rocks. Castle Hot Springs, located in the southwestern part of the basin, discharges around 200 gallons per minute from the Precambrian rocks. [21]

Groundwater Characteristics

In the Agua Fria basin, groundwater generally moves southward in the direction of the surface water drainage. [38] Groundwater recharge occurs primarily from direct infiltration of rain, snowmelt and stream flow. [38]

Depth to water ranges from a few feet above land surface to over 400 feet below the land surface, with about 70 percent yielding water within 100 feet bls. Wells in recharge areas on ridges tend to have greater depths to water than wells in discharge areas in which groundwater may be close to land surface.[38]

Figure 1 - Agua Fria National Monument; Bloody Basin is in the background.

Figure 2 - ADEQ's Karyn Hanson collecting isotope sample From Agua Fria River near Chauncey Ranch.

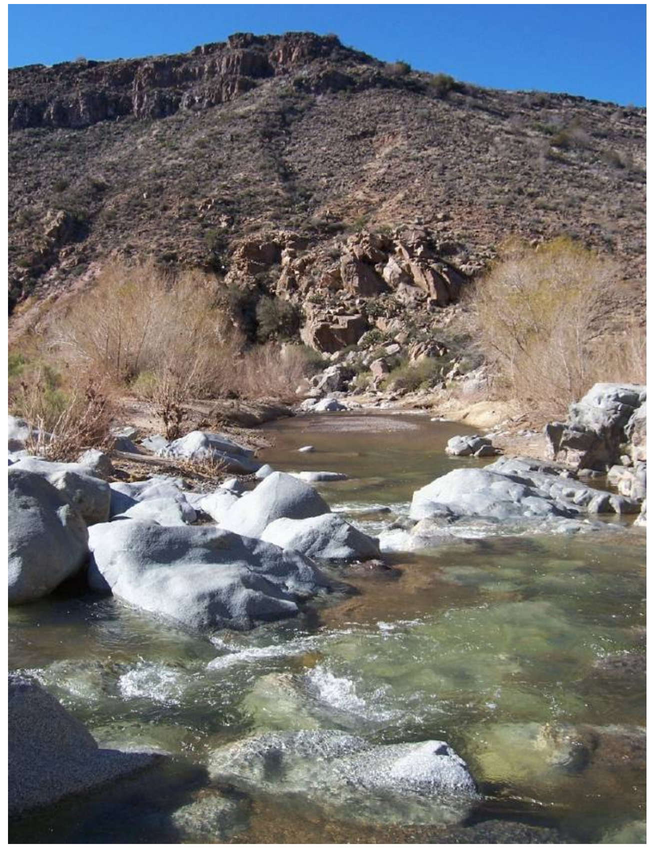


Figure 3 - Agua Fria River at the confluence of Badger Springs Wash.

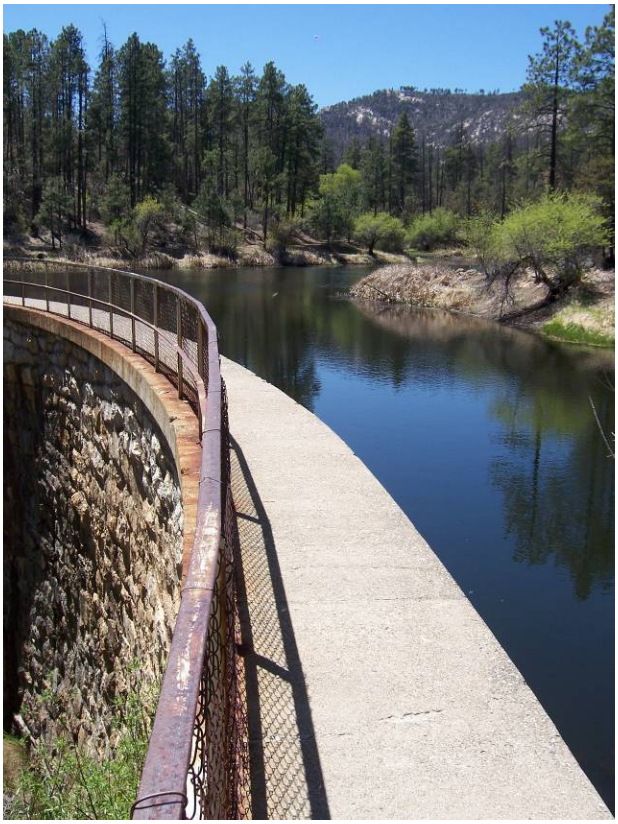
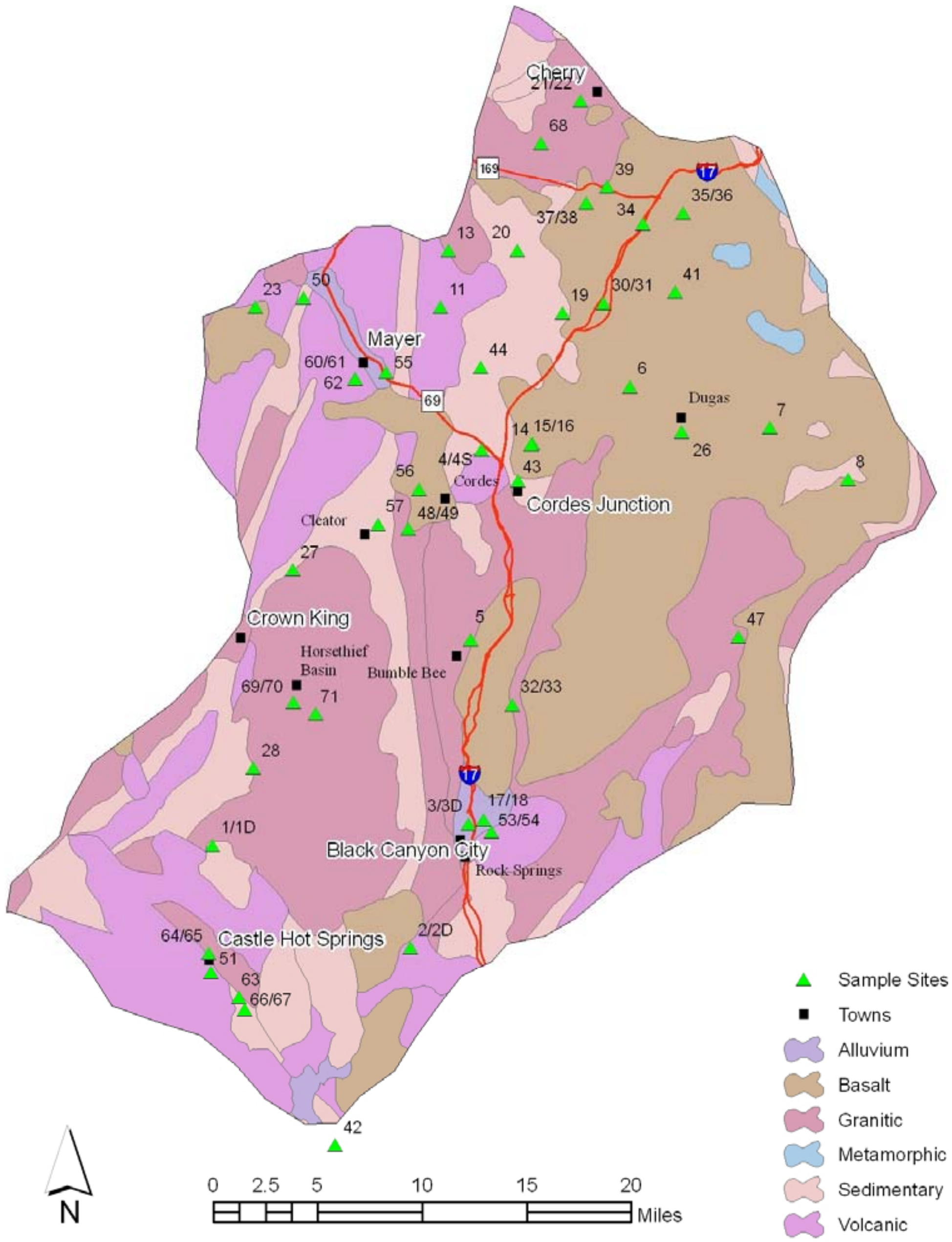


Figure 4 - Horsethief Basin Lake located in the Bradshaw Mountains is used for recreation.

Figure 5 – At the most downgradient point of the basin, the Agua Fria River is impounded by Lake Pleasant, which also stores Colorado River water.

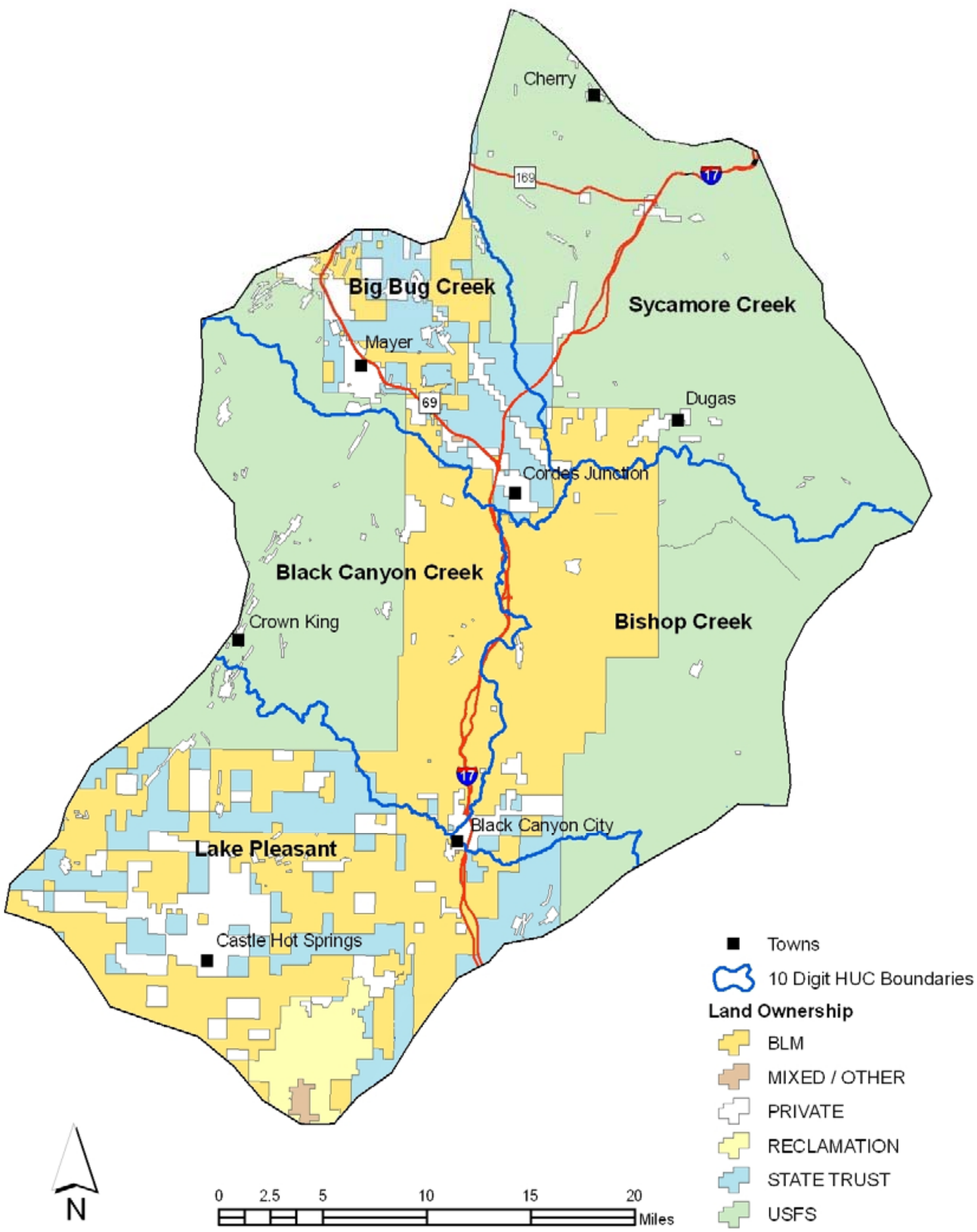
Figure 6 – Grasslands and scrub are common in the basin's uplands.

Map 2 - Agua Fria Basin Sample Sites and Geology



Source: [24]

Map 3 - Agua Fria Basin HUC Boundaries and Land Ownership



Several thermal springs are found within the study area, specifically within the Lake Pleasant HUC. Hot springs are based on a mean spring water temperature that exceeds the mean annual air temperature by 15 degrees C. The thermal springs include Henderson Ranch Spring (B-8-1-33bac) with a mean temperature of 30.3 degrees Celsius, Alkalai Spring (B-8-1-33db) with a mean temperature of 31.2 degrees Celsius, and Castle Hot Spring (B-8-1-34ccc). [41]

Development of groundwater resources is increasing in conjunction with the associated population growth of the Agua Fria basin, although no specific estimates of groundwater pumpage are available. [6]

INVESTIGATION METHODS

The ADEQ Ambient Groundwater Monitoring Program collected samples from 46 groundwater sites to characterize regional groundwater quality in the Agua Fria basin. Specifically, the following types of samples were collected:

- inorganic suites at 46 sites
- oxygen and deuterium isotopes at 44 sites
- radiochemistry at 33 sites
- radon at 30 sites
- In addition, 9 isotopes were collected and analyzed from surface water sources.

No bacteria sampling was conducted because microbiological contamination problems in groundwater are often transient and subject to a variety of changing environmental conditions including soil moisture content and temperature.[17] Ionic complexes often associated with bacteria, like nitrate and chloride, can be indicators of wastewater contamination, though the latter are more mobile in groundwater than bacteria.

Sampling Strategy

This study focused on regional groundwater quality conditions that are large in scale and persistent in time. The quantitative estimation of regional groundwater quality conditions requires the selection of sampling locations that follow scientific principles for probability sampling.[19]

Sampling followed a systematic, stratified, random site-selection approach. This is an efficient method because it requires sampling relatively few sites to make valid statistical statements about the conditions of large areas. This systematic approach requires that the selected wells be spatially distributed while the random element ensures that every well within a cell has an equal chance of being sampled. This strategy also reduces the possibility of biased well selection and assures adequate spatial coverage throughout the study area.[19]

Wells pumping groundwater for irrigation, stock and domestic purposes were sampled for this study, provided each well met ADEQ requirements. A well was considered suitable for sampling if the owner gave permission to sample, if a sampling point existed near the wellhead, and if the casing and surface seal appeared to be intact and undamaged.[7] Other factors such as information on depth of perforated casing and construction information were preferred but not essential.

For this study, of the 46 sites ADEQ personnel sampled, 17 were springs and 29 were wells. The wells used the following types of pumps: submersible (25 wells), turbine (1 well) and windmill (3 wells). Springs produce water for domestic, stock and/or wildlife use, submersible pumps produce water for municipal, domestic and/or stock use, the turbine pump produces water for irrigation use and the windmills produce water for stock use. Additional information on these groundwater sample sites is provided in Appendix A. Information compiled from the ADWR well registry is found in Appendix A. [39]

Several factors were considered to determine sample size for this study. Aside from administrative limitations on funding and personnel, this decision was based on three factors related to the conditions in the area:

- Amount of groundwater quality data already available;
- Extent to which impacted groundwater is known or believed likely to occur; and
- Hydrologic complexity and variability of the basin.[19]

Sample Collection

The sample collection methods for this study conformed to the *Quality Assurance Project Plan* (QAPP)[2] and the *Field Manual For Water Quality Sampling*.[7] While these sources should be consulted as references to specific sampling questions, a brief synopsis of the procedures involved in collecting a groundwater sample is provided.

Figure 7 – ADEQ's Jason Jones collects a sample (AGF-19) from a 200-foot deep well at the Orme School. The samples from this well met all water quality standards.

Figure 8 – ADEQ's Elizabeth Boettcher collects a split sample (AGF-66/67) from a private 280-feet-deep well located south of Castle Hot Springs.

Figure 9 - Rancher Gary Halford assists in collecting a sample from Johnson Wash Windmill located just north of State Highway 169.

Figure 10 - Dripping Spring (AGF-63) emerges from a hillside "cave" south of Castle Hot Springs. Samples collected from this spring exceeded water quality standards for arsenic and fluoride.

Figure 11 – ADEQ's John Woods collects a sample (AGF-51) from a 70-foot-deep well that has casing raised high above ground level so that floods along Castle Hot Springs Wash don't flow over and potentially contaminate the well.

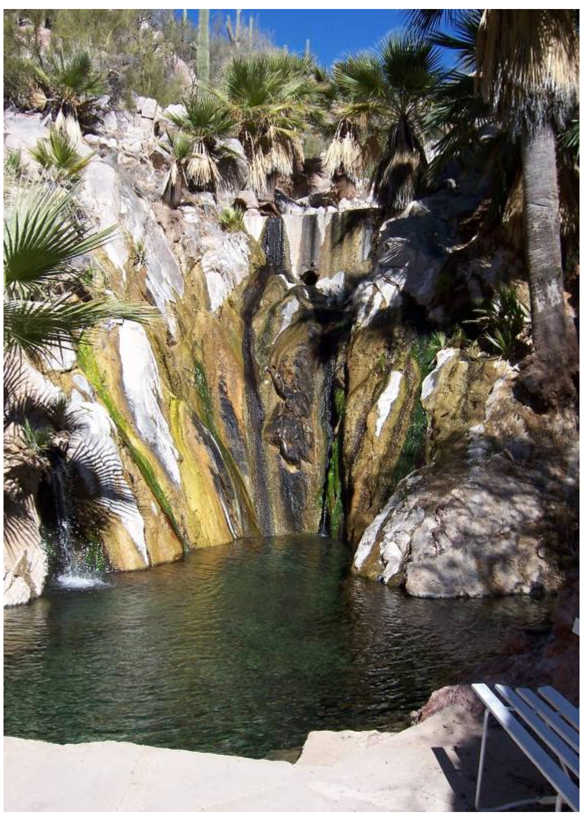


Figure 12 - The basin's most famous water source is Castle Hot Springs which flows at 200 gpm (AGF-64/65).

Figure 13 - Water is pumped from a well (AGF-32/33) deep in the Agua Fria River canyon up to the Black Mesa for use at the Sunset Rest Area along Interstate 17.

Figure 14 – ADEQ's Meghan Smart collects a sample (AGF-56) from Dripping Spring. Located near Cleator, the spring emerges from a cave and is piped many miles to several water troughs for livestock use.

Figure 15 - ADEQ's John Woods collects a water sample from a well (AGF-50) with the assistance of a solar-powered, submersible pump northwest of Mayer.

Figure 16 – Assisted by Arcosanti staff, ADEQ's Aiko Condon collects water from the John Rut Well (AGF-15/16); samples met all health-based water quality standards.

