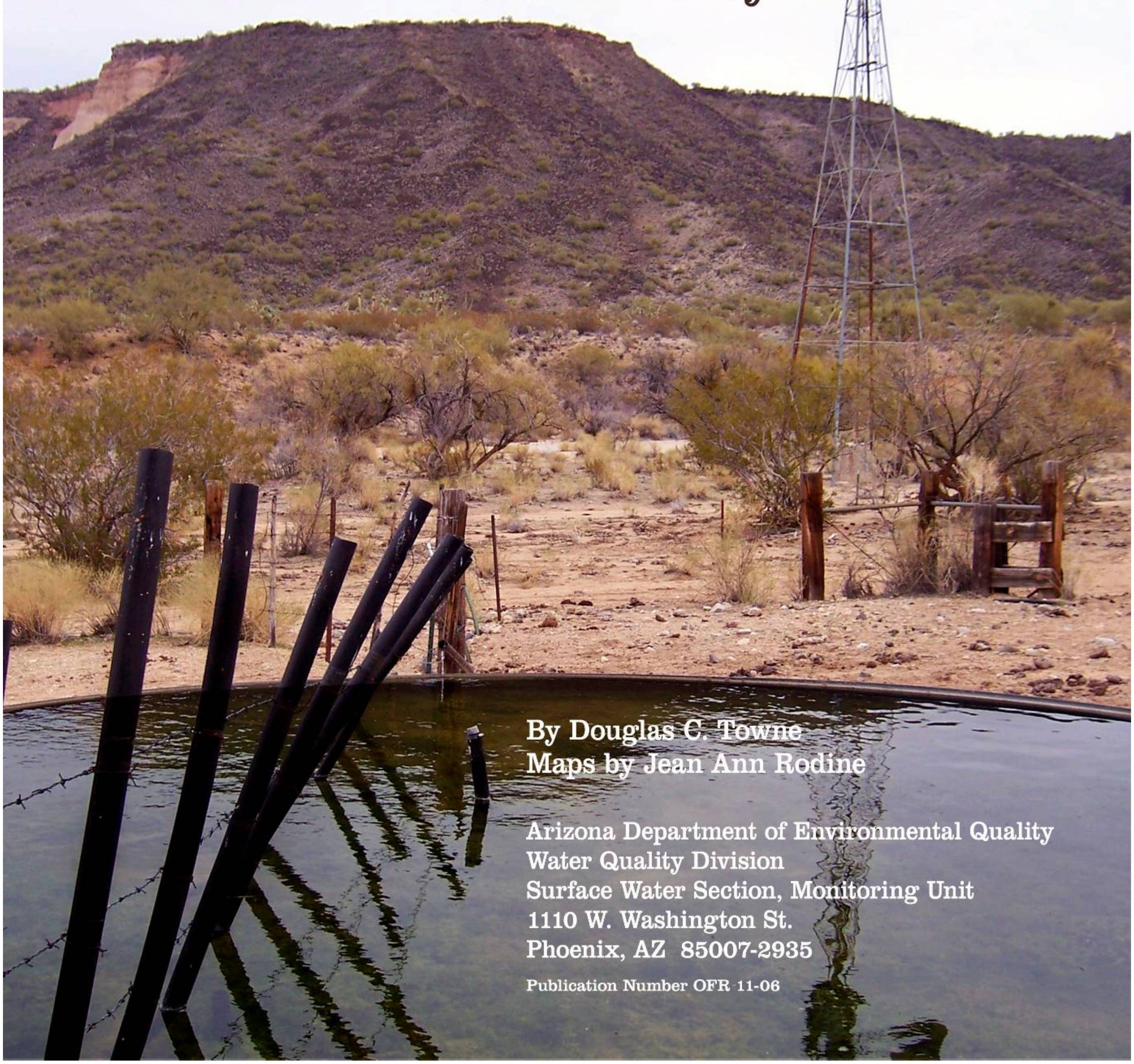
ADEQ
Arizona Department
of Environmental Quality

Ambient Groundwater Quality of the

Bill Williams Basin: A 2003-2009 Baseline Study



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Maps by Jean Ann Rodine

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Arizona Department of Environmental Quality Open File Report 2011-6

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Thanks:

Field Assistance: Elizabeth Boettcher, Susan Fitch, Joe Harmon, Jason Jones, Angela Lucci, Jason Sutter, Linda Taunt, and Wang Yu.

Special recognition is extended to the well owners who were kind enough to give permission to collect groundwater data on their property.

Report Cover: As evidenced by the overflowing stock tank, “Broken Windmill” was very much operational during sampling activities conducted in January 2008. Laboratory analysis indicated the sample (BWM-58) met all water quality standards and was of mixed-bicarbonate chemistry. The windmill supplies water for livestock in two grazing allotments that are separated by the fence stretching across the tank.

Other Publications of the ADEQ Ambient Groundwater Monitoring Program

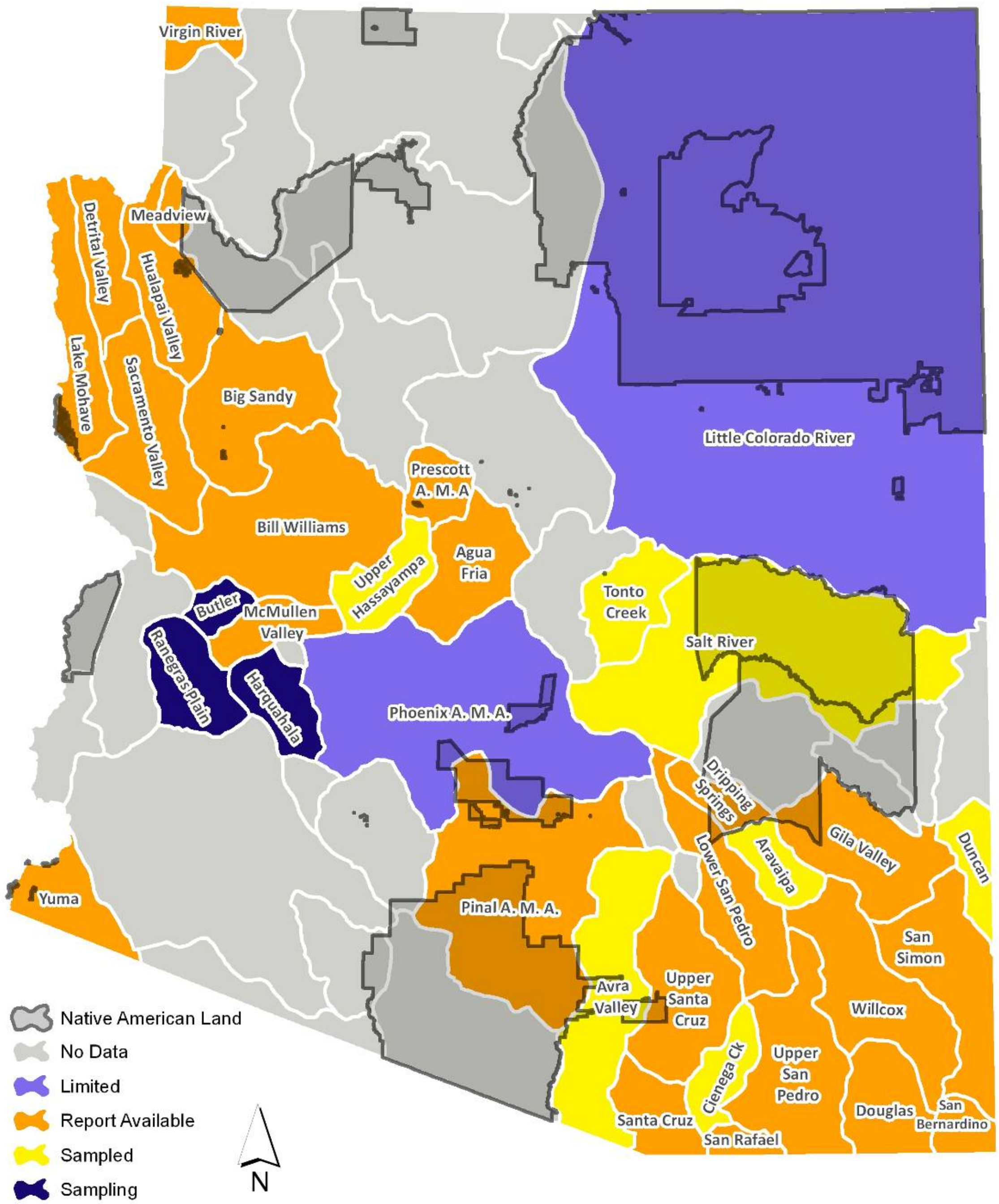
These publications are available on-line at: www.azdeq.gov/environ/water/assessment/ambient.html

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

GW Quality in Arizona: A 15-Year Overview	OFR 11-04, July 2010, 26 p.
San Bernardino Valley Basin	OFR 10-03, August 2010, 34 p.
Dripping Springs Wash Basin	OFR 10-02, July 2010, 33 p.
McMullen Valley Basin	OFR 11-02, June 2010, 94 p.
Gila Valley Sub-basin	OFR 09-12, November 2009, 99 p.
Agua Fria Basin	OFR 08-02, July 2008, 60 p.
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 USGS)
Prescott Active Management Area	OFR 00-01, May 2000, 77 p.
Upper San Pedro Basin	OFR 99-12, July 1999, 50 p. (With the USGS)
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):

Bill Williams Basin	FS 12-01, June 2011, 4 p.
San Bernardino Valley Basin	FS 10-31, December 2010, 4 p.
Dripping Springs Wash Basin	FS 11-02, August 2010, 4 p.
McMullen Valley Basin	FS 11-03, June 2010, 6 p.
Gila Valley Sub-basin	FS 09-28, November 2009, 8 p.
Agua Fria Basin	FS 08-15, 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 USGS)



Virgin River
Meadview
Detrital Valley
Hualapai Valley
Lake Mohave
Sacramento Valley
Big Sandy
Bill Williams
Prescott A. M. A.
Agua Fria
Upper Hassayampa
Butler
McMullen Valley
Ranegras Plain
Harquahala
Phoenix A. M. A.
Little Colorado River
Tonto Creek
Salt River
Dripping Springs
Lower San Pedro
Aravaipa
Gila Valley
Duncan
Yuma
Pinal A. M. A.
Avra Valley
Upper Santa Cruz
San Simon
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Cienega Ck
Upper San Pedro
Santa Cruz
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Douglas
San Bernardino
Native American Land
No Data
Limited
Report Available
Sampled
Sampling
N

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Abbreviations

amsl	above mean sea level
ac-ft	acre-feet
af/yr	acre-feet per year
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
BWM	Bill Williams Groundwater Basin
^{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
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
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 Bill Williams Basin: A 2003-2009 Baseline Study

Abstract – From 2003 through 2009, the Arizona Department of Environmental Quality (ADEQ) conducted a baseline groundwater quality study of the Bill Williams Basin located within La Paz, Mohave and Yavapai Counties in the west-central portion of Arizona. The basin covers approximately 3,200 square miles and is divided into five sub-basins: Alamo Reservoir, Burro Creek, Clara Peak, Santa Maria and Skull Valley.[4] Extensive portions of the basin are largely inaccessible because of rugged terrain. Lightly populated, there are limited wells and springs available in the basin for sampling. Major economic activities include ranching and the Freeport-McMoRan Bagdad copper mine, which imports water from the Big Sandy basin.[4]

Groundwater is the primary source for both domestic and stock uses with some irrigation of crops mainly for livestock consumption. The basin's main drainage is the Bill Williams River which is formed by the confluence of the Big Sandy and Santa Maria Rivers. Alamo Dam forms Alamo Lake about five miles downstream of the confluence. Streams in the basin with perennial reaches include the Big Sandy River, Burro Creek, Boulder Creek, Date Creek, Kirkland Creek, and the Santa Maria River.[4]

The Bill Williams basin consists of a heterogeneous mix of mountainous areas interspersed with alluvial deposits. Groundwater occurs in younger alluvial deposits, in basin-fill deposits, and in fractured and porous volcanic, metamorphic, sedimentary and granitic rock.[21] The younger alluvium has high water-yielding potential but is found only along stretches of some major streams and in Peeples Valley. Basin-fill deposits, comprised of conglomerate, siltstone and tuff are the basin's main water-bearing unit. Hard rock, where sufficiently fractured or decomposed, may produce enough well water for stock or domestic use.[21]

To characterize regional groundwater quality, samples were collected from 100 sites consisting of 84 domestic, stock, and irrigation wells along with 16 springs. Inorganic constituents and oxygen and deuterium isotopes were collected at all sites. In addition, 55 radionuclide, 47 radon, and 27 perchlorate samples were collected. Groundwater is typically *slightly-alkaline*, *fresh*, and *hard* to *very hard*, based upon pH levels and total dissolved solids (TDS) and hardness concentrations.[8, 12] Samples predominantly were of calcium, mixed or sodium-bicarbonate chemistry. Nutrient concentrations were typically low. Arsenic, barium, boron, fluoride and zinc were the only trace elements commonly detected.

Health-based, primary maximum contaminant levels (MCLs) are enforceable standards that define the maximum concentrations of constituents allowed in water supplied for drinking water purposes by a public water system. These water quality standards are based on a lifetime daily consumption of two liters.[23] Health-based primary MCLs were exceeded at 28 sites of the 100 sites. Constituents above Primary MCLs include arsenic (10 sites but only 2 sites exceeded the Arizona Water Quality Standard), cadmium (one site), chromium (one site), fluoride (four sites), gross alpha (16 sites), lead (one site), nitrate (three sites), radium 226+228 (four sites), and uranium (seven sites).