After obtaining permission from the owner to sample the well, the volume of water needed to purge the well three bore-hole volumes was calculated from well log and on-site information. Physical parameters—temperature, pH, and specific conductivity—were monitored at least every five minutes using an YSI multi-parameter instrument.

Typically to assure obtaining fresh water from the aquifer, the following methodology was used. After three bore volumes had been pumped and physical parameter measurements were stable (within 10 percent), a sample representative of the aquifer was collected from a point as close to the wellhead as possible. In certain instances, it was not possible to purge three bore volumes. In these cases, at least one bore volume was evacuated and the physical parameters had stabilized within 10 percent.

Sample bottles were filled in the following order, from most volatile to least volatile:

1. Radon
2. Isotope
3. Inorganic
4. Radiochemistry

Radon samples were collected in two unpreserved, 40-ml clear glass vials. Radon samples were carefully filled in minimize volatilization and subsequently sealed so that no headspace remained.[15]

The inorganic constituents were collected in three, 1-liter polyethylene bottles: samples to be analyzed for dissolved metals were delivered to the laboratory unfiltered and unpreserved where they were subsequently filtered into bottles using a positive pressure filtering apparatus with a 0.45 micron (µm) pore size groundwater capsule filter and preserved with 5 ml nitric acid (70 percent). Samples to be analyzed for nutrients were preserved with 2 ml sulfuric acid (95.5 percent). Samples to be analyzed for other parameters were unpreserved.[25]

Radiochemistry samples were collected in two collapsible 4-liter plastic containers and preserved with 5 ml nitric acid to reduce the pH below 2.5 su. [16]

Isotope samples were collected in a 500 ml polyethylene bottle with no preservative.

All samples were kept at 4^{o}C with ice in an insulated cooler, with the exception of the isotope and radiochemistry samples. Chain of custody procedures were followed in sample handling. Samples for this study were collected during fourteen field trips between October 2004 and April 2007.

Laboratory Methods

The inorganic and organic analyses for this study were conducted by the Arizona Department of Health Services (ADHS) Laboratory in Phoenix, Arizona. Inorganic sample splits analyses were conducted by Test America Laboratory in Phoenix, Arizona. A complete listing of inorganic parameters, including laboratory method, EPA water method and Minimum Reporting Level (MRL) for each laboratory is provided in Table 1.

Radon samples were analyzed by Radiation Safety Engineering, Inc. Laboratory in Chandler, Arizona.

Radiochemistry samples were analyzed by the Arizona Radiation Agency Laboratory in Phoenix and radiochemistry splits by the Radiation Safety Engineering, Inc. Laboratory. The following EPA SDW protocols were used: Gross alpha was analyzed, and if levels exceeded 5 picocuries per liter (pCi/L), then radium-226 was measured. If radium-226 exceeded 3 pCi/L, radium-228 was measured. If gross alpha levels exceeded 15 pCi/L initially, then radium-226/228 and total uranium were measured. [16]

Isotope samples were analyzed by the Department of Geosciences, Laboratory of Isotope Geochemistry located at the University of Arizona in Tucson, Arizona.

Table 1. ADHS/Test America/ARRA Laboratory Water Methods and Minimum Reporting Levels Used in the Agua Fria Basin Study

Constituent	Instrumentation	ADHS / Test America Water Method	ADHS / Test America Minimum Reporting Level
Physical Parameters and General Mineral Characteristics			
Alkalinity	Electrometric Titration	SM232OB	2 / 5
SC (uS/cm)	Electrometric	EPA 120.1/ SM2510B	-- / 1
Hardness	Titrimetric, EDTA	EPA 130.2 / SM2340B	10 / 1
Hardness	Calculation	Calculation	--
pH (su)	Electrometric	EPA 150.1	0.1
TDS	Gravimetric	EPA 160.1 / SM2540C	10 / 20
Turbidity (NTU)	Nephelometric	EPA 180.1	0.01 / 1
Major Ions			
Calcium	ICP-AES	EPA 200.7	1 / 2
Magnesium	ICP-AES	EPA 200.7	1 / 0.5
Sodium	ICP-AES	EPA 200.7 / EPA 273.1	1 / 5
Potassium	Flame AA	EPA 200.7 / EPA 258.1	0.5 / 1
Bicarbonate	Calculation	Calculation	2
Carbonate	Calculation	Calculation	2
Chloride	Potentiometric Titration	SM 4500 CL D	5 / 0.5
Sulfate	Colorimetric	EPA 375.4	1 / 0.5
Nutrients			
Nitrate as N	Colorimetric	EPA 353.2	0.02 / 0.1
Nitrite as N	Colorimetric	EPA 353.2	0.02 / 0.1
Ammonia	Colorimetric	EPA 350.1/ EPA 350.3	0.02 / 0.5
TKN	Colorimetric	EPA 351.2 / SM4500	0.05 / 0.5
Total Phosphorus	Colorimetric	EPA 365.4 / EPA 365.3	0.02 / 0.05

All units are mg/L except as noted
Source [15, 25]

Table 1. ADHS/Test America/ARRA Laboratory Water Methods and Minimum Reporting Levels Used in the Study--Continued

Constituent	Instrumentation	ADHS / Test America Water Method	ADHS / Del Mar Minimum Reporting Level
		Trace Elements	
Antimony	Graphite Furnace AA	EPA 200.9	0.005 / 0.004
Arsenic	Graphite Furnace AA	EPA 200.9	0.01 / 0.003
Barium	ICP-AES	EPA 200.7	0.1 / 0.01
Beryllium	Graphite Furnace AA	EPA 200.9	0.0005
Boron	ICP-AES	EPA 200.7	0.1 / 0.5
Cadmium	Graphite Furnace AA	EPA 200.9	0.001 / 0.0005
Chromium	Graphite Furnace AA	EPA 200.7	0.01 / 0.004
Copper	Graphite Furnace AA	EPA 200.7 / EPA 200.9	0.01 / 0.004
Fluoride	Ion Selective Electrode	SM 4500 F-C	0.1 / 0.1
Iron	ICP-AES	EPA 200.7	0.1 / 0.2
Lead	Graphite Furnace AA	EPA 200.9	0.005 / 0.002
Manganese	ICP-AES	EPA 200.7	0.05 / 0.02
Mercury	Cold Vapor AA	SM 3112 B / EPA 245.1	0.0002 / 0.0002
Nickel	ICP-AES	EPA 200.7	0.1 / 0.05
Selenium	Graphite Furnace AA	EPA 200.9	0.005 / 0.004
Silver	Graphite Furnace AA	EPA 200.9 / EPA 200.7	0.001 / 0.005
Thallium	Graphite Furnace AA	EPA 200.9	0.002
Zinc	ICP-AES	EPA 200.7	0.05
		Radiochemicals	
Gross alpha beta	Gas flow proportional counter	EPA 900.0	varies
Co-Precipitation	Gas flow proportional counter	EPA 00.02	varies
Radium 226	Gas flow proportional counter	EPA 903.0	varies
Radium 228	Gas flow proportional counter	EPA 904.0	varies
Uranium	Kinetic phosporimeter	EPA Laser Phosphorimetry	varies

All units are mg/L
Source [15, 16, 25]

DATA EVALUATION

Quality Assurance

Quality-assurance (QA) procedures were followed and quality-control (QC) samples were collected to quantify data bias and variability for the Agua Fria basin study. The design of the QA/QC plan was based on recommendations included in the *Quality Assurance Project Plan* (*QAPP*) and *the Field Manual For Water Quality Sampling*.[2, 7]

Types and numbers of QC samples collected for this study are as follows: inorganic: (6 duplicates, 11 splits, and 5 blanks), radiochemical: (no QC samples), radon: (5 duplicates), and isotope: (4 duplicates). Based on the QA/QC results, sampling procedures and laboratory equipment did not significantly affect the groundwater quality samples of this study.

Blanks – Six equipment blanks for inorganic analyses were collected to ensure adequate decontamination of sampling equipment, and that the de-ionized water was not impacting the groundwater quality sampling.[7] Equipment blank samples for major ion and nutrient analyses were collected by filling unpreserved and sulfuric acid preserved bottles with de-ionized water. Equipment blank samples for trace element analyses were collected with de-ionized water that was subsequently filtered and preserved with nitric acid at the ADHS laboratory.

In the 6 equipment blanks, turbidity in 5 samples, SC was detected in 4 samples, total phosphorus in 3 samples, and nitrate in 1 sample. Systematic contamination was judged to occur if more than 50 percent of the equipment blank samples contained measurable quantities of a particular groundwater quality constituent.[19]

For turbidity, equipment blanks had a mean level (0.042 ntu) less than 1 percent of the turbidity median level for the study. Testing indicates turbidity is present at 0.01 ntu in the de-ionized water supplied by the ADHS laboratory, and levels increase with time due to storage in ADEQ carboys.[25]

Similarly for SC, equipment blanks had a mean (4.2 uS/cm) which was less than 1 percent of the SC mean concentration for the study. The SC detections may be explained in two ways: water passed through a de-ionizing exchange unit will normally have an SC value of at least 1 uS/cm, and carbon dioxide from the air can dissolve in de-ionized water with the resulting bicarbonate and hydrogen ions imparting the observed conductivity.[25]

Total phosphorus had a mean concentration of 0.035 mg/L while the single detection of nitrate (as nitrogen) occurred at a concentration of 0.02 mg/L.

Duplicate Samples - Duplicate samples are identical sets of samples collected from the same source at the same time and submitted to the same laboratory. Different sample numbers and sample times are used so that the laboratory is not aware that the samples are duplicates. Data from duplicate samples provide a measure of variability from the combined effects of field and laboratory procedures.[7]

Duplicate samples were collected from sampling sites that were believed to have elevated constituent concentrations as judged by field SC values or pH values. Six duplicate samples were collected in this study.

Analytical results indicate that of the 23 constituents that had concentrations above the MRL, the maximum variation between duplicates was less than 5 percent (Table 2). The only exceptions were phosphorus (63 percent), copper (60 percent), turbidity (45 percent), fluoride (38 percent), chloride (36 percent), TKN (33 percent), zinc (12 percent) and sulfate (10 percent).

Duplicates for phosphorus, copper, turbidity, TKN, zinc and sulfate had fairly minor concentration differences; only chloride and fluoride results involving one set of duplicates (AGF-3 and AGF-3D) was considered significant. This set of duplicates had chloride concentrations of 160 mg/L and 76 mg/L (or a 36 percent difference) and fluoride concentrations of 2.9 mg/L and 6.5 mg/L (or a 38 percent difference). The ADEQ hydrologist who began the Agua Fria study did not, upon receiving these results, contact the lab to rerun these two tests. A later request to examine the paperwork associated with these tests could locate no apparent errors, though an error in making dilutions was surmised.[25] Using the major ion balance as a guide, the chloride concentration of 76 mg/L was used. No assessment could be made which fluoride result was correct by this means so the mean of the two results were used.

The median variation between duplicates was less than 4 percent except with TKN (22 percent) and turbidity (11 percent).

Isotope (7 duplicates) samples showed less than a 1 percent maximum variation between duplicates. Radon (5 duplicates) had a 36 percent maximum variation and a 4 percent median variation.

Table 2. Summary Results of Agua Fria Basin Duplicate Samples from the ADHS Laboratory

Parameter	Number	Difference in Percent			Difference in Concentrations		
		Minimum	Maximum	Median	Minimum	Maximum	Median
Physical Parameters and General Mineral Characteristics							
Alk., Total	6	0 %	1 %	0 %	0	10	0
SC (uS/cm)	6	0 %	3 %	0 %	0	40	0
Hardness	6	0 %	1 %	0 %	0	10	0
pH (su)	6	0 %	1 %	0 %	0	0.1	0
TDS	6	0 %	2 %	1 %	0	20	10
Turb. (ntu)	6	0 %	45 %	11 %	0	11	0.01
Major Ions							
Bicarbonate	6	0 %	4 %	0 %	0	10	0
Calcium	6	0 %	2 %	0 %	0	1	0
Magnesium	6	0 %	1 %	0 %	0	1	0
Sodium	6	0 %	2 %	0 %	0	10	0
Potassium	5	0 %	5 %	4 %	0	0.6	0.2
Chloride	6	0 %	36 %	0 %	0	84	0
Sulfate	6	0 %	10 %	1 %	0	40	1
Nutrients							
Nitrate (as N)	3	0 %	3 %	1 %	0	0.1	0.0.004
Phosphorus	3	2 %	63 %	3 %	0.003	0.38	0.003
TKN	5	1 %	33 %	22 %	0.01	0.07	0.033
Trace Elements							
Arsenic	3	0 %	1 %	0 %	0	0.001	0
Barium	2	0 %	5 %	-	0	0.01	-
Boron	2	1 %	2 %	-	0.01	0.1	-
Copper	1	-	-	60 %	-	-	0.098
Fluoride	6	0 %	38 %	0 %	0	3.6	0
Manganese	2	0 %	1 %	-	0	0.02	-
Zinc	1	-	-	12 %	-	-	0.05

All concentration units are mg/L except as noted with certain physical parameters.
Boron was detected near the MRL in one duplicate sample (0.15 mg/L) and not detected in the other duplicate sample (< 0.10 mg/L).

Split Samples - Split samples are identical sets of samples collected from the same source at the same time that are submitted to two different laboratories to check for laboratory differences.[7] Eleven inorganic split samples were collected and analytical results were evaluated by examining the variability in constituent concentrations in terms of absolute levels and as the percent difference.

Analytical results indicate that of the 36 constituents, only 21 had concentrations above MRLs for both ADHS and Test America (formerly Del Mar) laboratories (Table 3).

Three split samples involving TKN (AGF-60/61), sulfate (AGF-2/2S), and chloride (AGF-2/2S) had major differences in which each Test America analysis was deemed flawed and not used in this study. TKN results were 0.13 mg/L (reported by the ADHS lab) and 15 mgL (reported by the Test America lab); both laboratories examined their sample paperwork and confirmed their results. However, the Test America result was deemed unlikely to occur in natural water and not further used. Similarly, chloride concentrations of 25 mg/L (by ADHS laboratory) and 2.0 mg/L (by Test America) and sulfate concentrations 48 mg/L (by ADHS laboratory) and 3.8 mg/L (by Test America laboratory) were found in split samples collected when another investigator was running the Agua Fria study. A later request to examine the paperwork associated with these tests could locate no apparent errors. Using the major ion balance as a guide, the concentrations determined by the ADHS were used and the Test America concentrations were deemed incorrect.

Split samples were also evaluated using the non-parametric Sign test to determine if there were any significant ($p \leq 0.05$) differences between ADHS laboratory and Test America laboratory analytical results.[19] Results of the Sign test revealed significant differences involving three constituents: potassium, hardness and pH-lab. Hardness concentrations and pH-values reported by the ADHS laboratory were greater than those reported by the Test America laboratory; potassium exhibited the opposite pattern. Another ADEQ ambient groundwater quality study in the Pinal Active Management Area during 2005-2006 found a similar pattern with significantly lower potassium concentrations reported by the ADHS laboratory.

Split results reported by Test America laboratory detected fluoride, nitrate and TKN (twice) were detected in the Test America sample near the MRL and not detected in the ADHS sample; the opposite pattern occurred with one copper sample which was detected in the ADHS sample near the MRL and not detected in the Test America sample.

Based on the results of blanks, duplicates and the split sample collected for this study, no significant QA/QC problems were apparent with the groundwater quality collected for this study.

Data Validation

The analytical work for this study was subjected to the following five QA/QC correlations.[19, 20]

Cation/Anion Balances - In theory, water samples exhibit electrical neutrality. Therefore, the sum of milliequivalents per liter (meq/L) of cations must equal the sum of meq/L of anions. However, this neutrality rarely occurs due to unavoidable variation inherent in all water quality analyses. Still, if the cation/anion balance is found to be within acceptable limits, it can be assumed there are no gross errors in concentrations reported for major ions.[20] Overall, cation/anion meq/L balances of Agua Fria samples were significantly correlated (regression analysis, $p \leq 0.01$) and were within acceptable limits (90 - 110 percent).

SC/TDS - The SC and TDS concentrations measured by contract laboratories were significantly correlated as were field-SC and TDS concentrations (regression analysis, $r = 0.99$, $p \leq 0.01$). Typically, the TDS concentration in mg/L should be from 0.55 to 0.75 times the SC in µS/cm for groundwater up to several thousand TDS mg/L.[20]

Groundwater in which the ions are mostly bicarbonate and chloride will have a multiplication factor near the lower end of this range and groundwater high in sulfate may reach or even exceed the higher factor. The relationship of TDS to SC becomes undefined for groundwater with very high or low concentrations of dissolved solids.[20]

Hardness - Concentrations of laboratory-measured and calculated values of hardness were significantly correlated (regression analysis, $r = 0.99$, $p \leq 0.01$). Hardness concentrations were calculated using the following formula: [(Calcium x 2.497) + (Magnesium x 4.118)].[20]

SC - The SC measured in the field using a YSI meter at the time of sampling was significantly correlated with the SC measured by contract laboratories (regression analysis, $r = 0.99$, $p \leq 0.01$).

Table 3. Summary Results of Agua Fria Basin Split Samples from ADHS/Test America Labs

Parameter	Number	Difference in Percent		Difference in Levels		Significance
		Minimum	Maximum	Minimum	Maximum	
Physical Parameters and General Mineral Characteristics						
Alkalinity, total	11	0 %	13 %	0	200	ns
SC (uS/cm)	11	0 %	5 %	0	300	ns
Hardness	9	0 %	4 %	0	60	ADHS > TA
pH (su)	11	1 %	6 %	0.11	0.84	ADHS > TA
TDS	11	0 %	8 %	0	200	ns
Turbidity (ntu)	2	18 %	23 %	1.2	9	ns
Major Ions						
Calcium	11	0 %	6 %	0	10	ns
Magnesium	11	0 %	9 %	0	4	ns
Sodium	11	0 %	24 %	0	19	ns
Potassium	11	0 %	29 %	0	1.8	TA > ADHS
Chloride	11	0 %	85%	0	30	ns
Sulfate	11	0 %	85 %	0	44.2	ns
Nutrients						
Nitrate as N *	7	3 %	75 %	0.1	1.38	ns
Phosphorus, T.	3	6 %	69 %	0.008	0.09	ns
TKN *	4	15 %	98 %	0.15	14.87	ns
Trace Elements						
Arsenic	4	2 %	11 %	0.001	0.1	ns
Barium	1	3 %	3 %	0.01	0.01	ns
Chromium	1	21 %	21 %	0.006	0.006	ns
Fluoride *	10	0 %	23 %	0	0.18	ns
Iron	1	4 %	4 %	0.02	0.02	ns
Zinc	4	0 %	24 %	0	0.1	ns

All units are mg/L except as noted

ns = No significant ($p \leq 0.05$) difference between labs

* Fluoride, nitrate and TKN (twice) were detected in the Test America sample near the MRL and not detected in the ADHS sample; the opposite pattern occurred with one copper sample which was detected in the ADHS sample near the MRL and not detected in the Test America sample.

pH - The pH value is closely related to the environment of the water and is likely to be altered by sampling and storage.[20] Thus, the pH values measured in the field using a YSI meter at the time of sampling were not significantly correlated with laboratory pH values (regression analysis, r = 0.15).