Aesthetics-based secondary MCLs are unenforceable guidelines that define the maximum constituent concentration that can be present in drinking water without an unpleasant taste, color, or odor.[23] Aesthetics-based secondary MCLs were exceeded at 49 of the 100 sites. Constituents above Secondary MCLs include chloride (five sites), fluoride (23 sites), iron (two sites), manganese (11 sites), pH (four sites), sulfate (six sites), and TDS (32 sites). Of the 47 sites sampled for radon, 28 sites exceeded the proposed 300 pCi/L standard.[23]

Isotope samples collected from higher elevation sites such as the Skull Valley sub-basin tended to be lighter, less evaporated, and more depleted. In contrast, samples collected from lower elevation sites such as the Clara Peak and Alamo Reservoir sub-basins were heavier, more evaporated and enriched. However, some samples had isotope values more depleted than would be expected from recharge originating in the basin. These likely consist of paleowater recharged 8,000-12,000 years ago when the climate was cooler and subject to less evaporation.[10]

The basin's large size combined with its heterogeneous geology result in few groundwater quality patterns among sub-basins and rock types. Groundwater samples collected from Skull Valley sub-basin had significantly lower concentrations of sodium, fluoride, boron, oxygen-18 and deuterium than the other sub-basins. Groundwater samples collected from sites located in hard rock areas had significantly higher concentrations of hardness, calcium, magnesium, bicarbonate and zinc than alluvial areas; the opposite pattern occurred with pH-lab, potassium, boron, oxygen-18, and deuterium. (Kruskal-Wallis with Tukey test, $p \leq 0.05$).

INTRODUCTION

Purpose and Scope

The Bill Williams groundwater basin covers approximately 3,200 square miles within Yavapai, Mohave and La Paz Counties in west central Arizona (Map 1). [4] The large basin is lightly populated and includes the small communities of Bagdad, Hillside, Kirkland, Kirkland Junction, Peeples Valley, and Skull Valley.

Groundwater is the primary source for irrigation, mining, domestic and stock water supply within the basin. [21] Much of the land within the Bill Williams Basin is rugged, inaccessible by roads and consists of rangeland used for low-intensity livestock grazing. Irrigated agriculture consists of isolated fields particularly in Peeples Valley, and along lower Kirkland Creek and the Bill Williams River. Crops are grown primarily for supplemental livestock feed. Near Bagdad is the large open pit copper mine operated by Freeport-McMoRan; most water used there is imported from the Big Sandy Basin. [4]

Sampling by the Arizona Department of Environmental Quality (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*." [2]

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 Bill Williams Basin identifying water quality differences among sub-basins.
- 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 basin encompasses a large area in west-central Arizona. The eastern, upgradient portion of the basin is in the Central Highlands Physiographic Province and consists mainly of rugged mountains consisting of igneous, metamorphic, and well-consolidated sedimentary rocks along with a few small valleys. The western, downgradient portion is in the Basin and Range Physiographic Province which is characterized by mountains separated by broad valleys. [21]

The basin is bounded on the west by the McCracken, Mohave, and Bill Williams Mountains, on the north by the Hualapai and Mohon Mountains, on the east by the Juniper and Granite Mountains, and on the south by the Weaver, Date Creek, Harcuvar, and Buckskin Mountains.

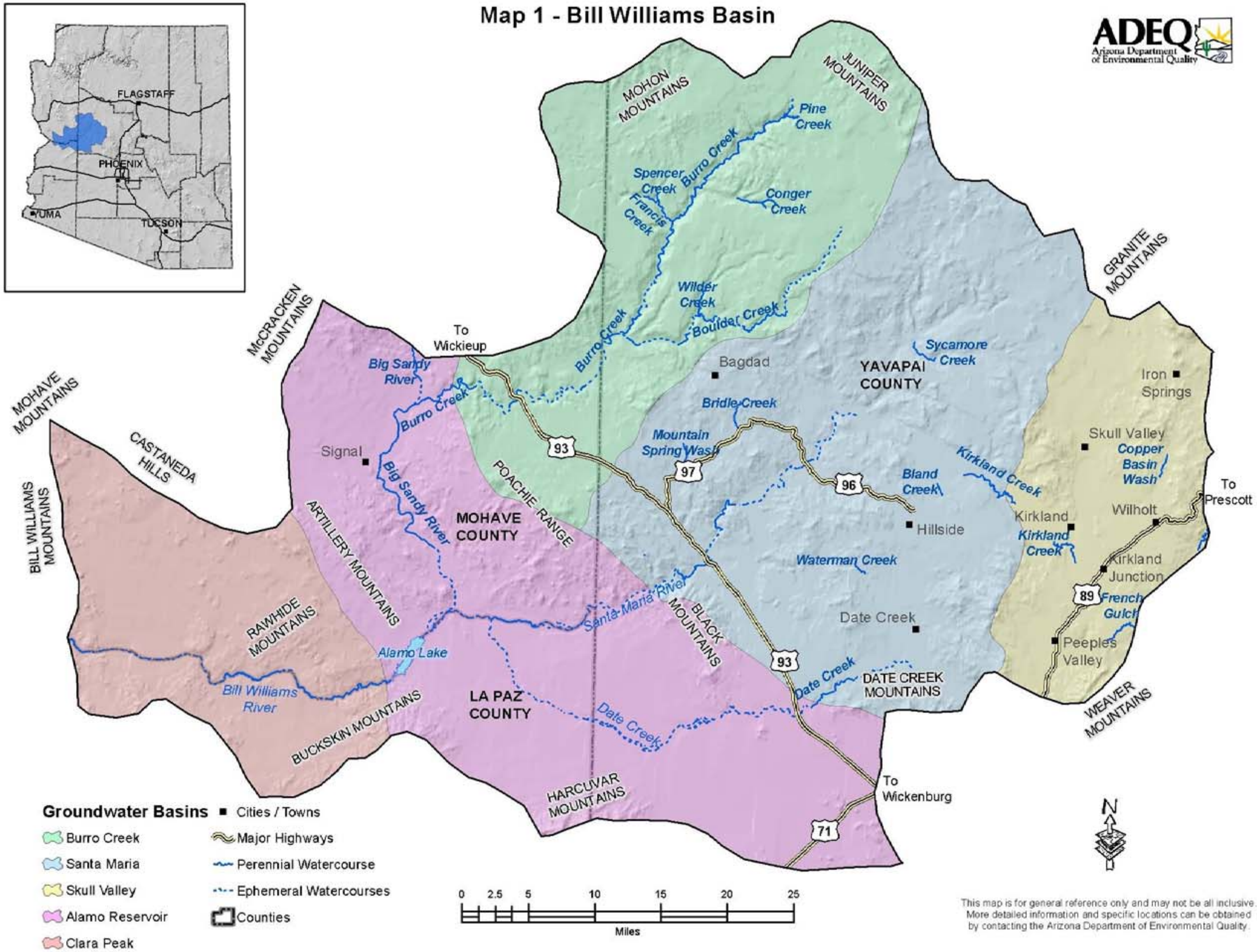
Elevations range from 7,244 feet above mean sea level (amsl) at Bear Mountain in the northeast part of the basin to approximately 500 feet amsl near Kohen Ranch where the Bill Williams River crosses into the Parker Basin.

Land Ownership – Land ownership predominantly consists of federal land managed by the Bureau of Land Management in the western two-thirds of the basin, with swaths of State Trust and federal land managed by the Forest Service in the eastern third; interspersed throughout the basin are scattered parcels of private land. [3]

Vegetation – Natural vegetation below 3,000 feet in the basin consists of Sonoran desert scrub including cacti, creosote and desert trees such as acacia, mesquite, palo verde and ironwood. From 3,000 – 5,500 feet the vegetation is Mohave desert scrub that includes Joshua trees, grasses, and agaves. At the highest elevations in the basin are found junipers, oaks and ponderosa pines. [4]

Climate – The Bill Williams Basin becomes cooler and wetter with increasing elevation. Annual average precipitation increases from almost 9 inches at Alamo Dam, to 14 inches at Bagdad to over 15 inches at Hillside. Precipitation occurs predominantly as rain in either late summer, localized monsoon thunderstorms or, less often, as widespread, low intensity winter rain that sometimes includes snow at higher elevations. [4]

Map 1 - Bill Williams Basin



This map is for general reference only and may not be all inclusive. More detailed information and specific locations can be obtained by contacting the Arizona Department of Environmental Quality.

HYDROLOGY

Surface Water – The major drainages in the Bill Williams basin include the Big Sandy River and Santa Maria River which converge approximately five miles upstream of Alamo Dam where their flow is impounded in Alamo Lake. Downstream, the Bill Williams River is fed from releases from Alamo Dam until it leaves the basin and eventually debouches into the Colorado River. [4]

Perennial surface water within the basin include portions of the Big Sandy River and Santa Maria River and some of their tributaries including Burro Creek, Francis Creek, Boulder Creek, Kirkland Creek, Cottonwood Canyon, and Date Creek. [4] Many of these waterways are supported by seeps and springs that are located at hard rock fissures and along fault zones.

Groundwater – Groundwater is found in the basin in the following geologic formations:

- Basin-fill deposits
- Terrace and channel deposits
- Crystalline and volcanic rocks

The majority of the Bill Williams basin consists of crystalline rocks (mainly schist, gneiss, and granite) and volcanic rocks. [21] These rocks, where sufficiently fractured or decomposed, may produce enough water for low-yield domestic or stock uses. Both perennial and ephemeral springs may issue from these rocks with generally low flows but may occasionally be as high as 36 gallons per minute. [21]

Valleys of varying sizes are interspersed throughout the mountainous, hardrock portions of the basin. In these areas, basin-fill deposits occur which are the main water-bearing unit in the Bill Williams Basin. The basin-fill deposits consist of boulder to pebble conglomerate and interbedded, coarse to fine-grained sandstone, siltstone, mudstone, and occasionally rhyolitic and basaltic tuff. [21]

The thickness of the basin-fill deposits is usually shallow in the Burro Creek and Santa Maria sub-basins except near Bagdad where the deposits extend 1,000 feet in depth. In the Alamo Reservoir and Clara Peak sub-basins, the basin-fill deposits are thicker and exceed 5,000 feet near Date Creek. [21]

Terrace and channel deposits occur along the Bill Williams River and its major tributaries. Consisting of gravel, sand, and silt, the deposits typically produce large amounts of water for irrigation, domestic and stock use but are of limited spatial extent. Terrace and channel deposits also occur in Peeples Valley where they are the main aquifer. [21]

Generally groundwater in northern sections of the Bill Williams Basin is found only where hardrock is highly fractured and along small valleys that contain varying thicknesses of water-bearing deposits. In contrast, groundwater in the western portion of the basin is found in larger valleys filled with deposits that generally store large amounts of water.[21]

In general, groundwater moves in the same direction as surface water, flowing from the mountainous eastern portion of the basin downstream to where the Bill Williams River exits the basin. Most recharge in the basin occurs from the infiltration of stream flow and precipitation along mountain fronts. Wells along the Bill Williams River have had 30-foot water level variations as a result of the amount of water released from Alamo Reservoir. [21]

Figure 1 – The basin is named for the Bill Williams River, shown downstream of Alamo Dam on its way to flow into the Colorado River at Lake Havasu. Formed by the confluence of the Big Sandy and Santa Maria Rivers, flow in the river is dependent upon water releases from Alamo Dam. [4]

Figure 2 – Boulder Creek is shown at the Camp Wood Road Crossing. Boulder Creek is listed as an impaired water body because of influences from the Hillside Mine complex which has contributed metal constituents to the stream in excess of surface water quality standards.[28]

Figure 3 – Irrigated agriculture in the basin is generally limited to fields in river floodplains such as Reid Valley along the Bill Williams River where alfalfa is grown at the historic Lincoln Ranch. Samples collected from wells closer to the river had TDS concentrations at roughly half the level of upgradient wells.

Figure 4 – Tres Alamos Spring, utilized for stock and wildlife, is located within the rugged Tres Alamos Wilderness Area. The sample collected from the spring (BWM-67) met all water quality standards.

Figure 5 – The Big Sandy River, one of the two main tributaries of the Bill Williams River, is shown upstream of Alamo Reservoir at Signal Road. It is one of several streams in the basin that have perennial stretches.[4]

Figure 6 – Along Kaiser Spring Wash just downgradient of U.S. Highway 93 is Kaiser Warm Spring (BWM-38), a perennial water source that flows at constant temperature of 35 degrees Celsius. Hot spring aficionados have created a soaking pool at the site.

Figure 7 – This isn't graffiti left on a stanchion of Broken Windmill (BWM-58) but rather informative hydrologic notes left when Balow Pump last serviced the well. The well is 244 feet in total depth, the pump is set at 236 feet, the static water level is 170 feet, and the cup size for the leathers is 1 7/8 inches.

Figure 8 – The Denny Moore Windmill (BWM-72) is located in the remote, upper reaches of the Boulder Creek drainage. While pumping water during preparation for sampling, the wind suddenly quit allowing only isotope and perchlorate samples to be collected at the site.

Figure 9 - Merritt Spring in the Santa Maria Mountains is located on federal land managed by the Forest Service. As the sign indicates, the spring is not a designated potable water source and should not be used as such because of potential bacteria issues. However, with the exception of a low pH value, the sample (BWM-77) from it met all inorganic water quality standards. Bacteria sampling was not conducted at the spring however.

INVESTIGATION METHODS

ADEQ collected samples from 100 groundwater sites to characterize regional groundwater quality in the Bill Williams Basin (Map 2). All the samples were located within the basin although it appears otherwise on the maps because of an imprecise geographic information system boundary cover. Specifically, the following types of samples were collected:

- oxygen and deuterium isotopes at 100 sites
- inorganic suites at 100 sites
- radon at 47 sites
- radionuclides at 55 sites
- perchlorate at 27 sites
- mercury at 28 sites

In addition, two surface water samples from the Big Sandy River and Burro Creek were collected for oxygen and deuterium isotope analysis.

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. [11]

Wells pumping groundwater for domestic, stock and irrigation purposes were sampled for this study provided each well met ADEQ requirements. A well was considered suitable for sampling when: the owner has given permission to sample, if a sampling point existed near the wellhead, and if the well casing and surface seal appeared to be intact and undamaged.[1,5] Other factors such as construction information were preferred but not essential.