Temperature / GW Depth /Well Depth – Groundwater temperature measured in the field was compared to groundwater depth and well depth. Groundwater temperature should increase with depth, approximately 3 degrees Celsius with every 100 meters or 328 feet.[9] However, because of the large number of shallow wells in the basin, temperature was not significantly correlated with either groundwater depth (r = 0.37) and well depth (r = 0.27).

The analytical work conducted for this study was considered valid based on the quality control samples and the QA/QC correlations.

Statistical Considerations

Various methods were used to complete the statistical analyses for the groundwater quality data of this study. All statistical tests were conducted using SYSTAT software.[37]

Data Normality: Data associated with 29 constituents were tested for non-transformed normality using the Kolmogorov-Smirnov one-sample test with the Lilliefors option.[10] Results of this test revealed that 7 of the 29 constituents (or 24 percent) examined were normally distributed. These normally distributed parameters constituents included well depth, temperature, pH-field, hardness, calculated hardness, calcium and deuterium. Results of the log-transformed test revealed that 15 of the 27 constituents (or 55 percent, oxygen and deuterium are negative numbers and could not be log-transformed) examined were normally distributed. These normally distributed constituents included groundwater depth, well depth, pH-field, hardness, calculated hardness, turbidity, calcium, sodium, potassium, total alkalinity, bicarbonate, chloride, sulfate, radon and gross beta.

Spatial Relationships: The non-parametric Kruskal-Wallis test using untransformed data was applied to investigate the hypothesis that constituent concentrations from groundwater sites having different water sources were the same. The Kruskal-Wallis test uses the differences, but also incorporates information about the magnitude of each difference.[37] The null hypothesis of identical mean values for all data sets within each test was rejected if the probability of obtaining identical means by chance was less than or equal to 0.05. Comparisons conducted using the Kruskal Wallis test include water chemistries, rock types and watersheds.

If the null hypothesis was rejected for any of the tests conducted, the Tukey method of multiple comparisons on the ranks of data was applied. The Tukey test identified significant differences between constituent concentrations when compared to each possibility with each of the tests.[19]

Both the Kruskal-Wallis and Tukey tests are not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.[19] The Kruskal-Wallis tests were applied to arsenic and TKN even though the result was not considered statistically valid in order to highlight possible significant differences. Highlights of these statistical tests are summarized in the groundwater quality section. The Kruskal-Wallis test was not calculated for trace parameters or nutrients rarely detected, such as ammonia, antimony, barium, beryllium, cadmium, carbonate, chromium, copper, iron, lead, manganese, mercury, nickel, nitrite, phenolphthalein alkalinity, radium, selenium, silver, thallium, total phosphorus, uranium and zinc.

Correlation between Constituent Concentrations: In order to assess the strength of association between constituents, their concentrations were compared to each other using the Pearson Correlation Coefficient test. The Pearson correlation coefficient varies between -1 and +1; with a value of +1 indicating that a variable can be predicted perfectly by a positive linear function of the other, and vice versa. A value of -1 indicates a perfect inverse or negative relationship. The results of the Pearson Correlation Coefficient test were then subjected to a probability test to determine which of the individual pair wise correlations were significant.[37] The Pearson test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.[19] Consequently, Pearson Correlation Coefficients were not calculated for the same constituents as in spatial relationships.

GROUNDWATER SAMPLING RESULTS

Water Quality Standards/Guidelines

The ADEQ ambient groundwater monitoring program characterizes regional groundwater quality. An important determination ADEQ makes concerning the collected samples is how the analytical results compare to various drinking water quality standards. ADEQ used three sets of drinking water standards to evaluate the suitability of groundwater in the basin for drinking water use. These standards reflect the best current scientific and technical judgment available on the suitability of water for drinking water use:

- Federal Safe Drinking Water (SDW) Primary Maximum Contaminant Levels (MCLs). These enforceable health-based standards establish the maximum concentration of a constituent allowed in water supplied by public systems.[33, 36]

- State of Arizona Aquifer Water Quality Standards. These apply to aquifers that are classified for drinking water protected use.[3] All aquifers within Arizona are currently classified and protected for drinking water use unless otherwise reclassified. To date no aquifers have been reclassified. These enforceable State standards are almost identical to the federal Primary MCLs.

- Federal SDW Secondary MCLs. These non-enforceable aesthetics-based guidelines define the maximum concentration of a constituent that can be present without imparting unpleasant taste, color, odor, or other aesthetic effects on the water.[33, 36]

Health-based drinking water quality standards (such as Primary MCLs) are based on a lifetime consumption of two liters of water per day and, as such, are chronic not acute standards.[33] Exceedances of specific constituents for each groundwater site is found in Appendix B.

Agua Fria Basin Sites - Of the 46 sites sampled for the Agua Fria basin study, 11 (24 percent) met all SDW Primary and Secondary MCLs.

Health-based Primary MCL water quality standards and State aquifer water quality standards were exceeded at 14 of 46 sites (30 percent; Map 4; Table 4). Constituents exceeding Primary MCLs include arsenic (12 sites), fluoride (5 sites), gross alpha (1 site), and nitrate (1 site). Potential health effects of these chronic Primary MCL exceedances are provided in Table 4.[33, 36]

Aesthetics-based Secondary MCL water quality guidelines were exceeded at 31 of 46 sites (67 percent; Map 4; Table 5). Constituents above Secondary MCLs include chloride (4 sites), fluoride (7 sites), iron (2 sites), manganese (9 sites), pH (1 site), sulfate (3 sites), and TDS (26 sites). Potential impacts of these Secondary MCL exceedances are provided in Table 5.[33, 36]

Radon is a naturally occurring, intermediate breakdown product from the radioactive decay of uranium-238 to lead-206.[12] Radon has a proposed drinking water standard of 300 picocuries per liter (pCi/L).[12] Of the 30 sites sampled for radon, 10 sites exceeded the proposed 300 pCi/L standard.

Suitability for Irrigation

The groundwater at each sample site was assessed as to its suitability for irrigation use based on salinity and sodium hazards. Excessive levels of sodium are known to cause physical deterioration of the soil and vegetation.[35] Irrigation water may be classified using specific conductivity (SC) and the Sodium Adsorption Ratio (SAR) in conjunction with one another.[35] Groundwater sites in the Agua Fria basin display a wide range of irrigation water classifications with salinity hazards generally greater than sodium hazards. The 46 sample sites are divided into the following salinity hazards: low (0), medium (21), high (22), and very high (3) and the following sodium or alkali hazards: low (40), medium (3), high (1), and very high (2).

Analytical Results

Analytical inorganic and radiochemistry results of the 46 Agua Fria basin sample sites are summarized (Table 6) using the following indices: minimum reporting levels (MRLs), number of sample sites over the MRL, upper and lower 95 percent confidence intervals ($CI_{95\%}$), median, and mean. Confidence intervals are a statistical tool which indicates that 95 percent of a constituent's population lies within the stated confidence interval.[19] Surface water quality data (2001-2002) from the Agua Fria River at Cordes Junction is included. Specific constituent information for each groundwater site is found in Appendix B.

Map 4 - Agua Fria Basin Ground Water Quality Status

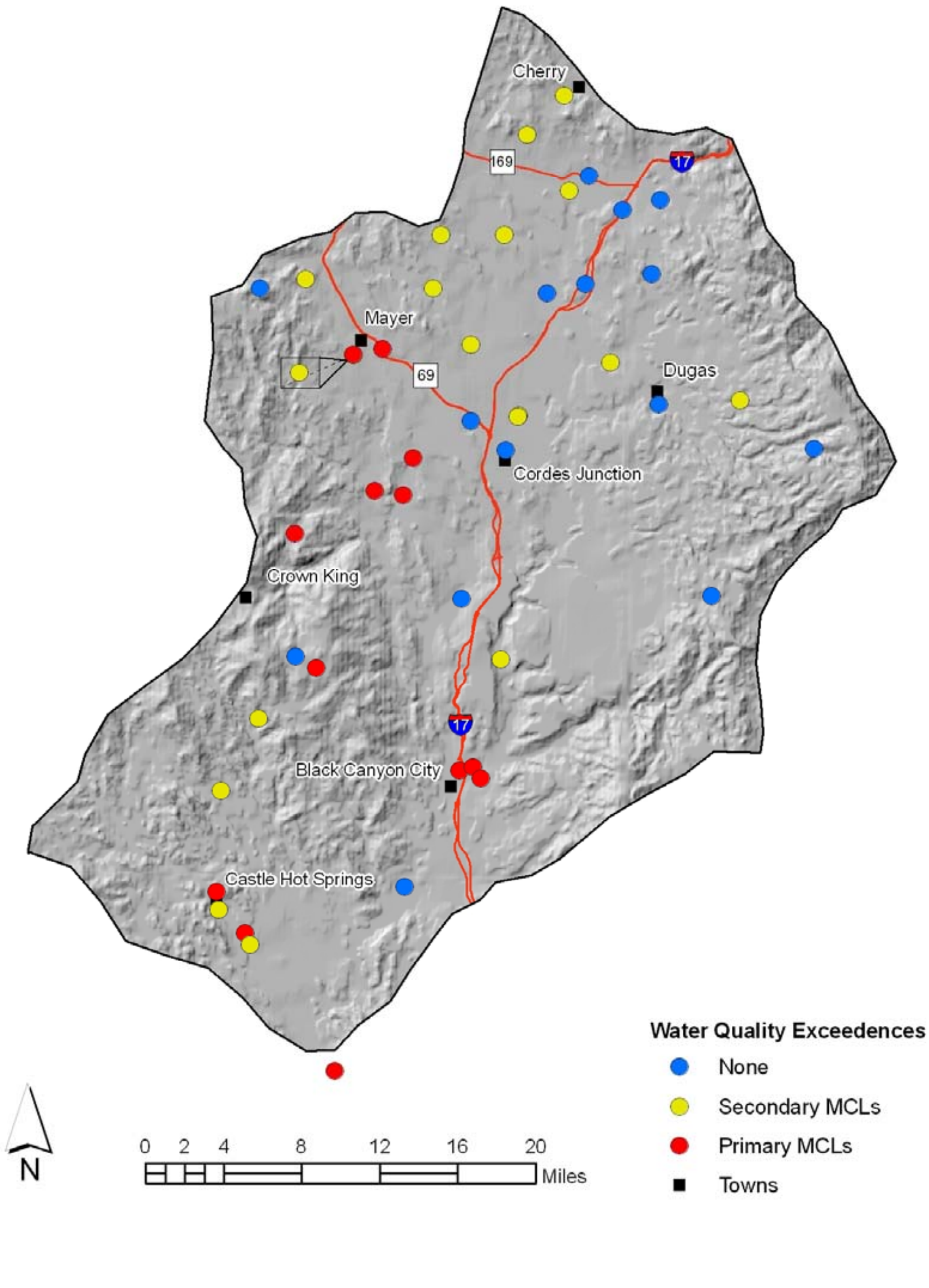


Table 4. Agua Fria Basin Sites Exceeding Health-Based (Primary MCL) Water Quality Standards

Constituent	Primary MCL	Number of Sites Exceeding Primary MCL	Concentration Range of Exceedances	Potential Health Effects of MCL Exceedances *
Nutrients				
Nitrite (NO_2-N)	1.0	0	-	
Nitrate (NO_3-N)	10.0	**1**	19	Methemoglobinemia
Trace Elements				
Antimony (Sb)	0.006	0	-	
Arsenic (As)	0.01	**12**	0.010 – 2.25	Dermal and nervous system toxicity
Barium (Ba)	2.0	0	-	
Beryllium (Be)	0.004	0	-	
Cadmium (Cd)	0.005	0	-	
Chromium (Cr)	0.1	0	-	
Copper (Cu)	1.3	0	-	
Fluoride (F)	4.0	**5**	4.1 – 10	Skeletal damage
Lead (Pb)	0.015	0	-	
Mercury (Hg)	0.002	0	-	
Nickel (Ni)	0.1	0	-	
Selenium (Se)	0.05	0	-	
Thallium (Tl)	0.002	0	-	
Radiochemistry Constituents				
Gross Alpha	15	**1**	23	Cancer
Ra-226+Ra-228	5	0	-	
Radon **	300	**10**	338 - 1032	Cancer
Uranium	30	0	-	

All units are mg/L except gross alpha, radium-226+228 and radon (pCi/L), and uranium (ug/L).

* Health-based drinking water quality standards are based on a lifetime consumption of two liters of water per day over a 70-year life span.[40, 44]

** Proposed EPA Safe Drinking Water Act standard for radon in drinking water.

Table 5. Agua Fria Basin Sites Exceeding Aesthetics-Based (Secondary MCL) Water Quality Standards

Constituents	Secondary MCL	Number of Sites Exceeding Secondary MCLs	Concentration Range of Exceedances	Aesthetic Effects of MCL Exceedances
		Physical Parameters		
pH - field	6.5 to 8.5	**1**	8.97	Corrosive water
		General Mineral Characteristics		
TDS	500	**26**	500 – 2,150	Unpleasant taste
		Major Ions		
Chloride (Cl)	250	**4**	250 – 660	Salty taste
Sulfate (SO_4)	250	**3**	255 – 370	Rotten-egg odor, unpleasant taste and laxative effect
		Trace Elements		
Fluoride (F)	2.0	**7**	2.2 – 20	Mottling of teeth enamel
Iron (Fe)	0.3	**2**	0.61 – 1.6	Rusty color, reddish stains and metallic tastes
Manganese(Mn)	0.05	**9**	0.05 – 1.0	Black stains and bitter taste
Silver (Ag)	0.1	0	-	-
Zinc (Zn)	5.0	0	-	-

All units mg/L except pH is in standard units (su). Source: [20, 33, 36]

Table 6. Summary Statistics for Agua Fria Basin Groundwater Quality Data

Constituent	Minimum Reporting Limit (MRL)	Number of Samples Over MRL	Lower 95% Confidence Interval	Median	Mean	Upper 95% Confidence Interval	Agua Fria River at Cordes Jct
Physical Parameters							
Temperature (C)	N/A	43	17.1	18.2	19.0	20.8	17.3
pH-field (su)	N/A	46	7.33	7.35	7.45	7.57	8.15
pH-lab (su)	0.01	46	7.82	7.98	7.91	8.00	8.28
Turbidity (ntu)	0.01	46	1.17	0.51	3.96	6.76	3.79
General Mineral Characteristics							
T. Alkalinity	2.0	46	289	310	348	407	315
Phenol. Alk.	2.0	2	> 50% of data below MRL				
SC-fld (uS/cm)	N/A	46	781	855	974	1166	1005
SC-lab (uS/cm)	N/A	46	809	860	1005	1200	1015
Hardness-lab	10.0	46	279	310	332	385	413
TDS	10.0	46	505	540	625	746	643
Major Ions							
Calcium	5.0	46	68	76	81	95	92
Magnesium	1.0	46	23	25	30	36	43
Sodium	5.0	46	50	42	91	132	62
Potassium	0.5	46	2.2	2.1	3.1	4.0	2.4
Bicarbonate	2.0	46	353	380	428	504	383
Carbonate	2.0	2	> 50% of data below MRL				
Chloride	1.0	46	47	46	84	122	69
Sulfate	10.0	46	66	61	94	122	130
Nutrients							
Nitrate (as N)	0.02	46	0.6	0.5	1.5	2.4	ND
Nitrite (as N)	0.02	1	> 50% of data below MRL				
TKN	0.05	28	0.09	0.08	0.15	0.22	-
T. Phosphorus	0.02	33	0.04	0.04	0.06	0.08	0.07

Table 6. Summary Statistics for Agua Fria Basin Groundwater Quality Data—Continued

Constituent	Minimum Reporting Limit (MRL)	Number of Samples Over MRL	Lower 95% Confidence Interval	Median	Mean	Upper 95% Confidence Interval	Agua Fria River at Cordes Jct
Trace Elements							
Antimony	N/A	0		> 50% of data below MRL			-
Arsenic	N/A	17		> 50% of data below MRL			-
Barium	0.01	10		> 50% of data below MRL			-
Beryllium	0.01	1		> 50% of data below MRL			-
Boron	2.0	7		> 50% of data below MRL			-
Cadmium	2.0	0		> 50% of data below MRL			-
Chromium	N/A	2		> 50% of data below MRL			-
Copper	N/A	3		> 50% of data below MRL			-
Fluoride	10.0	45	0.48	0.31	1.13	1.77	0.24
Iron	10.0	6		> 50% of data below MRL			-
Lead	5.0	0		> 50% of data below MRL			-
Manganese	1.0	9		> 50% of data below MRL			-
Mercury	5.0	1		> 50% of data below MRL			-
Nickel	0.5	0		> 50% of data below MRL			-
Selenium	2.0	0		> 50% of data below MRL			-
Silver	2.0	0		> 50% of data below MRL			-
Thallium	1.0	0		> 50% of data below MRL			-
Zinc	10.0	8		> 50% of data below MRL			-
Radiochemical Constituents							
Radon*	Varies	30	201	221	286	371	-
Gross Alpha*	Varies	24	1.6	1.6	3.4	5.1	-
Gross Beta*	Varies	30	2.8	2.8	4.5	6.2	-
Uranium**	Varies	2			> 50% of data below MRL		
Isotopes							
Oxygen***	Varies	46	- 9.7	- 9.0	- 8.8	- 7.8	-
Hydrogen ***	Varies	46	- 70.0	- 67.0	- 67.9	- 65.9	-

All units mg/L except where noted or * = pCi/L, ** = ⊙g/L, and *** = 0/00

GROUNDWATER COMPOSITION

General Summary

Groundwater in the Agua Fria basin was predominantly of calcium or mixed-bicarbonate chemistry (Map 5) (Figure 17). This cluster includes mixed-bicarbonate (18 sites), calcium-bicarbonate (15 sites), mixed-mixed (4 sites), calcium-mixed (2 sites) and mixed-chloride (1 site). The remaining six samples had a dramatically different chemistry. The chemistry of these six sites included sodium-bicarbonate (4 sites), sodium-chloride (1 site) and sodium-mixed (1 site) (Figure 18 – middle diagram).

Of the 46 sample sites in the Agua Fria basin, the dominant cation was calcium at 17 sites and sodium at 6 sites; at 23 sites there was no dominant cation (Figure 18 – left diagram). The dominant anion was bicarbonate at 37 sites and chloride at 2 sites; at 7 sites there was no dominant anion (Figure 18 – right diagram).