For this study, ADEQ personnel sampled 84 wells including 51 powered by submersible pumps, seven powered by turbine pumps, and 26 powered by windmills. In addition, 16 springs were sampled. Additional information on groundwater sample sites is compiled from the Arizona Department of Water Resources (ADWR) well registry in Appendix A. [4]

Sample Collection

The sample collection methods for this study conformed to the *Quality Assurance Project Plan* (QAPP) and the *Field Manual for Water Quality Sampling*.[1,5] 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.

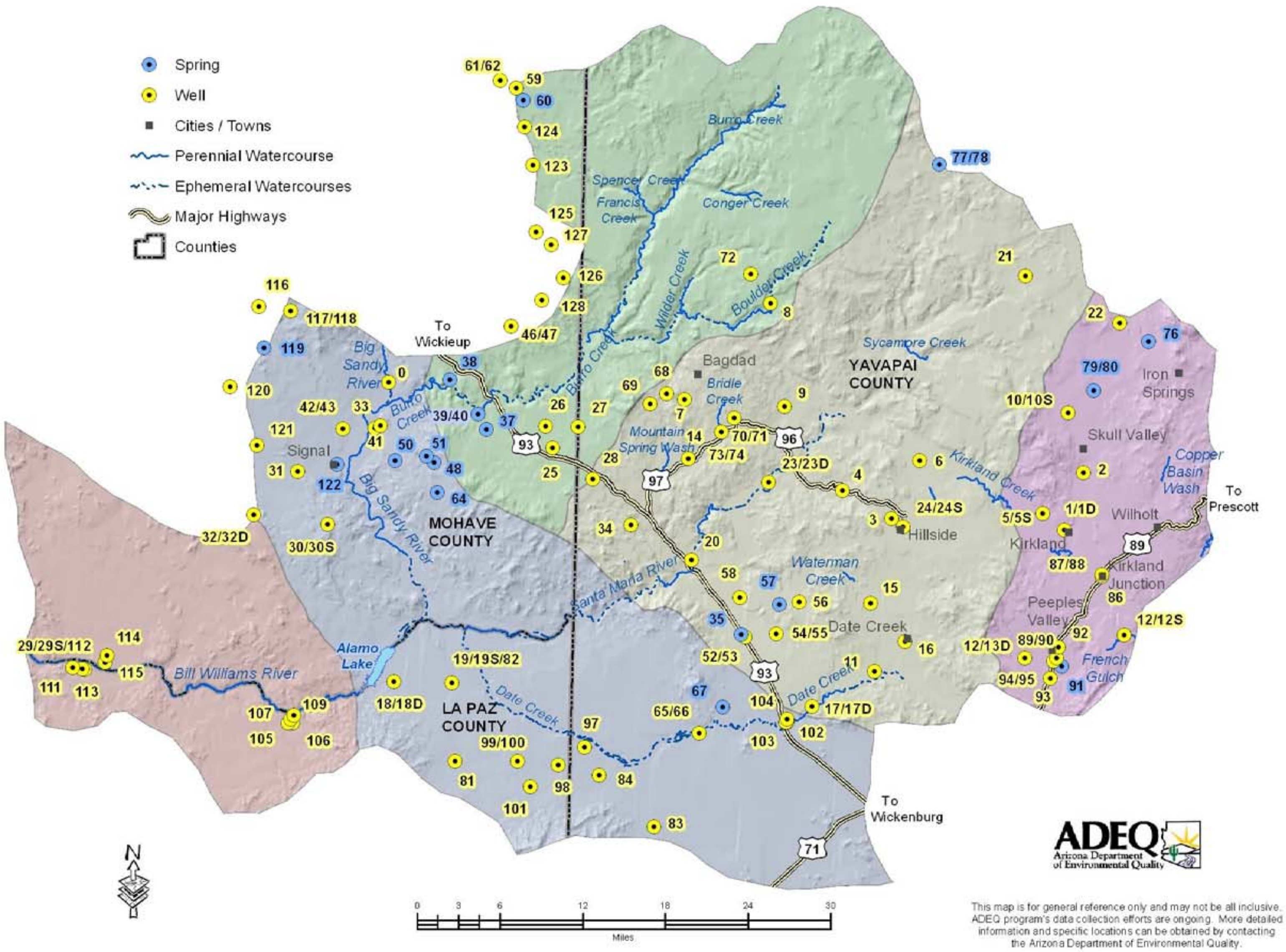
Figure 10 – A domestic well located near Date Creek is being purged prior to sampling. The sample (BWM-104) collected from the well met all water quality standards.

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. After three bore volumes had been pumped and physical parameter measurements had stabilized within 10 percent, a sample representative of the aquifer was collected from a point as close to the wellhead as possible, which assured fresh water from the aquifer. In certain instances, it was not possible to purge three bore volumes. In these cases, the sample was collected once at least one bore volume was evacuated and the physical parameters had stabilized within 10 percent.

Samples for this study were collected during 20 field trips conducted between August 2003 and June 2009. Sample bottles were filled in the following order: perchlorate, radon, mercury, inorganic, radionuclide, and isotopes.

Perchlorate and isotope samples were collected in unpreserved, 500 ml polyethylene bottles.

Map 2 - Sample Sites



Radon, a naturally occurring, intermediate breakdown from the radioactive decay of uranium-238 to lead-206, was collected in two unpreserved, 40-ml clear glass vials. Radon samples were filled to minimize volatilization and subsequently sealed so that no headspace remained.[9]

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. [19]

Radionuclide 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. [26]

Laboratory Methods

The inorganic 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, and Minimum Reporting Level (MRL) for each laboratory is provided in Table 1.

Perchlorate samples were analyzed by the Texas Tech University Environmental Services Laboratory in Lubbock, Texas. Radon samples were analyzed by Radiation Safety Engineering, Inc. Laboratory in Chandler, Arizona.

Radionuclide 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 five 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. [26]

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

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 Bill Williams 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*. [1,5] Types and numbers of QC samples collected for this study are as follows:

- Inorganic: (14 blanks, 17 duplicates, and 11 splits).
- Perchlorate: (no QA/QC samples)
- Radon: (no QA/QC samples)
- Radionuclide: (one split)
- Isotope: (no QA/QC samples)

Based on the QA/QC results, sampling procedures and laboratory equipment did not significantly affect the groundwater quality samples.

Blanks – Equipment blanks for inorganic analyses are collected to ensure adequate decontamination of sampling equipment, and that the filter apparatus and/or de-ionized water were not impacting the groundwater quality sampling. [8] Fourteen equipment blanks were collected for the study.

The blank results indicated detections just above the MRL of specific conductivity or SC (detected in 13 equipment blanks) and turbidity (detected in 9 equipment blanks). There were also trace detections of phosphorus (0.013 mg/L and 0.012 mg/L), sulfate (1.1 mg/L), and total kjeldahl nitrogen (TKN) (0.20 mg/L).

For SC, the 13 equipment blanks had a mean (4.4 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.[19]

For turbidity, the nine equipment blanks had a mean level (0.056 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

Table 1. Laboratory Water Methods and Minimum Reporting Levels Used in the Study

Constituent	Instrumentation	ADHS / Test America Water Method	ADHS / Test America Minimum Reporting Level
Physical Parameters and General Mineral Characteristics			
Alkalinity	Electrometric Titration	SM 2320B / M 2320 B	2 / 6
SC (uS/cm)	Electrometric	EPA 120.1/ M 2510 B	-- / 2
Hardness	Titrimetric, EDTA	SM 2340 C / SM 2340B	10 / 1
Hardness	Calculation	SM 2340 B	--
pH (su)	Electrometric	SM 4500 H-B	0.1
TDS	Gravimetric	SM 2540C	10 / 10
Turbidity (NTU)	Nephelometric	EPA 180.1	0.01 / 0.2
Major Ions			
Calcium	ICP-AES	EPA 200.7	1 / 2
Magnesium	ICP-AES	EPA 200.7	1 / 0.25
Sodium	ICP-AES	EPA 200.7	1 / 2
Potassium	Flame AA	EPA 200.7	0.5 / 2
Bicarbonate	Calculation	Calculation / M 2320 B	2
Carbonate	Calculation	Calculation / M 2320 B	2
Chloride	Potentiometric Titration	SM 4500 CL D / E300	5 / 2
Sulfate	Colorimetric	EPA 375.4 / E300	1 / 2
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 / M 4500-NH3	0.05 / 1.3
Total Phosphorus	Colorimetric	EPA 365.4 / M 4500-PB	0.02 / 0.1

All units are mg/L except as noted
Source [9, 19]

Table 1. Laboratory Water Methods and Minimum Reporting Levels Used in the Study--Continued

Constituent	Instrumentation	ADHS / Test America Water Method	ADHS / Test America Minimum Reporting Level
		Trace Elements	
Aluminum	ICP-AES	EPA 200.7	0.5
Antimony	Graphite Furnace AA	EPA 200.8	0.005 / 0.003
Arsenic	Graphite Furnace AA	EPA 200.9 / EPA 200.8	0.005 / 0.001
Barium	ICP-AES	EPA 200.8 / EPA 200.7	0.005 to 0.1 / 0.01
Beryllium	Graphite Furnace AA	EPA 200.9 / EPA 200.8	0.0005 / 0.001
Boron	ICP-AES	EPA 200.7	0.1 / 0.2
Cadmium	Graphite Furnace AA	EPA 200.8	0.0005 / 0.001
Chromium	Graphite Furnace AA	EPA 200.8 / EPA 200.7	0.01 / 0.01
Copper	Graphite Furnace AA	EPA 200.8 / EPA 200.7	0.01 / 0.01
Fluoride	Ion Selective Electrode	SM 4500 F-C	0.1 / 0.4
Iron	ICP-AES	EPA 200.7	0.1 / 0.05
Lead	Graphite Furnace AA	EPA 200.8	0.005 / 0.001
Manganese	ICP-AES	EPA 200.7	0.05 / 0.01
Mercury	Cold Vapor AA	SM 3112 B / EPA 245.1	0.0002 / 0.0002
Nickel	ICP-AES	EPA 200.7	0.1 / 0.01
Selenium	Graphite Furnace AA	EPA 200.9 / EPA 200.8	0.005 / 0.002
Silver	Graphite Furnace AA	EPA 200.9 / EPA 200.7	0.001 / 0.01
Thallium	Graphite Furnace AA	EPA 200.9 / EPA 200.8	0.002 / 0.001
Zinc	ICP-AES	EPA 200.7	0.05
		Radionuclides	
Gross alpha	Gas flow proportional counter	EPA 600 / 00.02	varies
Gross beta	Gas flow proportional counter	EPA 900.0	varies
Radium 226	Gas flow proportional counter	EPA 903.0	varies
Radium 228	Gas flow proportional counter	EPA 904.0	varies
Radon	Liquid scintillation counter	EPA 913.1	varies
Uranium	Kinnetic phosphorimeter	EPA Laser Phosphorimetry	varies

All units are mg/L
Source [9, 19, 26]

by the ADHS laboratory, and levels increase with time due to storage in ADEQ carboys. [19]

Duplicate Samples - Duplicate samples are identical sets of samples collected from the same source at the same time and submitted to the same laboratory. 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. Seventeen duplicate samples were collected in this study.

Analytical results indicate that of the 40 constituents examined, 22 had concentrations above the MRL. The maximum variation between duplicates was 10 percent or less (Table 2) with nine exceptions: turbidity (88 percent), iron (60 %), zinc (47 %), nitrate (33 percent), sulfate (29 percent), TKN (19 percent), barium (16 percent), manganese (15 %) and chloride (12 percent).

Constituents such as turbidity and TKN commonly have high maximum variations because of the difficulty of the laboratory tests. [19] Many constituents with a high percentage variation of concentrations such as iron, zinc, nitrate, barium manganese, and chloride have a low difference in actual concentrations.

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 40 constituents examined only 25 had concentrations above MRLs for both ADHS/ARRA and Test America laboratories (Table 3). The maximum variation between splits was 10 percent or less except for eight constituents: turbidity (84 percent), iron (47 percent), fluoride (33 percent), total phosphorus (23 percent), sulfate (22 percent), copper (17 percent), and potassium (15 percent).

Constituents such as turbidity commonly have high maximum variations because of the difficulty of the laboratory tests. [19] Many constituents with a high percentage variation of concentrations such as iron, fluoride, total phosphorus, copper and potassium have a low difference in actual concentrations.

Split samples were also evaluated using the non-parametric Sign test to determine if there were any significant differences between ADHS laboratory and Test America laboratory analytical results.[13] There were no significant differences in constituent concentrations between the labs (Sign test, $p \leq 0.05$).

QA/QC Conclusion - 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. [14] The analytical work conducted for this study was considered valid based on the quality control samples and the QA/QC correlations.

Cation/Anion Balances - In theory, water samples exhibit electrical neutrality. Therefore, the sum of milliquivalents per liter (meq/L) of cations should 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.[14]

Cation/anion meq/L balances of Bill Williams Basin samples were significantly correlated (regression analysis, $p \leq 0.01$). Of the 100 samples collected, 93 were within +/-5 percent and 4 more were within +/-10 percent. Of the remaining three samples, BWM-34 had a low cation/high anion difference of almost 14 percent. Two samples had large high cation/low anion differences including BWM-50 with an almost 32 percent difference. A duplicate pair of samples, BWM-54/55, each exhibited almost identical 19 percent differences. In the latter three examples, the ADHS laboratory was alerted but found no reason for the differences. [19]

SC/TDS - The SC and TDS concentrations measured by contract laboratories were significantly correlated as were SC-field and TDS concentrations (regression analysis, $r = 0.98$, $p \leq 0.01$). 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.[14] Groundwater high in bicarbonate and chloride will have a multiplication factor near the lower end of this range; 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.[14]