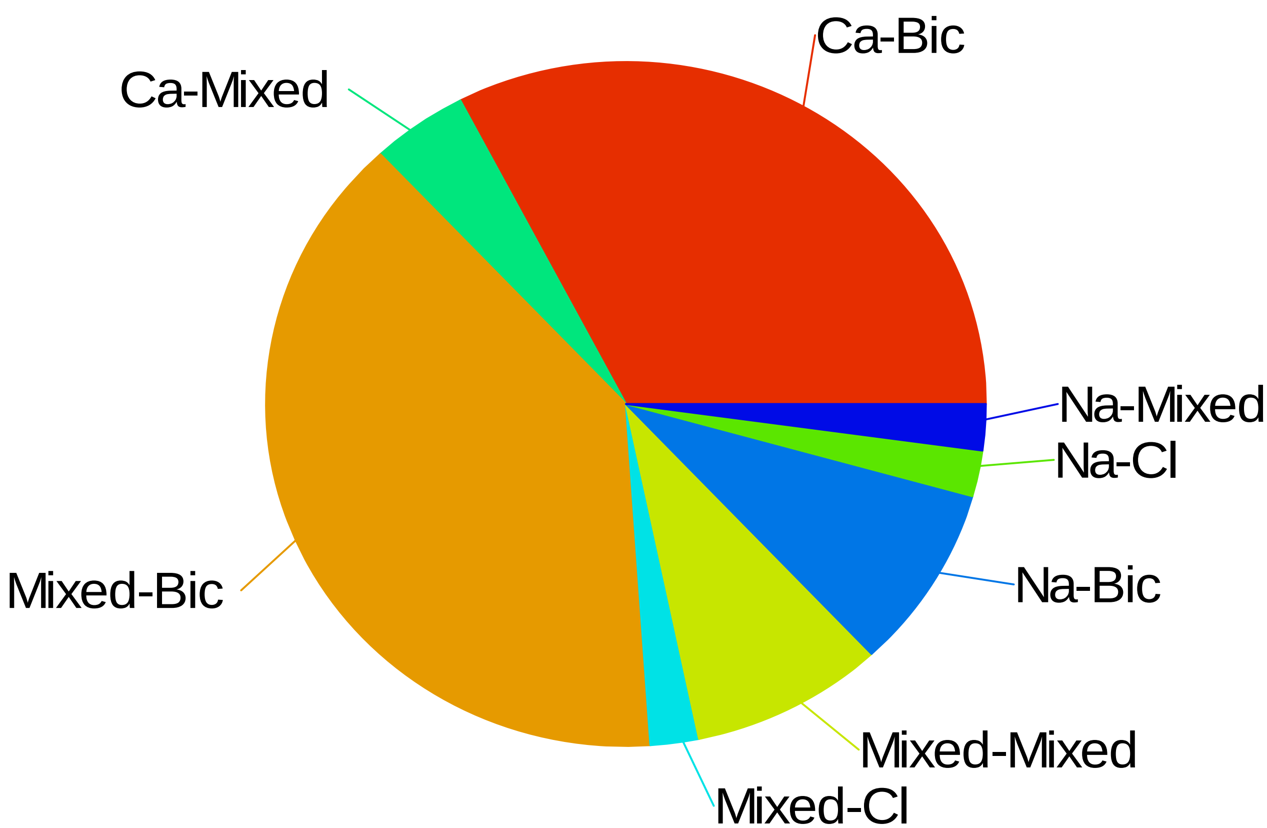


Figure 17 – From a water chemistry perspective, the 46 sample sites in the Agua Fria basin can be considered as falling into two groups based on the relative proportion of cations (positively charged ions). Forty sample sites have calcium or mixed water chemistry while 6 sample sites have sodium water chemistry. Samples from each of these two groups vary significantly in many water quality indices.

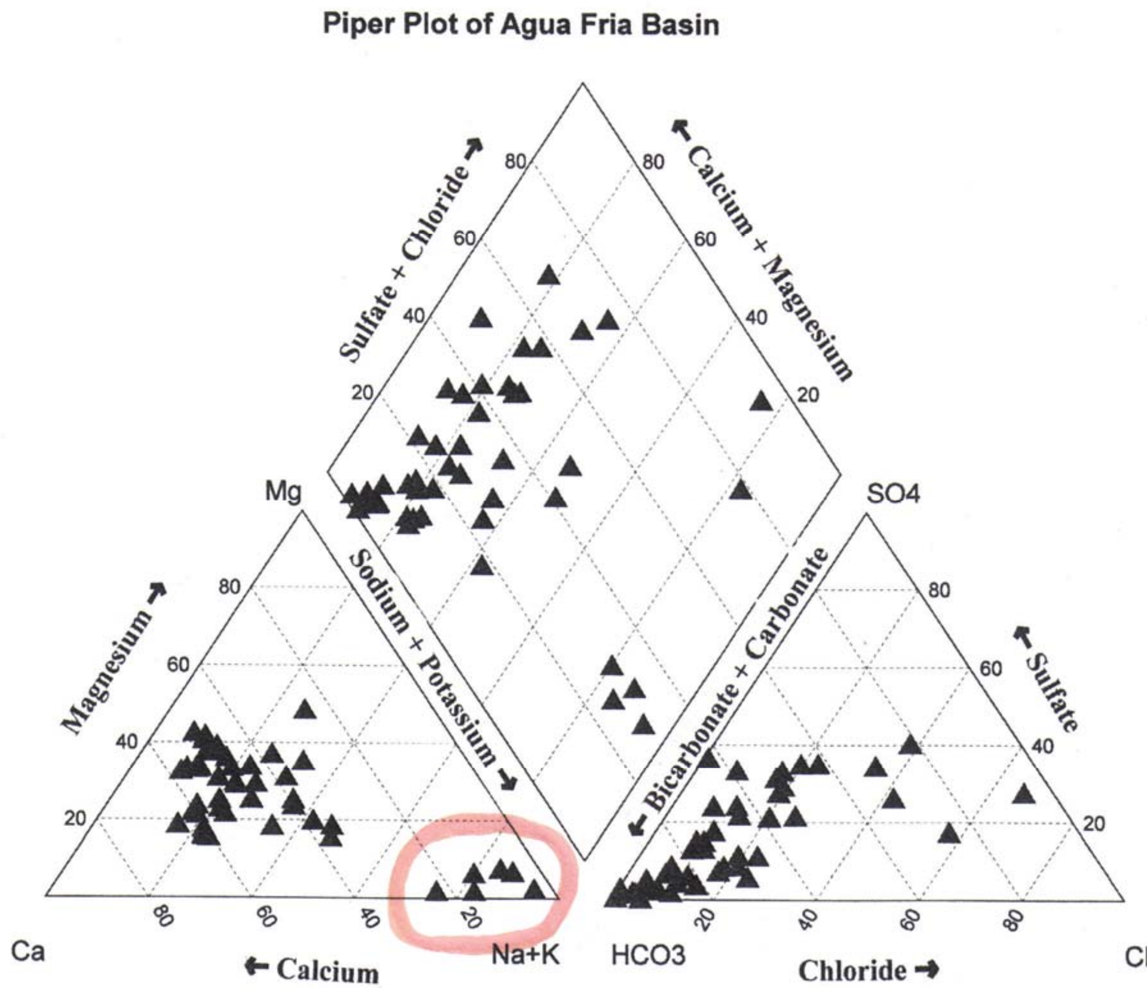


Figure 18 – The Piper trilinear diagram shows how the 6 sodium-dominated samples form a distinct cluster (highlighted by the orange circle in the lower left diagram) separate from the more typical calcium or mixed water chemistry of samples collected in the Agua Fria basin. The sodium chemistry samples have very minor concentrations of calcium and magnesium which is often associated with elevated concentrations of trace elements.

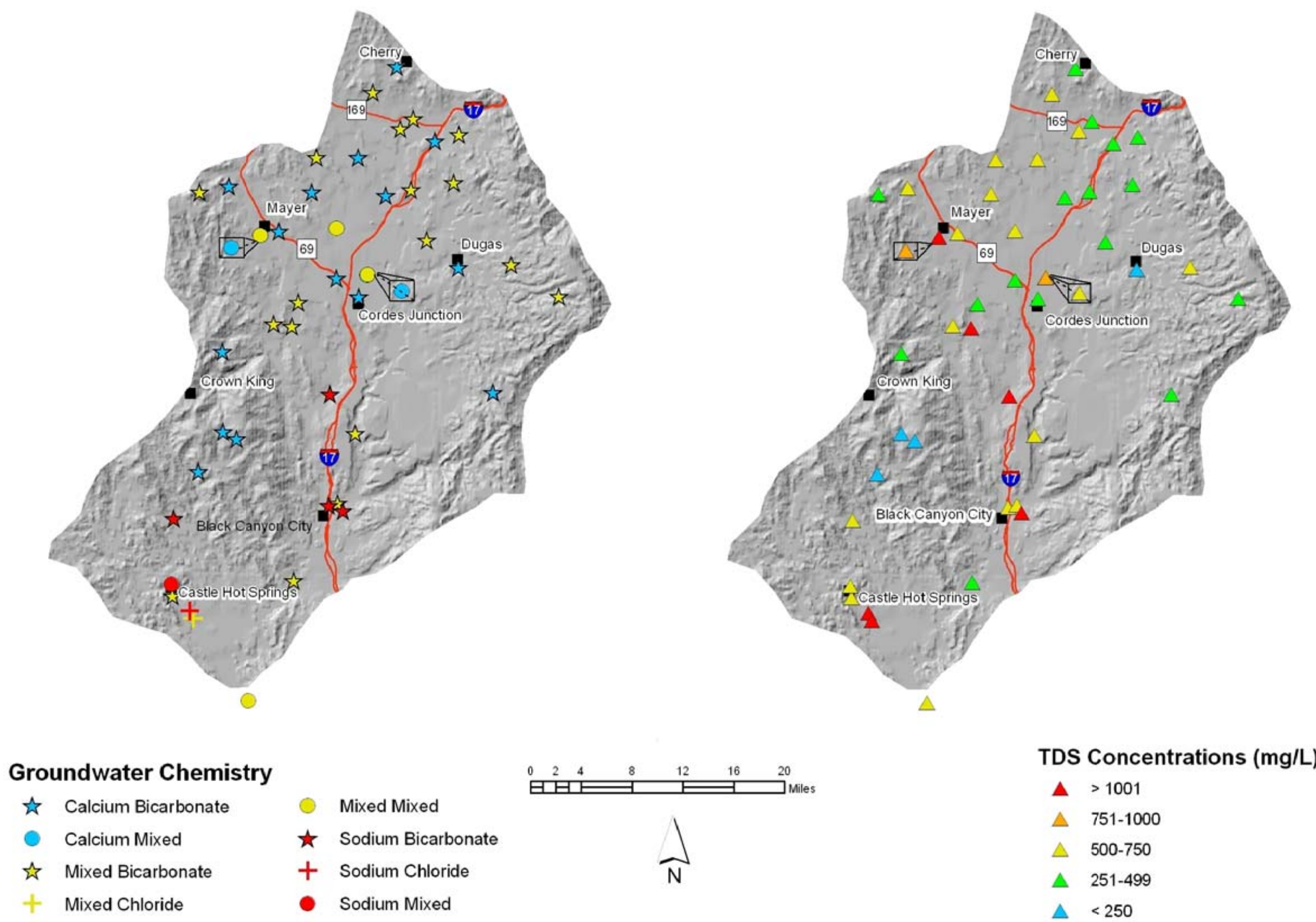
Groundwater in the Agua Fria basin was generally *slightly alkaline*, *fresh*, and *hard*-to-*very hard* as indicated by pH values and TDS and hardness concentrations. Levels of pH were *slightly alkaline* (above 7 su) at 40 sites and slightly acidic (below 7 su) at 6 sites.[18] The 6 sites with acidic water were all located in the Bradshaw Mountains.

TDS concentrations were considered *fresh* (below 1,000 mg/L) at 40 sites, *slightly saline* (1,000 to 3,000 mg/L) at 6 sites and none were *moderately saline* (3,000 to 10,000 mg/L) (Map 5).[18]

TDS concentrations are best predicted among major ions by sodium concentrations (standard coefficient = 0.37), among cations by sodium concentrations (standard coefficient = 0.52) and among anions, bicarbonate (standard coefficient = 0.53) (multiple regression analysis, $p \leq 0.01$).

Hardness concentrations were *soft* (below 75 mg/L) at 1 site, *moderately hard* (75 – 150 mg/L) at 5 sites, *hard* (150 – 300 mg/L) at 15 sites, and *very hard* (above 300 mg/L) at 25 sites (Map 6 and Figure 19).[14]

Map 5 - Agua Fria Basin Groundwater Chemistry and TDS Concentrations



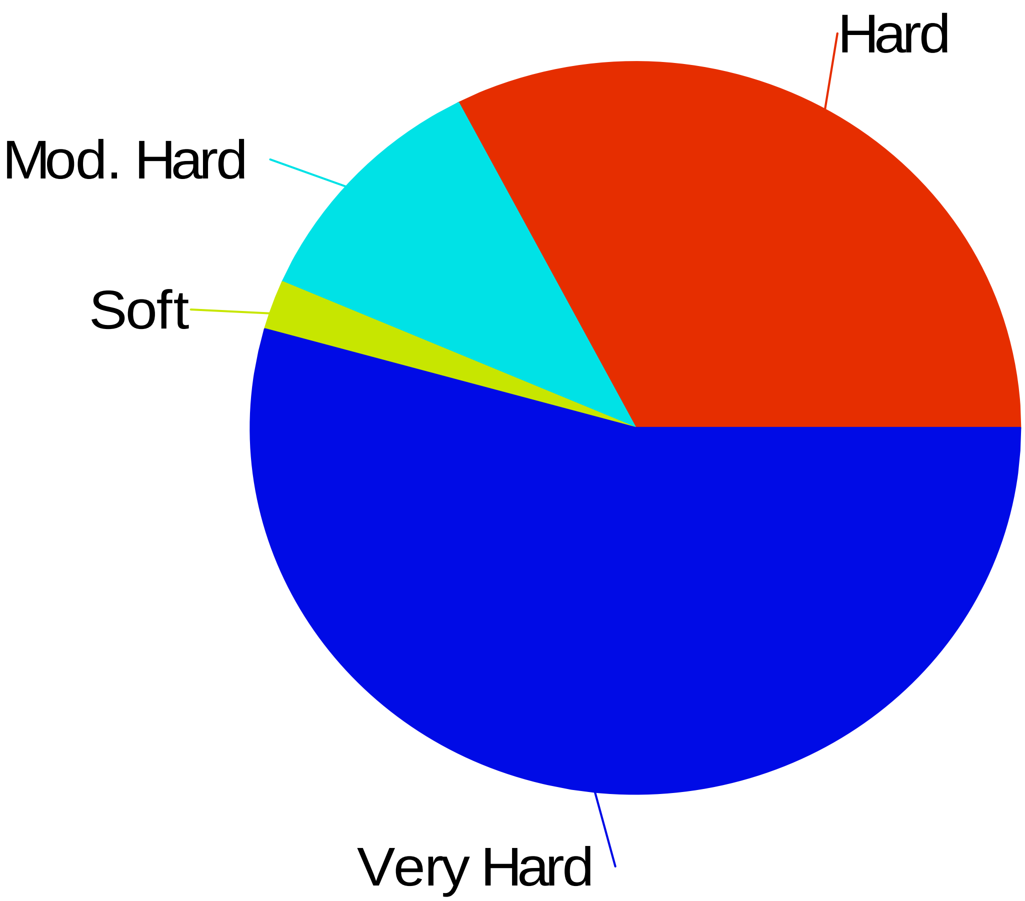


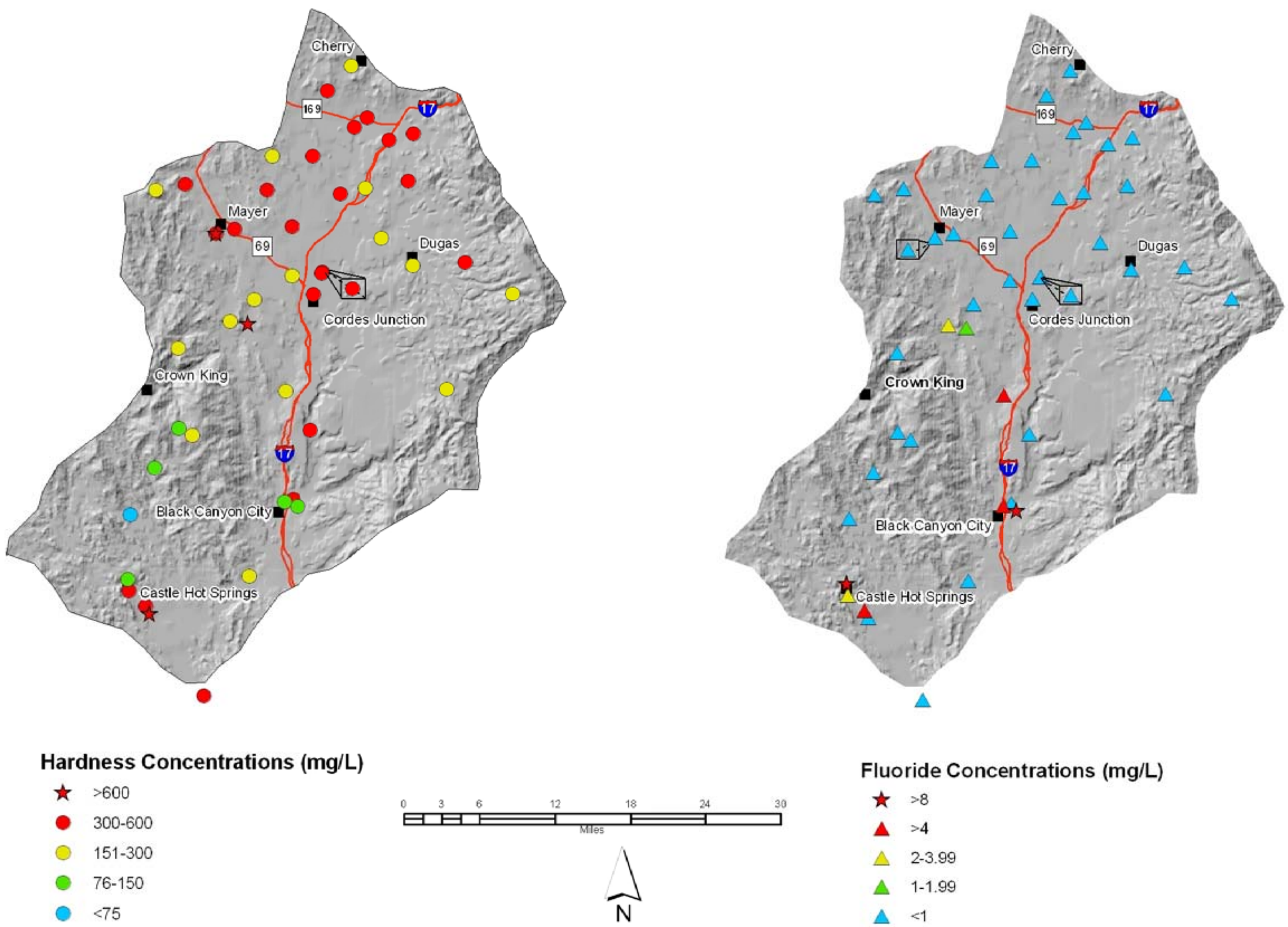
Figure 19 – This pie chart illustrates that most sample sites in the Agua Fria basin consisted of *very hard* or *hard* water. In a well near the town of Mayer, hardness concentrations were as high as 890 mg/L—almost three times the 300 mg/L concentration that is considered *very hard*. While hardness (or the total amount of calcium and magnesium ions) does not have a drinking water standard, it affects detergents by limiting suds formation and accelerates scale formation in piping and appliances. [20]

Most trace elements such as antimony, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium and zinc were rarely–if ever—detected. Only arsenic, barium, fluoride and manganese were detected at more than 20 percent of the sites.

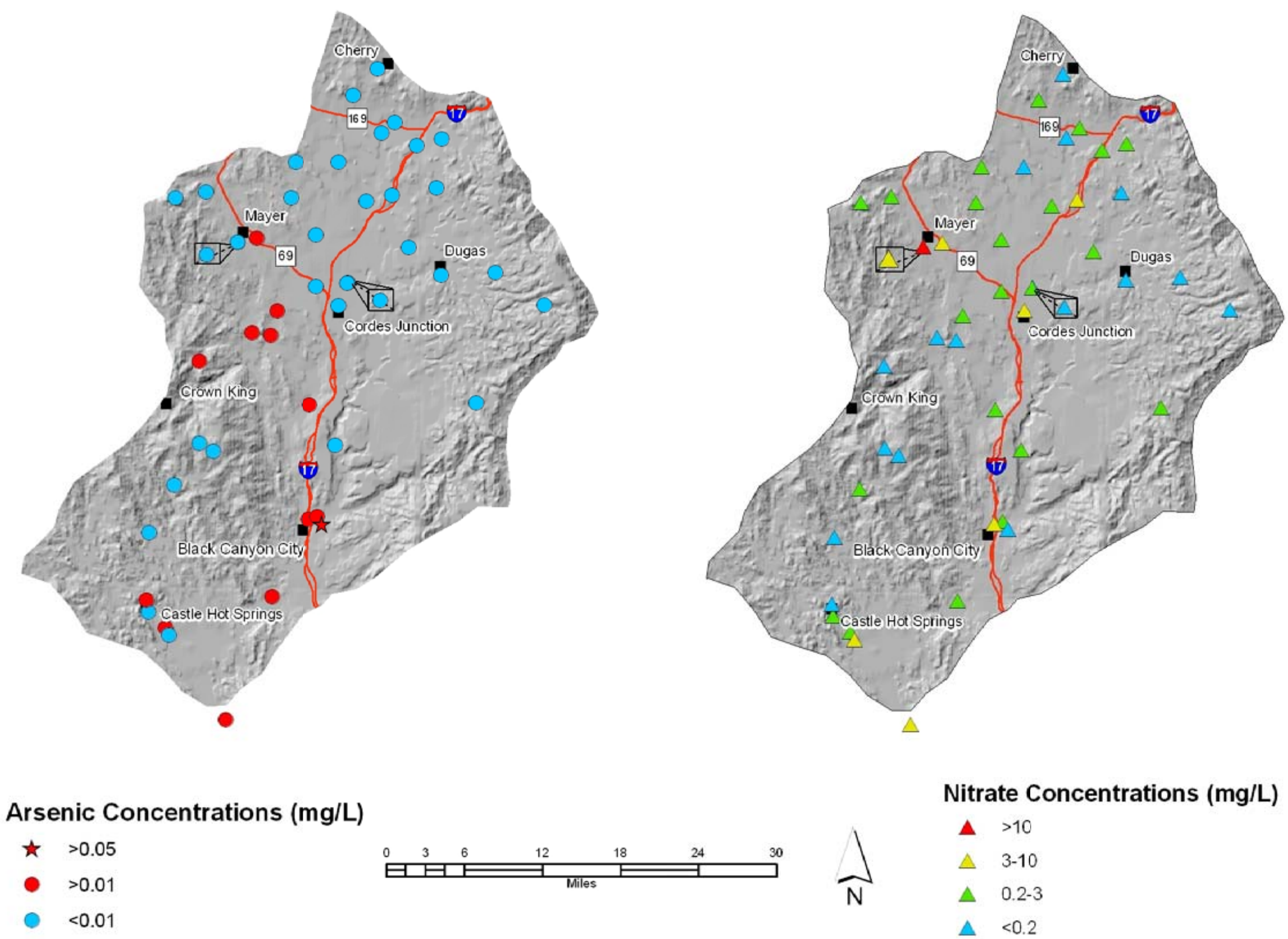
Constituent Co-Variation

The co-variation of constituent concentrations was determined to scrutinize the strength of the association. The results of each combination of constituents were examined for statistically-significant positive or negative correlations. A ***positive correlation*** occurs when, as the level of a constituent increases or decreases, the concentration of another constituent also correspondingly increases or decreases. A ***negative correlation*** occurs when, as the concentration of a constituent increases, the concentration of another constituent decreases, and vice-versa. A positive correlation indicates a direct relationship between constituent concentrations; a negative correlation indicates an inverse relationship.[37]

Map 6 - Agua Fria Basin Hardness and Fluoride Concentrations



Map 7 - Agua Fria Basin Arsenic and Nitrate Concentrations



Several significant correlations occurred among the 46 sample sites (Table 7, Pearson Correlation Coefficient test, $p \leq 0.05$). Three groups of correlations were identified:

- Negative correlations occurred between pH-field and the following constituents: SC, TDS, hardness, magnesium, and sulfate.
- Positive correlations occurred between sodium and the following constituents: SC, TDS, potassium, bicarbonate, chloride, arsenic, and fluoride. Negative correlations occur between sodium and oxygen-18 and deuterium.
- Positive correlations occurred between hardness and the following constituents: calcium, magnesium (Figure 20) and sulfate.

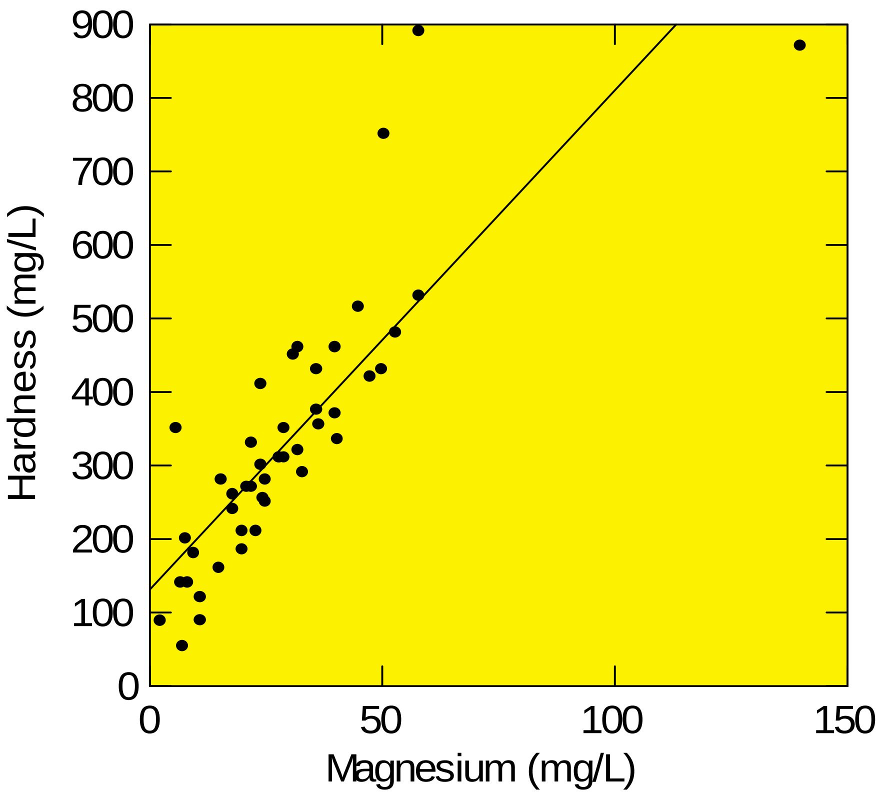


Figure 20 – The graph illustrates a strong positive correlation between two constituents; as hardness concentrations increase so do magnesium concentrations. The regression equation for this relationship is $y = 6.71x + 131$, $n = 46$, $r = 0.83$. Magnesium is one of two main contributors to hardness; calcium being the other. The term "hardness" comes from the fact that it is hard to develop suds from detergents in hard water because calcium and magnesium react strongly with negatively-charged chemicals like soap to form insoluble compounds. As a result, hard water reduces the effectiveness of the cleaning process.[18]

Table 7. Correlation among Agua Fria Basin Groundwater Quality Constituent Concentrations Using Pearson Correlation Probabilities

Constituent	Temp	pH-f	Turb	SC-f	TDS	Hard	Ca	Mg	Na	K	Bic	Cl	SO_4	NO_3	As	F	O	D
Physical Parameters																		
Temperature										*								
pH-field				+	+	+		+					+					
Turbidity							*					*						
General Mineral Characteristics																		
SC-field					**				**	**	**	**	*		**	**		
TDS									**	**	**	**	*		**	**		
Hardness							**	**					**					
Major Ions																		
Calcium												*						
Magnesium													*					
Sodium										**	**	*			**	**	++	++
Potassium											**	*			**	**		+
Bicarbonate															**	**		
Chloride																		
Sulfate																		
Nutrients																		
Nitrate																		
Trace Elements																		
Arsenic																**	+	+
Fluoride																	+	+
Isotopes																		
Oxygen																		**
Deuterium																		

Blank cell = not a significant relationship between constituent concentrations
* = Significant positive relationship at $p \leq 0.05$
** = Significant positive relationship at $p \leq 0.01$
+ = Significant negative relationship at $p \leq 0.05$
++ = Significant negative relationship at $p \leq 0.01$

Groundwater Variation

Groundwater quality constituent concentrations were compared among water chemistries, watersheds defined by hydrologic unit codes (HUCs), and rock types.

The 40 sample sites with a calcium or mixed chemistry were compared to the 6 sample sites with sodium chemistry. Significant concentration differences were found with 13 constituents (Table 8).

Temperature, SC, TDS (Figure 21), sodium, potassium, chloride, sulfate, arsenic and fluoride (Figure 22) were higher in the sodium-dominated sample sites than in the calcium and mixed sample sites. Calcium, magnesium and hardness were higher in the calcium and mixed sample sites than in the sodium sample sites (Kruskal-Wallis test, $p \leq 0.05$). For constituents having significantly different concentrations between sub-basins, 95 percent confidence intervals are provided in Table 8.

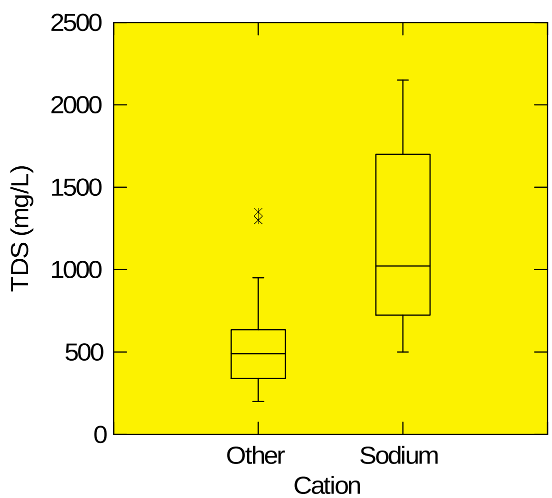


Figure 21. TDS concentrations in sodium-dominated groundwater samples in the Agua Fria basin are significantly higher than in calcium or mixed cation-dominated samples (Kruskal-Wallis test, $p \leq 0.05$). Low concentrations of sodium are typically present in recharge areas; in downgradient areas sodium often becomes the dominant cation usually as the result of silicate weathering and halite dissolution along with limited ion exchange.[26]

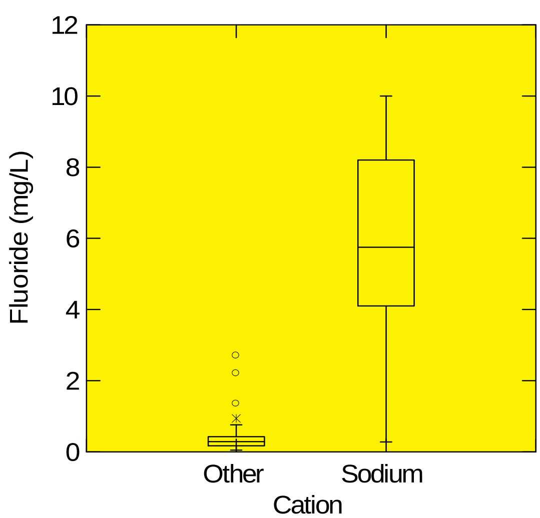


Figure 22. Fluoride concentrations in sodium chemistry groundwater samples in the Agua Fria basin are significantly higher than in calcium or mixed cation chemistry samples (Kruskal-Wallis test, $p \leq 0.05$). Fluoride concentrations below 5 mg/L appear to be controlled by pH levels; the main control on higher fluoride concentrations appears to be calcium concentrations through precipitation or dissolution of the mineral fluorite. If a source of fluoride ions is available for dissolution, large concentrations of dissolved fluoride may occur if the groundwater is depleted in calcium.[26]

Table 8. Variation in Groundwater Quality Constituent Concentrations between Different Cation-Dominated Samples Using Kruskal-Wallis Test and 95 Percent Confidence Intervals

Constituent	Significance	Differences Between Cation	Sodium	Other Cation
Well Depth	ns	-	-	-
Groundwater Depth	ns	-	-	-
Temperature - field	**	Sodium > Other Cations	19 to 34	16 to 19
pH – field	ns	-	-	-
pH – lab	ns	-	-	-
SC - field	**	Sodium > Other Cations	690 to 2873	700 to 1005
SC - lab	**	Sodium > Other Cations	765 to 3005	724 to 1022
TDS	**	Sodium > Other Cations	509 to 1864	450 to 632
Turbidity	ns	-	-	-
Hardness	**	Other Cations > Sodium	36 to 277	304 to 414
Calcium	**	Other Cations > Sodium	2 to 88	73 to 101
Magnesium	**	Other Cations > Sodium	4 to 15	26 to 40
Sodium	**	Sodium > Other Cations	128 to 614	37 to 61
Potassium	**	Sodium > Other Cations	2.3 to 13.1	1.8 to 3.0
Bicarbonate	ns	-	-	-
Chloride	**	Sodium > Other Cations	-19 to 467	35 to 92
Sulfate	*	Sodium > Other Cations	49 to 286	55 to 111
Nitrate (as N)	ns	-	-	-
TKN	ns	-	-	-
Total Phosphorus	ns	-	-	-
Arsenic***	**	Sodium > Other Cations	-0.56 to 1.35	0.006 to 0.009
Fluoride	**	Sodium > Other Cations	2.1 to 9.3	0.3 to 0.6
Oxygen	ns	-	-	-
Deuterium	ns	-	-	-
Gross Alpha ***	ns	-	-	-
Gross Beta ***	ns	-	-	-
Radon	ns	-	-	-

ns = not significant * = significant at $p \leq 0.05$ or 95% confidence level ** = significant at $p \leq 0.01$ or 99% confidence level
*** = for information only, statistical test not valid because of the large number of non-detects
All units mg/L except temperature (degrees Celsius) and SC (uS/cm).

The sample sites were compared among watersheds as defined by Hydrologic Unit Codes (HUCs) devised by the U.S. Geological Survey. The five HUCS within the Agua Fria basin and the number of sites sampled within each are as follows: Sycamore Creek (14 sites), Big Bug Creek (12 sites), Black Canyon Creek (6 sites), Bishop Creek (5 sites) and Lake Pleasant (8 sites).

Significant concentration differences were found with four constituents. Potassium was higher in Bishop Creek than Sycamore Creek and Big Bug Creek; bicarbonate was higher in Bishop Creek than Big Bug Creek and Lake Pleasant; total phosphorus and manganese were higher in Sycamore Creek than in Big Bug Creek and Lake Pleasant (Kruskal-Wallis test with Tukey test, $p \leq 0.05$).

The sample sites were compared among general rock types.[24] The number of sample sites within each rock types are as follows: alluvium (2 sites), basalt (14 sites), granite (12 sites), sedimentary (11 sites) and volcanic (7 sites).

No significant concentration differences were found with the constituents (Kruskal-Wallis test with Tukey test, $p \leq 0.05$).

Isotope Comparison

Groundwater characterizations using oxygen and hydrogen isotope data may be made with respect to the climate and/or elevation where the water originated, residence within the aquifer, and whether or not the water was exposed to extensive evaporation prior to collection.[13] This is accomplished by comparing oxygen-18 isotopes ($\delta^{18}O$) and deuterium (δD), an isotope of hydrogen, data to the Global Meteoric Water Line (GMWL). The GMWL is described by the linear equation:

$$\delta D = 8\delta^{18}O + 10$$

where δD is deuterium in parts per thousand (per mil, $^0/_{00}$), 8 is the slope of the line, $\delta^{18}O$ is oxygen-18 $^0/_{00}$, and 10 is the y-intercept.[13] The GMWL is the standard by which water samples are compared and represents the best fit isotopic analysis of numerous worldwide water samples.

Isotopic data from a region may be plotted to create a Local Meteoric Water Line (LMWL) which is affected by varying climatic and geographic factors. When the LMWL is compared to the GMWL, inferences may be made about the origin or history of the local water.[13] The LMWL created by $\delta^{18}O$ and δD values for samples collected at sites in the Agua Fria basin were compared to the GMWL. The δD and $\delta^{18}O$ data lie to the right of the GMWL. Meteoric waters exposed to evaporation characteristically plot increasingly below and to the right of the GMWL. Evaporation tends to preferentially contain a higher percentage of lighter isotopes in the vapor phase and causes the water that remains behind to be isotopically heavier.[13]

Groundwater from arid environments is typically subject to evaporation, which enriches δD and $\delta^{18}O$, resulting in a lower slope value (usually between 3 and 6) as compared to the slope of 8 associated with the GMWL.[13] The data for the Agua Fria conform to this theory, having a slope of 5.3, with the LMWL described by the linear equation:

$$\delta D = 5.3^{18}O - 18.4$$

The LMWL for the Agua Fria basin (5.3) is similar to other arid basins in Arizona such as Detrital Valley (5.15), Sacramento Valley (5.5) Big Sandy (6.1), Pinal Active Management Area (6.4) and San Simon (6.5).[29, 30, 31]

The isotopic data were compared by cation, watershed and rock type for significant differences but none were found. Of the six sodium-dominated sample sites, three were depleted isotopically and the remaining three were located in the cluster in the middle of the graph. Cluster analysis was used to separate the isotope values into various groupings based on precipitation time periods (summer, winter and mixture) but no significant differences were found.