Table 2. Summary Results of Bill Williams 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	17	0 %	9 %	0 %	0	30	0
SC (uS/cm)	17	0 %	2 %	0 %	0	100	0
Hardness	17	0 %	5 %	0 %	0	40	0
pH (su)	17	0 %	1 %	0 %	0	0.2	0
TDS	17	0 %	6 %	0 %	0	100	0
Turb. (NTU) *	17	0 %	88 %	6 %	0	10	0.02
Major Ions							
Bicarbonate	17	0 %	7 %	0 %	0	30	0
Carbonate	1	-	-	6 %	-	-	2
Calcium	17	0 %	6 %	0 %	0	40	0
Magnesium	17	0 %	4 %	0 %	0	10	0
Sodium	17	0 %	5 %	0 %	0	20	0
Potassium	17	0 %	5 %	0 %	0	1	0
Chloride	17	0 %	12 %	0 %	0	10	0
Sulfate	17	0 %	29 %	1 %	0	100	0.2
Nutrients							
Nitrate (as N)	17	0 %	33 %	2 %	0	0.6	0.015
TKN *	2	6 %	19 %	-	0.02	0.09	
Ammonium	1	-	-	6 %	-	-	0.004
Phosphorus, T. *	4	1 %	5 %	3 %	0.001	0.03	0.002
Trace Elements							
Arsenic	3	0 %	0 %	0 %	0	0	0
Barium	10	0 %	16 %	3 %	0	0.1	0.002
Boron *	10	0 %	6 %	0 %	0	0.07	0
Chromium	2	0 %	1 %	-	0	0.001	-

All concentration units are mg/L except as noted with certain physical parameters.

Table 2. Summary Results of Bill Williams Basin Duplicate Samples from the ADHS Laboratory—Continued

Parameter	Number	Difference in Percent			Difference in Concentrations		
		Minimum	Maximum	Median	Minimum	Maximum	Median
Trace Elements							
Copper	1	-	-	3 %	-	-	0.001
Fluoride	17	0 %	5 %	0 %	0	0.3	0
Iron	2	0 %	60 %	-	0	0.67	-
Manganese	4	0 %	15 %	6 %	0	0.06	0.011
Strontium	2	0 %	4 %	-	0	0.03	-
Zinc	8	3 %	47 %	5 %	0.005	2.3	0.1

All concentration units are mg/L except as noted with certain physical parameters.
Chromium was detected at 0.11 mg/L in one duplicate and not detected in the other duplicate at an MRL of 0.10 mg/L.
Copper was detected at 0.14 mg/L in one duplicate and not detected in the other duplicate at an MRL of 0.01 mg/L.

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)].[14]

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

pH - The pH value is closely related to the environment of the water and is likely to be altered by sampling and storage.[14] Still the pH values measured in the field using a YSI meter at the time of sampling were significantly correlated with laboratory pH values (regression analysis, $r = 0.60$, $p \leq 0.01$).

Statistical Considerations

Various methods were used to complete the statistical analyses for the groundwater quality data of the study. All statistical tests were conducted using SYSTAT software.[25]

Data Normality: Data associated with 27 constituents were tested for non-transformed normality using the Kolmogorov-Smirnov one-sample test with the Lilliefors option.[6] Results of this test revealed that of the 27 constituents examined only radon concentrations were normally distributed.

Spatial Relationships: The non-parametric Kruskal-Wallis test using untransformed data was applied to investigate the hypothesis that constituent concentrations from groundwater sites from different sub-basins and geologic classifications were the same. The Kruskal-Wallis test uses the differences, but also incorporates information about the magnitude of each difference.[25] 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.

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.[25] 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.[13]

Table 3. Summary Results of Bill Williams Basin Split Samples from ADHS/ARRA-Test America Labs

Constituents	Number	Difference in Percent		Difference in Levels		Significance
		Minimum	Maximum	Minimum	Maximum	
Physical Parameters and General Mineral Characteristics						
Alkalinity, total	11	0 %	3 %	0	20	ns
SC (uS/cm)	11	0 %	4 %	0	100	ns
Hardness	11	0 %	5 %	0	100	ns
pH (su)	11	0 %	4 %	0.06	0.59	ns
TDS	11	0 %	10 %	0	100	ns
Turbidity (ntu)	4	8 %	84 %	0.2	0.6	ns
Major Ions						
Calcium	11	0 %	4 %	0	10	ns
Magnesium	11	2 %	4 %	0	2	ns
Sodium	11	1 %	3 %	1	3	ns
Potassium	9	0 %	15 %	0	0.1	ns
Chloride	11	0 %	6 %	0	5	ns
Sulfate	11	0 %	22 %	0	9	ns
Nutrients						
Nitrate as N	6	0 %	8 %	0	0.5	ns
Phosphorus, T.	1	23 %	23%	0.053	0.053	ns
Trace Elements						
Barium	5	0 %	8 %	0	0.03	ns
Cadmium	1	7 %	7 %	.0011	.0011	ns
Chromium	1	0 %	0 %	0	0	ns
Copper	2	8 %	17 %	0.002	0.015	ns
Fluoride	11	2 %	33 %	0.02	0.4	ns
Iron	2	4 %	47 %	0.2	0.9	ns
Manganese	3	0 %	4 %	0	1	ns

ns = No significant ($p \leq 0.05$) difference
All units are mg/L except as noted

Table 3. Summary Results of Bill Williams Basin Split Samples From ADHS/ARRA Test America Labs –Continued

Constituents	Number	Difference in Percent		Difference in Levels		Significance
		Minimum	Maximum	Minimum	Maximum	
Trace Elements						
Zinc	2	3%	4 %	0.01	0.02	ns
Radionuclides						
Gross alpha (pCi/L)	1	8 %	8 %	3.8	3.8	ns
Gross beta (pCi/L)	1	0 %	0 %	0	0	ns
Uranium (µg/L)	1	1 %	1 %	0.4	0.4	ns

ns = No significant ($p \leq 0.05$) difference
* = Significant ($p \leq 0.05$) difference
** = Significant ($p \leq 0.05$) difference
All units are mg/L except as noted

Figure 10 – East Well located in the remote Bullard Wash drainage uses a jack pump to raise groundwater to the surface for stock use. The sample (BWM-99/100) collected from the well met all water quality standards.

GROUNDWATER SAMPLING RESULTS

Water Quality Standards/Guidelines

The ADEQ ambient groundwater 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 that reflect the best current scientific and technical judgment available to evaluate the suitability of groundwater in the basin 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. [23]

- State of Arizona Aquifer Water Quality Standards. These apply to aquifers that are classified for drinking water protected use. All aquifers within Arizona are currently classified and protected for drinking water use. These enforceable State standards are identical to the federal Primary MCLs. [2]

- 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. [23]

Health-based drinking water quality standards (such as Primary MCLs) are based on the lifetime consumption (70 years) of two liters of water per day and, as such, are chronic not acute standards. [23]

Overall Results – Of the 100 sites sampled in the Bill Williams study, 48 sites met all health-based and aesthetic-based, water quality standards (excluding the proposed radon standard discussed below).