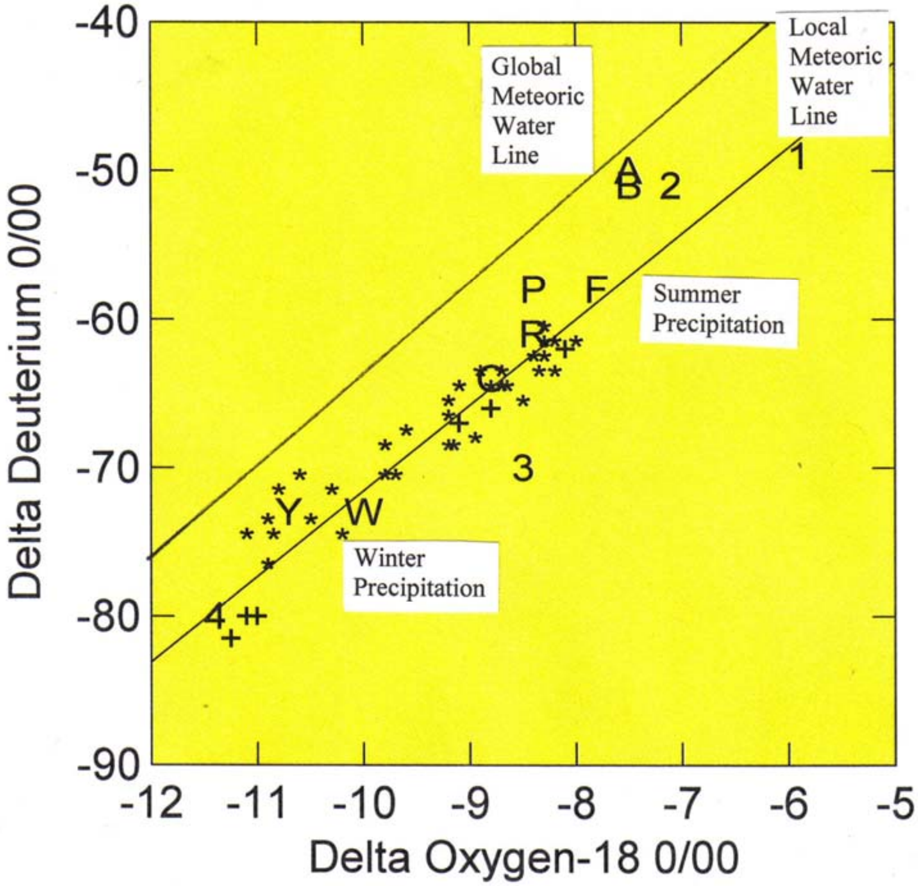


Figure 23. This graph illustrates oxygen-18 and deuterium values of 44 groundwater sites, 8 surface water sites and 1 precipitation event.

The two points highest on the precipitation trajectory (upper right of graph) of the Local Meteoric Water Line (LMWL) are samples from two shallow wells, Wilder Well (1) and Sunset Rest Area Well (2), both located along the Agua Fria River. These two groundwater samples have similar isotopic values to the surface water samples collected during the summer from the Agua Fria River (A) near U-Cross Ranch and Big Bug Creek (B). All four samples appear to strongly reflect summer precipitation isotope values. [40]

Lower on the LMWL are six surface water isotope samples: French Creek (F), Poland Creek (P), two samples from the Agua Fria River (R) near Chauncy Ranch, and Cienega Creek (C). Although collected from October through January, all appear, to a lesser degree, to reflect the influence of summer precipitation. Far lower on the precipitation trajectory is a sample from Sycamore Creek (Y) collected in late-May which appears to consist largely of winter precipitation (W). [40] Interspersed along the LMWL with these eight surface water samples are the majority of groundwater samples (*) that have isotope values that range along the continuum from summer precipitation to winter precipitation with many appearing to be a mixture of each source.

The six samples with sodium-dominated water chemistry (+) are found all along the LMWL although three samples are found near the bottom of the precipitation trajectory below winter precipitation. Other noteworthy isotope outliers include the sample collected from Lake Pleasant Harbor Marina (3) and from Kellner Spring (4) that is near the bottom of the trajectory curve, yet has calcium-bicarbonate water chemistry.

CONCLUSIONS

Overview

Groundwater quality in the Agua Fria basin is remarkably uniform in many respects. Water chemistry, TDS concentrations, and trace element detections are very similar across the basin. The vast majority of sample sites were of calcium-bicarbonate or mixed-bicarbonate chemistry, had concentrations of TDS that rarely varied outside the 450 to 625 mg/L range, had low concentrations of nutrients and had few occurrences of trace elements other than fluoride.

The exception to this overview of groundwater quality in the Agua Fria basin involves a limited subgroup of sample sites that have sodium as their major cation. Besides very different water chemistry, these sample sites tend to have higher TDS concentrations and concentrations of arsenic and fluoride above health-based, water quality standards (Kruskal-Wallis test, $p \leq 0.05$).

Constituents Having Health-Based Water Quality Standards

The groundwater quality of the Agua Fria basin generally is suitable for municipal or domestic use as 70 percent of sampled sites met all health-based, drinking water standards. Health-based drinking water quality standards are based on a lifetime consumption of two liters of water per day and, as such, are chronic not acute standards.[36]

The remaining 30 percent of the sampled sites, which had concentrations of at least one constituent exceeding a Primary MCL, followed two patterns:

- The sample sites not meeting health-based, water quality standards were all located in the Bradshaw Mountains in an area stretching from high elevations down to the floodplain of the Agua Fria River. However, simply using a well or spring for domestic use in this area was not necessarily a cause for concern as some sample sites there met health-based, water quality standards.

- The sample sites having a sodium-dominated chemistry, all of which were located in the Bradshaw Mountain area indicated above, almost invariably had arsenic and fluoride concentrations that exceeded drinking water standards.

Arsenic - Arsenic was the most common constituent exceeding health-based, drinking water standards with 26 percent of sample sites having concentrations over the 0.01 mg/L standard. The sample sites exceeding arsenic were typically just slightly over the 0.01 mg/L standard—except if the sample site exhibited water chemistry with sodium as the dominant cation. In that case, arsenic concentrations tended to be significantly higher (Kruskal-Wallis test, $p \leq 0.05$) including a well near Black Canyon City that had one of highest arsenic levels ever recorded in groundwater in Arizona—2.25 mg/L. Incidentally, a split sample collected at this site confirmed the high arsenic concentration.

Groundwater with elevated arsenic concentrations is associated with four types of geologic environments: Cenozoic lake beds, volcanic rocks and their associated sediments, geothermal environments, and areas of gold and uranium deposits—all of which are found within the basin.[28]

Fluoride - Fluoride was the next most common constituent exceeding health-based, drinking water standards with 11 percent of sample sites having concentrations over the 4.0 mg/L standard. Similar to the pattern involving arsenic, the significantly higher fluoride concentrations (Kruskal-Wallis test, $p \leq 0.05$) were found at sample sites that exhibited water chemistry with sodium as the dominant ion and a corresponding lack of calcium ions. The highest fluoride concentration (10 mg/L) was recorded at the same well near Black Canyon City that had the highest arsenic concentration.

Fluoride elevations are thought to be influenced by two reactions. Fluoride concentrations below 5 mg/L appear to be controlled by pH levels; the main control on higher fluoride concentrations appears to be calcium concentrations through precipitation or dissolution of the mineral fluorite. If a source of fluoride ions is available for dissolution, large concentrations of dissolved fluoride may occur if the groundwater is depleted in calcium.[26] None of the water samples from wells or springs at the higher altitudes exceeded either the health-based or aesthetics-based water quality standards, a finding that previous studies had also noted.[21]

Nitrate - One nitrate exceedance of 19 mg/L (as nitrogen), almost double the 10 mg/L water quality standard, occurred in a 285-foot-deep well located upgradient of the town of Mayer.[39] A nearby, 602 foot deep well that was also sampled had a nitrate concentration of 3 mg/L (as nitrogen).[39] The most likely source of the nitrate is septic systems that treat the wastewater of the homes in the area or poor wellhead protection/well construction problem allowing surface runoff to enter the well. This is supported by the elevated chloride concentrations (250 mg/L and 230 mg/L, respectively) found in both wells. Another well near Cordes Junction has a nitrate concentration of 5.6 mg/L that also suggests something other than natural background nitrate contributions. However, generally nitrate does not appear to be a major water quality issue in the Agua Fria basin as 83 percent of the sample sites had nitrate concentrations less than 3 mg/L—a level one study suggested was not impacted by human activites.[23]

Gross Alpha - One gross alpha exceedance of 23 pCi/L occurred at Coal Camp Spring high in the Bradshaw Mountains in Horsethief Basin. This area is composed of granite, a rock type often associated with elevated concentrations of radiochemical elements.[22] Other sample sites located in the granite geology portion of the Bradshaw Mountains did not reveal elevated concentrations of gross alpha. As a result, this constituent does not appear to be a widespread water quality issue in the area.

Constituents Having Aesthetics-Based Water Quality Guidelines

More than half the sample sites (67 percent) in the Agua Fria basin exceeded an aesthetics-based water quality guideline that set the maximum concentration of a constituent that can be present without imparting unpleasant taste, color, odor or other aesthetic effect on the water. [33, 36]

Total Dissolved Solids - TDS was the most common constituent exceeding aesthetics-based water quality guidelines, with 26 sample sites having concentrations above 500 mg/L guideline. These sample sites having TDS exceedances occur in all areas of the Agua Fria basin; however, sample sites having sodium as the dominant cation had significantly higher TDS concentrations (Kruskal-Wallis test, $p \leq 0.05$).

Non-sodium dominated sample sites had little variability with TDS concentrations. This difference is highlighted by comparing 95 percent confidence intervals for each cation group. The sodium group ranged from 509 to 1,864 mg/L while the other cation group ranged from 450 to 632 mg/L. In other words, if 100 additional groundwater quality samples were collected for this study with sodium not as the dominant cation, 95 sites should be within the calculated confidence interval (450 to 632 mg/L) and 5 sites should be either higher or lower than the range of confidence intervals.

Manganese - Manganese was the next most common aesthetics-based water guideline with nine sample sites having concentrations exceeding 0.05 mg/L. In an interesting relationship, the sample sites which consisted of eight springs and one well were all located in upper part of the Agua Fria basin.

Chloride and **Sulfate** - The chloride and sulfate exceedances are related to previously discussed issues with the exception of the sample site (AGF-48/49) a 345-foot-deep well downgradient of the De Soto Mine located near the community of Cleator in the Bradshaw Mountains.[39] The mine extracted copper but ceased operations before World War II. Water quality exceedances of arsenic, TDS and sulfate in samples from the well, along with a low 6.8 su pH level, strongly indicate influence from mining. Previous studies in the Bradshaw Mountains have found wells and surface waters near mine tailings high in concentrations of metals such as arsenic, cadmium, copper, lead, mercury, molybdenum, nickel and zinc. [42]

Occurrence of Sodium Chemistry Sample Sites

The most diverse water quality in the basin occurred at the eastern and southern flanks of the Bradshaw Mountains stretching downgradient as far as the Agua Fria River floodplain. Samples sites in these areas were a combination of calcium or mixed-bicarbonate chemistry commonly found in the basin along with sites having unique sodium chemistry. Besides very different water chemistry, the sodium sample sites tend to have higher TDS concentrations and concentrations of arsenic and fluoride above health-based, water quality standards (Kruskal-Wallis test, $p \leq 0.05$).

An earlier investigation in the Castle Hot Springs area that sampled 11 wells and springs found this same dichotomy between water samples.[27] Sites with sodium chemistry, such as Castle Hot Springs, tended to have high fluoride concentrations while sites with a calcium or mixed-chemistry tended to have much lower concentrations of fluoride. Arsenic wasn't tested for in the study. [27]

The water chemistry differences between these two groups of samples having different water chemistry may be explained by the geology of the area. Unconsolidated alluvial deposits of the Agua Fria

River in the Black Canyon City area are hydrologically separated from the underlying water-bearing schist by confining layers of impermeable beds of clay and silica-rich caliche that range from 100 to 200 feet thick. [21] Water produced from the schist contains elevated concentrations of TDS, fluoride and arsenic while water produced from wells that only penetrated the overlying gravel, sand and silt had significantly lower concentrations of these constituents. [21] The schist deposits are also present in places north of Lake Pleasant between French Creek and the Agua Fria River. [21]

How Does Each Sample Site Fit the Hypothesis?

Data from the nine sample sites collected in eastern and southern flanks of the Bradshaw Mountains for this ADEQ study appears to generally support the theory that an aquitard of clay and silica-rich caliche separates shallow groundwater of calcium or mixed chemistry from deeper sodium chemistry groundwater. However, many of the sample sites lack well log information (or are springs) making it difficult to determine which geologic strata was penetrated during well construction and at what depths the well casing was perforated to produce water. [39]

Two samples sites in the area with calcium or mixed-bicarbonate water chemistry commonly found in the basin appeared to support this theory:

- In Black Canyon City, a domestic well (AGF-17/18) with a depth of 120 feet located in the Agua Fria River floodplain had a mixed chemistry.[39] Although no log information was available for this well; it likely only produces water from the unconsolidated river deposits.

- Near Castle Hot Springs, a 70-foot well (AGF-51) located in the floodplain of Castle Creek had a mixed chemistry.[39] Well log information indicates only sand, gravel and clay were penetrated by this well which is perforated between 20-30 feet bls.

One samples site in the area with calcium or mixed-bicarbonate water chemistry commonly found in the basin appears not to support this theory:

- Near Castle Hot Springs, a 280-foot deep well (AGF-66/67) located on a ridge less than a mile from Dripping Spring had a mixed chemistry.[39] Well log information indicates the well is perforated from 240-280 feet and schist was encountered from 154 -280 feet. If this well's annular seal has been compromised however, water produced by the well could show characteristics of a shallow well.

The remainder of the six samples collected in this area had sodium water chemistry. Four of these sites appear to support the theory:

- A private, domestic well (AGF-53/54), that is 360 feet in depth located in Black Canyon City on the east side of the Agua Fria River floodplain.[39] The driller's log from this well shows the well was cased from 260 – 360 feet and substrate drilled through included "blue-green granite" from 50 – 300 feet and "brown and red river sand" from 300 – 360 feet. [39]

- A private, domestic well (AGF-3/3D), that is 580 feet in depth located in Black Canyon City between Black Canyon Creek and the Agua Fria River. The driller's log for this well reveals the well was cased from 420 - 460 feet and the substrate drilled through from 40 – 580 feet was "rock" along with various combinations of clay and sand. [39]

- The waters of Castle Hot Springs (AGF-64/65), which discharge at 200 gpm, are thought to be part of a deep circulating system heated by the earth's interior since igneous heat sources for the springs appear unlikely because of the lack of Pleistocene silicic volcanism.[41]

- Dripping Spring (AGF-63), a non-geothermal spring located a few miles from Castle Hot Springs, apparently also discharges from granite geology. [21]

The remaining two samples collected in this area with sodium water chemistry appear either not to support the theory or not enough information was available to evaluate them:

- A private, domestic well (AGF-1/1D), that is 140 feet in depth located in about six miles north of Castle Hot Springs near a tributary to Cow Creek. The chemistry of water from this well is sodium. No log information was available for this well. [39]

- A private, domestic well (AGF-5), that is 122 feet in depth located near Bumble Bee in the floodplain of Bumble Bee Creek. The chemistry of water from this well is sodium. No log information was available for this well though it seems too shallow to penetrate into the water-bearing schist. [39]

These mixed results may indicate that the water quality variations are the result of the aquitard not being continuous throughout the area encourages well owners to have their water source tested for constituents that include, but are not necessarily limited to, nitrate.

RECOMENDATIONS

ADEQ encourages well owners to periodically collect samples, with the assistance of certified laboratories, for analysis of the full range of constituents having Safe Drinking Water standards. A list of certified labs can be obtained from the ADHS Environmental Laboratory Licensure and Certification Section. Call (602) 255-3454 or see http://www.azdhs.gov/lab/license/env.htm. ADEQ also encourages well owners to inspect and, if necessary, repair faulty surface seals, degraded casing or other factors that may affect well integrity. ADWR well construction regulations require a minimum 20-foot surface seal.

Based on interpretations of the analytical results from groundwater samples collected for this study, the following recommendations are offered for domestic well owners in the Agua Fria basin:

- ADEQ encourages those having wells or springs used for domestic water use in the basin, but particularly the Bradshaw Mountain area, to test their water for arsenic since this is the constituent most likely to exceed health-based water quality standards.

- ADEQ encourages those having wells or springs used for domestic water use in the basin, but particularly in the Black Canyon City area and around Castle Hot Springs that exhibit sodium chemistry to test their water for constituents including, but not limited, to arsenic and fluoride. These sites have a high likelihood of having arsenic and fluoride concentrations that not only exceed health-based water quality standards, but are often several orders of magnitude above their respective standards.

- ADEQ encourages well owners to have their septic systems inspected periodically to assure safety and compliance with the Arizona Administrative Code R18-9-A309(A)(7)(f). [3] If the septic systems appear not to be operating properly, ADEQ further encourages well owners to have their water source tested for constituents that include, but are not necessarily limited to, nitrate.

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Appendix A. Data for Sample Sites, Agua Fria Basin, 2004-2006

Site #	Cadastral / Pump Type	Latitude / Longitude (NAD 27)	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth (bls)	Water Depth (bls)	Perforation Interval (bls)
1st Field Trip, October 5, 2004 - Lucci & Yu									
AGF-1/1D	B(8-1)03cca windmill	34°03'37.896" 112°21'26.911"	628702	63850	Waldeck Well	Inorganic, Radiochem O & H Isotopes	140'	40'	-
AGF-2/2S	A(8-2)31dac submersible	33°59'27.887" 112°11'29.684"	587042	63851	Wilder Well	Inorganic, Radiochem O, H isotopes	100'	21'	40-80'
2nd Field Trip, October 27, 2004 - Lucci & Yu									
AGF-3/3D	A(9-2)34baa submersible	34°04'39.439" 112°08'38.026"	586043	63950	Musil Well	Inorganic, Radiochem, O, H isotopes	580'	300'	420-460'
AGF-4/4S	A(11-2)15abc submersible	34°20'16.439" 112°08'13.593"	501717	63951	Elliott Well	Inorganic, Radon	250'	-	-
AGF-5	A(10-2)33ada submersible	34°12'19.368" 112°08'38.344"	645686	12284	BB Ranch Well	Inorganic, Radiochem	122'	35'	-
3rd Field Trip, May 31, 2006 - Towne (Equipment Blank, AGF-10)									
AGF-6	A(12-3)35baa spring	34°22'59.448" 112°00'48.147"	--	12885	Brown Spring	Inorganic O, H isotopes	-	-	-
AGF-7	A(11-4)1ccd spring	34°21'19.093" 111°53'44.337"	--	12545	Willow Spring	Inorganic O, H isotopes	-	-	-
AGF-8	A(11-5)21ada spring	34°19'11.203" 111°49'45.303"	--	12547	Nelson Place Spr.	Inorganic, Radiochem Radon, O, H isotopes	-	-	-
AGF-9	Above Salt Flat	-	--		Sycamore Creek	O, H isotopes	-	-	-
4th Field Trip, June 28, 2006 – Towne & Condon									
AGF-11	A(12-2)8acc submersible	34°26'11.126" 112°10'20.627"	608829	12857	State Well	Inorganic, Radiochem Radon, O, H isotopes	52'	28'	-
AGF-12	At U-Cross Ranch	-	-	-	Agua Fria River	O, H isotopes	-	-	-
AGF-13	A(13-2)30ddb windmill	34°28'33.394" 112°09'58.926"	608832	13338	Pick n' Drill Well	Inorganic, Radiochem, O, H isotopes	20'	6'	-
AGF-14	A(11-2)12ddb submersible	34°20'33.723" 112°05'39.512"	623540	66736	Camp RanchWell	Inorganic, Radiochem Radon, O, H isotopes	65'	36'	-
AGF-15/16	A(11-2)12dcc submersible	34°20'29.731" 112°05'42.740"	509894	66737	John Rut Well	Inorganic, Radiochem Radon, O, H isotopes	600'	82'	60-188'
5th Field Trip, August 7, 2006 – Towne & Jones									
AGF-17/18	A(9-2)35 submersible	34°04'50.27" 112°07'54.65"	-	66898	Zimmer-man Well	Inorganic, Radon O, H isotopes	120'	20'	-
AGF-19	A(12-3)8cac submersible	34°26'00.24" 112°04'13.17"	626436	57600	Orme School	Inorganic, Radon O, H isotopes	200'	30'	-
AGF-20	A(13-2)26cbc spring	34°28'40." 112°06'37."	-	66897	Osborne Spring	Inorganic O, H isotopes	-	-	-
6th Field Trip, August 24, 2006 – Towne (Equipment Blank, AGF-25)									
AGF-21/22	A(14-3)20bdc spring	34°34'51.948" 112°03'24.574"	-	66936	Sunny-brook Spr.	Inorganic, Radiochem, O, H isotopes	-	-	-
AGF-23	B(12.5-1)26ddc spring	34°26'05.8" 112°19'40.4"	-	66938	Kellner Spring	Inorganic O, H isotopes	-	-	-
AGF-24	Near Poland Junction	-	-	-	Big Bug Creek	O, H isotopes	-	-	-
AGF-26	A(11-4)7aad submersible	34°21'05.543" 111°58'08.532"	631974	66937	Sycamore Cyn Cabin	Inorganic, Radon O, H isotopes	95'	14'	-

Well depth and water depth are from ADWR database as reported by well drillers

Appendix A. Data for Sample Sites, Agua Fria Basin, 2004-2006--Continued

Site #	Cadastral / Pump Type	Latitude / Longitude (NAD 27)	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth (bls)	Water Depth (bls)	Perforation Interval (bls)
7th Field Trip, October 11, 2006 – Towne & Smart									
AGF-27	A(11-1)31acd hillside spring	34°15'10.316" 112°17'36.944"	-	67057	Blancho Spring	Inorganic, Radiochem Radon, O, H isotopes	-	-	-
AGF-28	B(10-1)36cbb adit spring	34°09'51.866" 112°19'27.796"	-	67056	Bartol Spring	Inorganic, Radiochem, O, H isotopes	-	-	-
AGF-29	At Crown King	-	-	-	Poland Creek	O, H isotopes	-	-	-
AGF-30/31	A(12-3)10bac submersible	34°26'25.994" 112°02'08.755"	646575	12877	Highway Well	Inorganic, Radiochem Radon, O, H isotopes	200’	100'	-
8th Field Trip, November 30, 2006 - Towne & Valdez									
AGF-32/33	A(9.5-2)36cad submersible	34°09'38.676" 112°06'30.829"	614122	12274	Sunset Rest Area Well	Inorganic, Radiochem Radon, O, H isotopes	73’	30’	-
AGF-34	A(13-3)22adb spring	34°29'46.084" 112°00'11.738"	-	67296	Cedar Spring	Inorganic O, H isotopes	-	-	-
9th Field Trip, December 18, 2006 – Towne									
AGF-35/36	A(13-3)13dcb submersible	34°30'13.643" 111°58'10.307"	577898	67396	Flowerpot RanchWell	Inorganic O, H isotopes	145’	30’	25-45’
AGF-37/38	A(13-3)17 spring	34°30'35.586" 112°03'04.260"	-	67397	Landfill Spring	Inorganic O, H isotopes	-	-	-
AGF-39	A(13-3)9cbb windmill	34°31'17.254" 112°02'01.073"	631988	13342	Johnson Wash Well	Inorganic, Radiochem Radon, O, H isotopes	246’	46’	-
AGF-40	At Flowerpot Ranch	-	-	-	Cienega Creek	O, H isotopes	-	-	-
AGF-41	A(13-3)9acc spring	34°26'55.833" 111°58'33.919"	-	67398	Reimer Spring	Inorganic O, H isotopes	-	-	-
10th Field Trip, January 17-18, 2007 – Towne, Hanson & Woods (Equipment Blank, AGF-52)									
AGF-42	A(6-1)22bbd submersible	33°51'09.919" 112°15'07.436"	540579	51528	Pleasant Hrb Marina	Inorganic, Radiochem, Radon, O, H isotopes	630’	120’	225-625’
AGF-43	A(11-2)24caa submersible	34°19'00.242" 112°06'24.670"	526024	67458	Garden Well	Inorganic, Radiochem, Radon, O, H isotopes	145’	60’	80-145’
AGF-44	A(12-2)27bda submersible	34°23'41.967" 112°08'16.454"	803061	12866	Pond Well	Inorganic, Radiochem, Radon, O, H isotopes	311’	18’	-
AGF-45	At YMCA Chauncy Ranch	-	-	-	Agua Fria River	O, H isotopes	-	-	-
AGF-46	At YMCA Chauncy Ranch	-	-	-	Agua Fria River Spr	O, H isotopes	-	-	-
AGF-47	A(10-4)34aba spring	34°12'33.230" 111°55'11.736"	-	67457	Shirttail Spring	Inorganic, Radiochem, Radon, O, H isotopes	-	-	-
AGF-48/49	A(11-2)31ccc submersible	34°16'57.103" 112°17'13.910"	544213	67459	Hanover Well	Inorganic, Radiochem, Radon, O, H isotopes	345’	38’	305-345’
AGF-50	A(12-1)7aaa submersible	34°26'31.459" 112°17'13.910"	544465	67460	Wallace Well	Inorganic, Radiochem, Radon, O, H isotopes	200’	-	-
AGF-51	B(7-1)3ccb submersible	33°58'19.983" 112°21'26.916"	584099	67461	Wilson Well	Inorganic, Radiochem, Radon, O, H isotopes	70’	12’	20-30’
AGF-52	Above Lake Pleasant	-	-	-	French Creek	O, H isotopes	-	-	-

Well depth and water depth are from ADWR database as reported by well drillers

Appendix A. Data for Sample Sites, Agua Fria Basin, 2004-2006--Continued

Site #	Cadastral / Pump Type	Latitude / Longitude (NAD 27)	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth (bls)	Water Depth (bls)	Perforation Interval (bls)
11th Field Trip, February 21-22, 2007 – Towne & Smart (Equipment Blank, AGF-58)									
AGF-53/54	A(9-2)35cda submersible	34°04'19.232" 112°07'29.944"	570317	67577	James Well	Inorganic, Radiochem, Radon, O, H isotopes	360'	240'	260-360'
AGF-55	A(12-1)26dda submersible	34°23'27.592" 112°13'02.599"	528627	56803	Mayer Cliff Well	Inorganic, Radiochem, Radon, O, H isotopes	305'	65'	65-305'
AGF-56	A(11-2)30abb spring	34°18'36.295" 112°11'19.902"	-	67578	Dripping Spring	Inorganic, Radiochem, Radon, O, H isotopes	-	-	-
AGF-57	A(11-1)23abd submersible	34°17'06.754" 112°13'21.496"	589137	67579	Brad Mtn Well	Inorganic, Radiochem, Radon, O, H isotopes	395'	255'	295-395'
AGF-59	Bumble Ranch Road	-	-	-	Winter Precip.	O, H isotopes	-	-	-
12th Field Trip, March 1, 2007 – Towne & Smart									
AGF-60/61	A(12-1)27cdd submersible	34°23'10.115" 112°14'35.774"	570425	67617	Ong Well	Inorganic, Radiochem, Radon, O, H isotopes	602'	82'	502-602'
AGF-62	A(12-1)27cdd submersible	34°23'10." 112°14'36."	551414	67618	Wildman Well	Inorganic, Radon O, H isotopes	285'	77'	-
AGF-63	B(7-1)14baa spring	33°57'17.068" 112°20'02.860"	-	67619	Dripping Spring	Inorganic, Radiochem, Radon, O, H isotopes	-	-	-
AGF-64/65	B(8-1)31ccc spring	33°59'07.683" 112°21'34.690"	-	67620	Castle Hot Spring	Inorganic, Radiochem, Radon, O, H isotopes	-	-	-
13th Field Trip, March 7, 2007 – Towne & Boettcher									
AGF-66/67	B(7-1)14dda submersible	33°56'46.803" 112°19'45.042"	527702	67660	Boyle Well	Inorganic, Radiochem, Radon, O, H isotopes	280'	128'	240-280'
14th Field Trip, April 19, 2007 – Towne (Equipment Blank, AGF-72)									
AGF-68	A(14-2.5)36bdd spring	34°33'06.12" 112°05'22.47"	-	68078	Balky Spring	Inorganic, Radiochem, Radon, O, H isotopes	-	-	-
AGF-69/70	A(10-1)31dad Submersible	34°09'39.28" 112°17'29.49"	631910	68077	Horsethief Cabin Well	Inorganic, Radiochem, Radon, O, H isotopes	134'	13'	-
AGF-71	A(9-1)05aaa spring	34°09'10.12" 112°16'22.85"	-	68097	Coal Camp Spring	Inorganic, Radiochem, O, H isotopes	-	-	-

Well depth and water depth are from ADWR database as reported by well drillers

Appendix B. Groundwater Quality Data, Agua Fria Basin, 2004-2006

Site #	MCL Exceedances	Temp (ºC)	pH-field (su)	pH-lab (su)	SC-field (µS/cm)	SC-lab (µS/cm)	TDS (mg/L)	Hard (mg/L)	Hard - cal (mg/L)	Turb (ntu)
AGF-1/1D	TDS	25.3	8.42	*8.55*	741	790	**500**	53.5	54	0.15
AGF-2/2S	As	29.6	7.34	*7.7*	617	665	385	255	260	0.08
AGF-3/3D	TDS, As, **F**	28.0	7.42	*8.25*	913	1100	**745**	88.5	89.5	3.0
AGF-4/4S	-	19.5	7.35	*7.95*	537	650	405	280	280	*0.71*
AGF-5	TDS, As, **F**	20.2	7.19	*8.2*	1811	2000	**1300**	240	230	0.27
AGF-6	Mn, pH	17.2	**8.97**	*7.6*	287	480	300	250	240	0.82
AGF-7	TDS, Mn	18.6	7.79	7.6	883	880	**560**	480	470	21
AGF-8	Radon	19.8	7.73	*7.6*	411	410	270	210	200	0.04
AGF-11	TDS	17.3	7.56	*6.9*	819	810	**540**	330	320	0.03
AGF-13	TDS, Mn	22.6	7.55	*7.6*	859	850	**510**	270	260	1.5
AGF-14	TDS	17.4	7.35	*7.3*	1075	1100	**710**	430	420	0.08
AGF-15/16	TDS	19.4	7.15	*7.25*	1154	1100	**815**	515	510	ND
AGF-17/18	TDS, As	24.8	7.35	*7.725*	850	870	**575**	335	330	3.9
AGF-19	-	18.0	7.34	*8.1*	665	690	420	310	310	0.08
AGF-20	TDS, Fe, Mn	21.4	7.23	*7.9*	986	1020	**630**	460	460	0.53
AGF-21/22	Mn	19.2	7.81	*7.9*	597	620	370	270	270	3.45
AGF-23	-	14.7	7.60	*8.0*	325	350	210	160	160	0.07
AGF-26	-	18.2	7.29	*7.9*	560	560	360	290	300	1.1
AGF-27	As, Radon	16.9	7.13	*7.8*	421	430	280	180	190	4.0
AGF-28	Fe	9.8	7.61	*8.1*	345	350	250	140	150	9.0
AGF-30/31	Mn	20.1	7.72	*8.06*	416	415	275	185	190	0.05
AGF-32/33	TDS	17.6	7.22	*8.12*	970	1000	**610**	420	445	2.85
AGF-34	Mn	11.8	7.27	*8.06*	689	720	470	320	340	54
AGF-35/36	-	14.0	7.10	*7.95*	665	702.5	440	355	360	0.04
AGF-37/38	TDS, Mn	11.9	7.17	*8.1*	1005	1100	**665**	375	380	17.5
AGF-39	-	13.2	7.57	*8.2*	696	750	440	310	310	17
AGF-41	Mn	6.7	7.77	*8.2*	688	750	450	370	360	4.8

italics = constituent exceeded holding time
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level
Radon is only a proposed EPA Safe Drinking Water Act constituent

Appendix B. Groundwater Quality Data, Agua Fria Basin, 2004-2006

Site #	MCL Exceedances	Temp (ºC)	pH-field (su)	pH-lab (su)	SC-field (µS/cm)	SC-lab (µS/cm)	TDS (mg/L)	Hard (mg/L)	Hard - cal (mg/L)	Turb (ntu)
AGF-42	TDS, As, Radon	27.1	7.52	*8.1*	1005	1100	**740**	430	410	1.9
AGF-43	-	18.2	7.58	*8.1*	633	690	410	310	300	0.12
AGF-44	TDS	13.5	7.56	*8.1*	1033	1100	**690**	460	430	0.76
AGF-47	-	12.6	7.30	*8.0*	579	560	320	280	270	0.05
AGF-48/49	TDS, As, SO_4 Radon	19.2	6.80	*7.38*	1977	2100	**1300**	870	880	2.6
AGF-50	TDS, Radon	16.0	6.95	7.9	1055	1100	**600**	450	430	0.06
AGF-51	TDS, F, Radon	21.1	7.33	8.1	1035	1050	**640**	300	280	0.20
AGF-53/54	TDS, Cl, As, **F** Radon	22.3	7.10	7.9	3244	3450	**2150**	120	120	ND
AGF-55	TDS, As, Radon	17.1	6.90	8.0	943	900	**550**	410	370	0.02
AGF-56	As	17.6	7.75	8.3	564	420	300	210	200	0.78
AGF-57	TDS, As, F Radon	20.9	7.37	8.2	972	910	**570**	260	230	0.32
AGF-60/61	TDS	-	7.42	8.06	1619	1620	**950**	530	550	ND
AGF-62	TDS, Cl, SO_4, NO_3	-	6.78	7.9	2065	1970	**1300**	890	900	0.05
AGF-63	TDS, Cl, SO_4 As, **F**, Radon	22.7	7.25	7.8	2810	2820	**1700**	350	320	0.20
AGF-64/65	TDS, As, **F**	40.3	7.99	8.0	1170	1150	**725**	88	90	0.045
AGF-66/67	TDS, Cl	25.7	7.26	7.58	2481	2390	**1350**	750	730	25.5
AGF-68	TDS	17.2	8.17	8.08	915	970	**540**	350	320	0.48
AGF-69/70	-	-	6.99	7.80	313	345	200	140	130	3.65
AGF-71	Gross Alpha	10.8	7.54	7.87	381	410	240	200	150	1.5

italics = constituent exceeded holding time
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level
Radon is only a proposed EPA Safe Drinking Water Act constituent

Appendix B. Groundwater Quality Data, Agua Fria Basin, 2004-2006—Continued

Site #	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	T. Alk (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
AGF-1/1D	9.75	7.2	170	3.95	280	320	12	22	89
AGF-2/2S	60.5	24.5	38.5	3.7	260	300	ND	25	48
AGF-3/3D	18	11	225	6.5	445	545	ND	76	50.5
AGF-4/4S	87	15.5	24	1.5	215	270	ND	31	81
AGF-5	62	18	420	3.3	840	1000	ND	160	130
AGF-6	53	25	16	2.0	310	380	ND	9.2	5.2
AGF-7	100	53	23	2.4	570	690	ND	14	11
AGF-8	44	23	6.9	1.2	270	340	ND	ND	4.1
AGF-11	90	22	45	1.4	270	320	ND	66	130
AGF-13	69	22	87	0.80	480	590	ND	50	35
AGF-14	110	36	72	1.2	350	420	ND	78	200
AGF-15/16	130	45	24	2.9	330	430	ND	85	225
AGF-17/18	61	40.5	66.5	6.5	310	430	ND	55.5	115
AGF-19	78	29	31	1.5	410	500	ND	26	41
AGF-20	130	32	44	0.80	503	610	ND	81	47
AGF-21/22	73	21	33	ND	350	420	ND	12	19
AGF-23	41	15	8.3	1.2	200	250	ND	ND	1.0
AGF-26	65	33	15	1.5	340	420	ND	ND	9.9
AGF-27	59	9.6	24	1.2	240	300	ND	9	11
AGF-28	46	8.3	18	1.5	120	150	ND	ND	69
AGF-30/31	42.5	20	16	3.1	195	250	ND	12.5	15.5
AGF-32/33	99.5	47.5	58.5	2.7	450	550	ND	48.5	76
AGF-34	85	32	22	2.1	330	400	ND	28	53
AGF-35/36	79	36.5	21	2.4	375	470	ND	18	13
AGF-37/38	92	36	95	0.585	450	545	ND	50	107
AGF-39	76	28	40	1.1	340	410	ND	43	15
AGF-41	79	40	25	2.4	420	510	ND	18	ND

italics = constituent exceeded holding time
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Agua Fria Basin, 2004-2006--Continued

Site #	**Calcium** (mg/L)	**Magnesium** (mg/L)	**Sodium** (mg/L)	**Potassium** (mg/L)	**T. Alk** (mg/L)	**Bicarbonate** (mg/L)	**Carbonate** (mg/L)	**Chloride** (mg/L)	**Sulfate** (mg/L)
AGF-42	83	50	60	7.9	240	290	ND	92	190
AGF-43	75	28	19	1.5	230	280	ND	57	38
AGF-44	106	40	55	1.0	270	330	ND	83	200
AGF-47	65	25	18	0.86	310	380	ND	9.1	5.5
AGF-48/49	120	140	140	3.5	640	800	ND	220	**255**
AGF-50	120	31	55	2.4	420	510	ND	100	33
AGF-51	74	24	110	3.8	290	360	ND	77	160
AGF-53/54	27	11	780	16	1300	1700	ND	**285**	165
AGF-55	110	24	39	0.61	290	350	ND	71	100
AGF-56	46	20	21	1.4	220	270	ND	20	11
AGF-57	69	18	100	4.2	310	380	ND	30	170
AGF-60/61	115	58	105	7.25	260	300	3.6	230	195
AGF-62	260	58	84	4.3	320	390	ND	**250**	**340**
AGF-63	120	5.8	440	12	83	100	ND	**660**	**370**
AGF-64/65	32	2.4	190	4.6	110	135	ND	140	200
AGF-66/67	210	50.5	175	7.0	300	360	ND	**470**	195
AGF-68	80	29	83	0.71	410	500	ND	35	79
AGF-69/70	42.5	6.8	17	1.6	165	200	ND	10.5	4.55
AGF-71	49	7.8	21	1.9	190	240	ND	17	4.2

italics = constituent exceeded holding time
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Agua Fria Basin, 2004-2006--Continued

Site #	Nitrate-Nitrite-N (mg/L)	Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Total Phosphorus (mg/L)	SAR (value)	Irrigation Quality
AGF-1/1D	ND	ND	*ND*	0.049	ND	ND	10.1	CS-S2
AGF-2/2S	1.7	ND	*ND*	0.074	ND	0.061	1.1	C2-S1
AGF-3/3D	5.25	5.25	*ND*	ND	ND	0.0465	10.1	C3-S2
AGF-4/4S	1.55	1.55	*ND*	ND	ND	ND	0.7	C2-S1
AGF-5	0.21	0.21	ND	ND	ND	0.043	12.1	C3-S3
AGF-6	0.31	0.31	ND	0.18	-	ND	0.5	C2-S1
AGF-7	ND	ND	ND	0.38	-	0.32	0.5	C3-S1
AGF-8	0.17	0.17	ND	ND	-	0.054	0.2	C2-S1
AGF-11	0.72	0.72	ND	0.074	-	0.038	1.1	C3-S1
AGF-13	0.28	0.28	ND	0.17	-	0.053	2.3	C3-S1
AGF-14	0.15	0.15	ND	0.090	-	0.063	1.5	C3-S1
AGF-15/16	1.03	1.03	ND	0.59	ND	0.044	0.4	C3-S1
AGF-17/18	1.4	1.4	ND	ND	ND	0.044	1.4	C3-S1
AGF-19	0.42	0.42	ND	ND	-	0.050	0.8	C2-S1
AGF-20	ND	ND	ND	0.071	-	0.11	0.9	C3-S1
AGF-21/22	ND	ND	ND	0.155	-	0.30	0.9	C2-S1
AGF-23	0.065	0.065	ND	ND	-	0.049	0.3	C2-S1
AGF-26	0.52	0.52	ND	ND	-	0.047	0.4	C2-S1
AGF-27	ND	ND	ND	0.13	-	0.023	0.8	C2-S1
AGF-28	0.21	0.21	ND	0.15	-	0.043	0.6	C2-S1
AGF-30/31	4.9	4.9	ND	0.055	ND	ND	0.5	C2-S1
AGF-32/33	0.82	0.82	ND	0.098	-	0.0985	1.2	C3-S1
AGF-34	0.667	0.64	0.027	0.57	-	0.20	0.5	C2-S1
AGF-35/36	0.91	0.91	ND	ND	ND	0.059	0.5	C2-S1
AGF-37/38	ND	ND	ND	0.080	-	0.143	2.1	C3-S1
AGF-39	0.79	0.79	ND	ND	-	0.079	1.0	C2-S1
AGF-41	ND	ND	ND	0.25	-	0.058	0.6	C2-S1

italics = constituent exceeded holding time
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Agua Fria Basin, 2004-2006--Continued

Site #	**Nitrate-Nitrite-N** (mg/L)	**Nitrate-N** (mg/L)	**Nitrite-N** (mg/L)	**TKN** (mg/L)	**Ammonia** (mg/L)	**Total Phosphorus** (mg/L)	**SAR** (value)	**Irrigation Quality**
AGF-42	3.9	3.9	*ND*	0.18	-	ND	1.3	C3-S1
AGF-43	5.6	5.6	*ND*	0.10	-	ND	.5	C2-S1
AGF-44	1.3	1.3	*ND*	ND	-	0.042	1.2	C3-S1
AGF-47	0.52	0.52	*ND*	ND	-	0.031	.5	C2-S1
AGF-48/49	ND	ND	ND	1.2	ND	ND	2.1	C3-S1
AGF-50	1.1	1.1	ND	ND	-	ND	1.2	C3-S1
AGF-51	0.24	0.24	ND	0.11	-	0.037	2.8	C3-S1
AGF-53/54	ND	ND	ND	0.30	ND	0.065	31.1	C4-S4
AGF-55	3.0	3.0	ND	ND	-	0.03	0.9	C3-S1
AGF-56	1.9	1.9	ND	0.20	-	0.12	0.7	C2-S1
AGF-57	ND	ND	ND	-	-	ND	2.8	C3-S1
AGF-60/61	3.05	3.05	ND	0.13	0.056	ND	1.9	C3-S1
AGF-62	**19**	**19**	ND	-	0.022	ND	1.2	C3-S1
AGF-63	0.12	0.12	ND	0.078	0.11	ND	10.6	C4-S4
AGF-64/65	0.08	0.08	ND	0.0815	0.0715	ND	8.7	C2-S2
AGF-66/67	4.22	4.22	ND	0.49	ND	ND	2.7	C4-S1
AGF-68	0.56	0.56	ND	0.17	-	0.06	2.0	C3-S1
AGF-69/70	0.034	0.034	ND	ND	-	0.03	0.6	C2-S1
AGF-71	ND	ND	ND	0.08	-	0.02	0.7	C2-S1

italics = constituent exceeded holding time
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Agua Fria Basin, 2004-2006--Continued

Site #	Antimony (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Fluoride (mg/L)
AGF-1/1D	ND	ND	ND	ND	ND	ND	ND	ND	0.28
AGF-2/2S	ND	**0.0125**	ND	ND	0.12	ND	ND	ND	0.325
AGF-3/3D	ND	**0.031**	ND	ND	2.15	ND	ND	0.225	**4.7**
AGF-4/4S	ND	ND	ND	ND	ND	ND	ND	ND	0.30
AGF-5	ND	**0.010**	0.14	ND	ND	ND	ND	0.053	**6.8**
AGF-6	ND	ND	ND	ND	ND	ND	ND	0.014	0.14
AGF-7	ND	ND	ND	ND	ND	ND	ND	ND	0.24
AGF-8	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-11	ND	ND	ND	ND	ND	ND	ND	ND	0.94
AGF-13	ND	ND	0.25	ND	ND	ND	ND	ND	0.41
AGF-14	ND	0.0058	ND	ND	0.12	ND	ND	ND	0.38
AGF-15/16	ND	ND	ND	ND	ND	ND	ND	ND	0.265
AGF-17/18	ND	**0.0155**	0.046	ND	0.14	ND	ND	ND	0.32
AGF-19	ND	ND	ND	ND	ND	ND	ND	ND	0.16
AGF-20	ND	ND	0.081	ND	ND	ND	ND	ND	0.38
AGF-21/22	ND	ND	0.10	ND	ND	ND	ND	ND	0.25
AGF-23	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-26	ND	ND	ND	ND	ND	ND	ND	ND	0.15
AGF-27	ND	**0.013**	ND	ND	ND	ND	ND	ND	0.69
AGF-28	ND	ND	ND	ND	ND	ND	ND	ND	0.45
AGF-30/31	ND	/ND	0.011	ND	ND	ND	0.014	ND	0.195
AGF-32/33	ND	0.0079	ND	ND	ND	ND	ND	ND	0.15
AGF-34	ND	.0054	ND	ND	ND	ND	ND	ND	0.16
AGF-35/36	ND	ND	ND	ND	ND	ND	ND	ND	0.185
AGF-37/38	ND	ND	0.105	ND	ND	ND	ND	ND	0.51
AGF-39	ND	ND	ND	ND	ND	ND	ND	ND	0.29
AGF-41	ND	ND	ND	ND	ND	ND	ND	ND	0.51

italics = constituent exceeded holding time
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Agua Fria Basin, 2004-2006--Continued

Site #	Antimony (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Fluoride (mg/L)
AGF-42	ND	**0.017**	ND	ND	ND	ND	ND	ND	ND
AGF-43	ND	ND	ND	ND	ND	ND	ND	ND	0.18
AGF-44	ND	ND	ND	ND	ND	ND	ND	ND	0.25
AGF-47	ND	ND	ND	ND	ND	ND	ND	ND	0.15
AGF-48/49	ND	**0.027**	ND	0.31	ND	ND	ND	ND	1.35
AGF-50	ND	ND	ND	ND	ND	ND	ND	ND	0.76
AGF-51	ND	0.0086	ND	ND	0.32	ND	ND	ND	**2.7**
AGF-53/54	ND	**2.25**	ND	ND	9.6	ND	ND	ND	**10**
AGF-55	ND	**0.014**	ND	ND	ND	ND	ND	ND	0.28
AGF-56	ND	**0.010**	ND	ND	ND	ND	0.011	ND	0.39
AGF-57	ND	**0.020**	ND	ND	0.15	ND	ND	ND	**2.2**
AGF-60/61	ND	ND	ND	ND	0.13	ND	ND	ND	0.405
AGF-62	ND	ND	ND	ND	ND	ND	ND	ND	0.16
AGF-63	ND	**0.015**	ND	ND	1.7	ND	ND	ND	**4.1**
AGF-64/65	ND	**0.0445**	ND	ND	0.875	ND	ND	ND	**8.2**
AGF-66/67	ND	ND	ND	ND	0.19	ND	ND	ND	0.39
AGF-68	ND	ND	0.12	ND	ND	ND	ND	ND	0.53
AGF-69/70	ND	ND	0.205	ND	ND	ND	ND	ND	0.205
AGF-71	ND	ND	0.34	ND	ND	ND	ND	ND	0.27

italics = constituent exceeded holding time
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Agua Fria Basin, 2004-2006--Continued

Site #	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Zinc (mg/L)
AGF-1/1D	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-2/2S	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-3/3D	ND	ND	ND	ND	ND	ND	ND	ND	0.225
AGF-4/4S	ND	ND	ND	ND	ND	ND	ND	ND	0.18
AGF-5	ND	ND	ND	ND	ND	ND	ND	ND	0.058
AGF-6	ND	ND	**0.072**	ND	ND	ND	ND	ND	ND
AGF-7	ND	ND	**1.0**	ND	ND	ND	ND	ND	ND
AGF-8	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-11	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-13	ND	ND	**0.050**	ND	ND	ND	ND	ND	ND
AGF-14	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-15/16	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-17/18	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-19	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-20	**0.61**	ND	**0.29**	ND	ND	ND	ND	ND	ND
AGF-21/22	ND	ND	**0.73**	ND	ND	ND	ND	ND	ND
AGF-23	ND	ND	ND	0.00025	ND	ND	ND	ND	ND
AGF-26	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-27	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-28	**1.6**	ND	ND	ND	ND	ND	ND	ND	ND
AGF-30/31	0.15	ND	**0.32**	ND	ND	ND	ND	ND	ND
AGF-32/33	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-34	ND	ND	**0.30**	ND	ND	ND	ND	ND	ND
AGF-35/36	ND	ND	ND	ND	ND	ND	ND	ND	0.07
AGF-37/38	ND	ND	**0.10**	ND	ND	ND	ND	ND	ND
AGF-39	ND	ND	ND	ND	ND	ND	ND	ND	0.69
AGF-41	ND	ND	**0.51**	ND	ND	ND	ND	ND	ND

italics = constituent exceeded holding time
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Agua Fria Basin, 2004-2006--Continued

Site #	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Zinc (mg/L)
AGF-42	ND	ND	ND	ND	ND	ND	ND	ND	0.062
AGF-43	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-44	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-47	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-48/49	0.25	ND	ND	ND	ND	ND	ND	ND	ND
AGF-50	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-51	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-53/54	0.14	ND	ND	ND	ND	ND	ND	ND	ND
AGF-55	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-56	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-57	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-60/61	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-62	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-63	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-64/65	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-66/67	0.13	ND	ND	ND	ND	ND	ND	ND	1.15
AGF-68	ND	ND	ND	ND	ND	ND	ND	ND	ND
AGF-69/70	ND	ND	ND	ND	ND	ND	ND	ND	0.175
AGF-71	ND	ND	ND	ND	ND	ND	ND	ND	ND

italics = constituent exceeded holding time
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Agua Fria Basin, 2004-2006--Continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Ra-226 (pCi/L)	Uranium (µg/L)	$\delta^{18}O$ (‰)	δD (‰)	Type of Chemistry
AGF-1/1D	-	5.5	2.8	< LLD	-	- 8.1	- 62	sodium-bicarbonate
AGF-2/2S	-	0.79	3.9	-	-	- 7.1	-51	mixed-bicarbonate
AGF-3/3D	-	1.6	2.7	-	-	- 8.8	-66	sodium-bicarbonate
AGF-4/4S	289	-	-	-	-	-	-	calcium-bicarbonate
AGF-5	-	4.8	1.7	-	-	- 9.1	- 67	sodium-bicarbonate
AGF-6	-	-	-	-	-	- 8.7	- 65	mixed-bicarbonate
AGF-7	-	-	-	-	-	- 8.0	- 62	mixed-bicarbonate
AGF-8	**338**	< LLD	< LLD	-	-	- 10.9	- 74	mixed-bicarbonate
AGF-9	-	-	-	-	-	- 10.7	- 73	-
AGF-11	272	0.05	1.2	-	-	- 8.7	- 64	calcium-bicarbonate
AGF-12	-	-	-	-	-	- 7.5	- 50	-
AGF-13	-	1.6	1.0	-	-	- 9.7	- 71	mixed-bicarbonate
AGF-14	212	1.4	0.75	-	-	- 8.4	- 63	mixed-mixed
AGF-15/16	111.5	1.25	< LLD	3.8	1.6	- 8.65	- 65	calcium-mixed
AGF-17/18	157	-	-	-	-	- 8.3	- 62	mixed-bicarbonate
AGF-19	259	-	-	-	-	- 9.2	- 67	calcium-bicarbonate
AGF-20	-	-	-	-	-	- 9.2	- 69	calcium-bicarbonate
AGF-21/22	-	< LLD	1.7	-	-	- 10.85	- 75	calcium-bicarbonate
AGF-23	-	-	-	-	-	- 11.4	- 80	calcium-bicarbonate
AGF-24	-	-	-	-	-	- 7.5	- 50	-
AGF-26	229	-	-	-	-	- 8.8	- 65	mixed-bicarbonate
AGF-27	**351**	12	5.2	< LLD	-	- 10.3	- 72	calcium-bicarbonate
AGF-28	-	4.4	2.9	-	-	- 11.1	- 75	calcium-bicarbonate
AGF-29	-	-	-	-	-	- 8.4	- 58	-
AGF-30/31	108	1.2	2.1	-	-	- 8.95	- 68.5	mixed-bicarbonate
AGF-32/33	149	2.5	5.1	-	-	- 5.9	- 49	mixed-bicarbonate
AGF-34	-	-	-	-	-	- 8.2	- 64	calcium-bicarbonate
AGF-35/36	-	-	-	-	-	- 8.9	- 64	mixed-bicarbonate

LLD = Lower Limit of Detection
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level
Radon is only a proposed EPA Safe Drinking Water Act constituent

Appendix B. Groundwater Quality Data, Agua Fria Basin, 2004-2006--Continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Ra-226 (pCi/L)	Uranium (µg/L)	$\delta^{18}O$ (‰)	δD (‰)	Type of Chemistry
AGF-37/38	-	-	-	-	-	- 9.6	- 68	mixed-bicarbonate
AGF-39	176	1.9	2.7	-	-	- 9.2	- 66	mixed-bicarbonate
AGF-40	-	-	-	-	-	- 8.8	- 64	-
AGF-41	-	-	-	-	-	- 8.2	- 62	mixed-bicarbonate
AGF-42	**395**	2.1	10	-	-	- 8.5	- 70	mixed-mixed
AGF-43	88	0.74	1.5	-	-	- 8.3	- 63	calcium-bicarbonate
AGF-44	175	< LLD	2.6	-	-	- 8.3	- 61	mixed-mixed
AGF-45	-	-	-	-	-	- 8.4	- 61	-
AGF-46	-	-	-	-	-	- 8.5	- 61	-
AGF-47	264	< LLD	2.1	-	-	- 8.8	- 65	calcium-bicarbonate
AGF-48/49	**480**	8.9	5.3	1.3	-	- 8.35	- 64	mixed-bicarbonate
AGF-50	**787**	13	7.5	< LLD	-	- 10.2	- 75	calcium-bicarbonate
AGF-51	**478**	9.2	10	< LLD	-	- 9.1	- 65	mixed-bicarbonate
AGF-52	-	-	-	-	-	- 7.8	- 58	-
AGF-53/54	**363.5**	< LLD	25	-	-	- 11.1	- 80	sodium-bicarbonate
AGF-55	**645**	1.3	0.67	-	-	- 9.8	- 69	calcium-bicarbonate
AGF-56	137	< LLD	0.81	-	-	- 8.5	- 66	mixed-bicarbonate
AGF-57	**1032**	1.9	5.6	-	-	- 8.7	- 65	mixed-bicarbonate
AGF-59	-	-	-	-	-	- 10.0	- 73	-
AGF-60/61	59	< LLD	8.6	-	-	- 10.9	- 77	mixed-mixed
AGF-62	38	-	-	-	-	- 9.8	- 71	calcium-mixed
AGF-63	**495**	< LLD	3.5	-	-	- 11.1	- 80	sodium-chloride
AGF-64/65	203.5	2.0	8.4	-	-	- 11.25	- 81.5	sodium-mixed
AGF-66/67	166	3.6	8.7	-	-	- 9.15	- 69	mixed-chloride
AGF-68	75	< LLD	3.2	-	-	- 10.5	- 74	mixed-bicarbonate
AGF-69/70	50	5.2	2.7	< LLD	-	- 10.6	- 71	calcium-bicarbonate
AGF-71	-	**23**	8.3	< LLD	12	- 10.8	- 72	calcium-bicarbonate

LLD = Lower Limit of Detection
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level
Radon is only a proposed EPA Safe Drinking Water Act constituent