Of the 100 sites sampled in the Bill Williams study, health-based water quality standards were exceeded at 28 sites (28 percent). Constituents above Primary MCLs include arsenic (10 sites), cadmium (one site), chromium (one site), fluoride (four sites), gross alpha (16 sites), lead (one site), nitrate (three sites), radium 226+228 (four sites), and uranium (seven sites).

Inorganic Constituent Results - Of the 100 sites sampled for the full suite of inorganic constituents in the Bill Williams study, 50 (50 percent) met all SDW Primary and Secondary MCLs.

Health-based Primary MCL water quality standards and State aquifer water quality standards for inorganic constituents were exceeded at 18 sites (18 percent) of the 100 sites (Map 3). Constituents above Primary MCLs include arsenic (10 sites), cadmium (one site), chromium (one site), fluoride (four sites), lead (one site), and nitrate (three sites). Potential impacts of these Primary MCL exceedances are provided in Table 4.[23]

Aesthetics-based Secondary MCL water quality guidelines were exceeded at 49 of 100 sites (49 percent; Map 3; Table 5). Constituents above Secondary MCLs include chloride (five sites), fluoride (23 sites), iron (two sites), manganese (11 sites), pH (four sites), sulfate (six sites), and TDS (32 sites). Potential impacts of these Secondary MCL exceedances are provided in Table 5. [23]

Radionuclide Results - Health based Primary MCL water quality standards and State aquifer water quality standards were exceeded at 16 of the 55 sites (29 percent; Table 4; Map 10) at which a radionuclide sample was collected. Of the 55 sites sampled for radionuclides, Primary MCL standards were exceeded at 16 sites (29 percent) for gross alpha, four sites (7 percent) for radium 226+228, and seven sites (13 percent) for uranium. All the radium 226+228 and uranium exceedances occurred at sites where gross alpha concentration also exceeded Primary MCL standards.

Radon Results - Of the 47 sites sampled for radon, none exceeded the proposed 4,000 picocuries per liter (pCi/L) standard that would apply if Arizona establishes an enhanced multimedia program to address the health risks from radon in indoor air. Twenty-eight (28) sites exceeded the proposed 300 pCi/L standard that would apply if Arizona doesn't develop a multimedia program. [23]

Perchlorate Results – Of the 27 sites sampled for perchlorate, none exceeded the 0.006 mg/L drinking water quality standard used by the State of California.[27]

Map 3 - Water Quality Standards

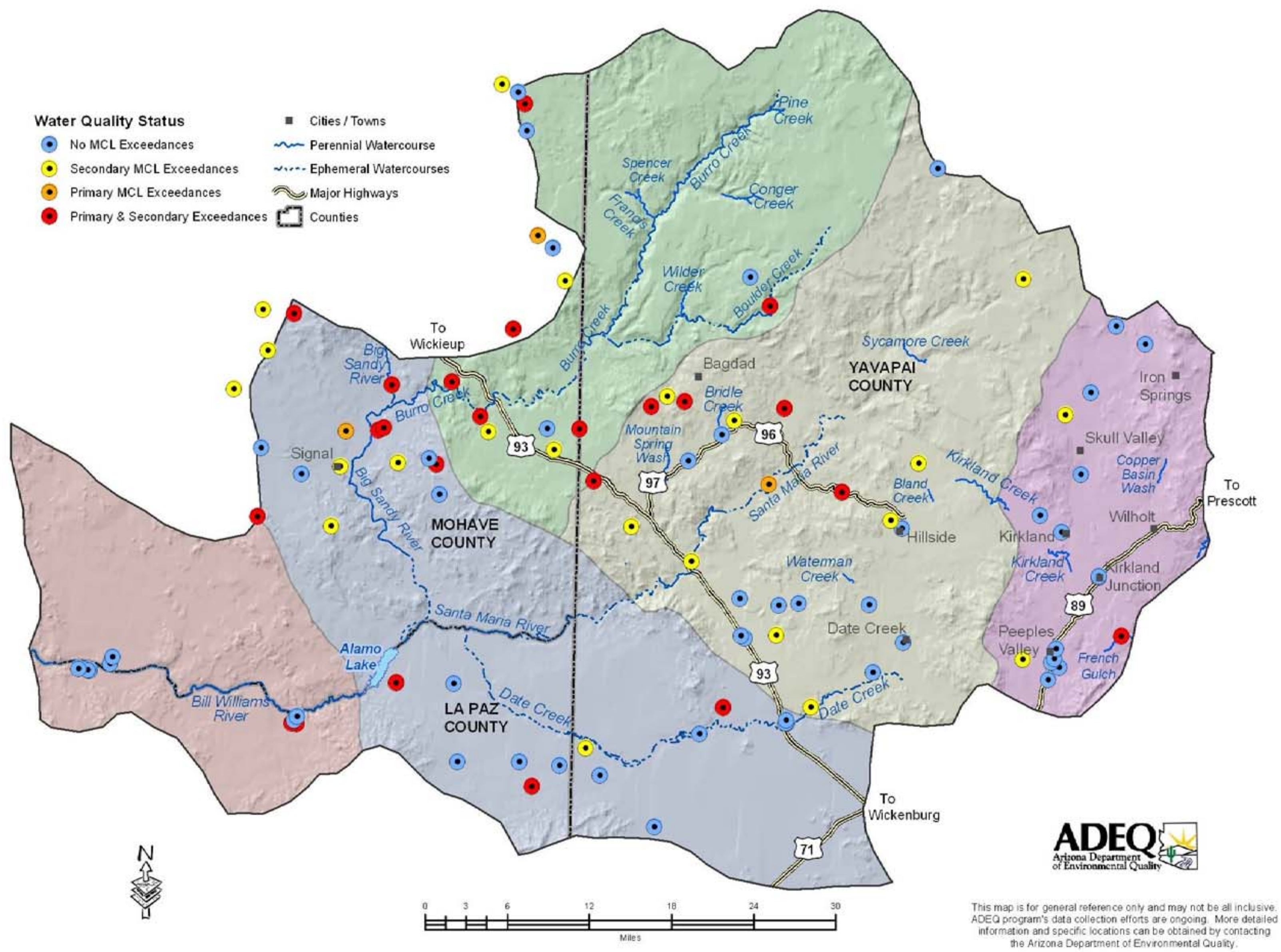


Table 4. Bill Williams Basin Sites Exceeding Health-Based (Primary MCL) Water Quality Standards

Constituent	Primary MCL	Number of Sites Exceeding Primary MCL	Highest Concentration	Potential Health Effects of MCL Exceedances *
		Nutrients		
Nitrite (NO_2-N)	1.0	0	-	-
Nitrate (NO_3-N)	10.0	**3**	110	methemoglobinemia
		Trace Elements		
Antimony (Sb)	0.006	0	-	-
Arsenic (As)	0.01	**10**	030	dermal and nervous system toxicity
Barium (Ba)	2.0	0	-	-
Beryllium (Be)	0.004	0	-	-
Cadmium (Cd)	0.005	**1**	0.00735	kidney damage
Chromium (Cr)	0.1	**1**	0.11	allergic dermatitis
Copper (Cu)	1.3	0	-	-
Fluoride (F)	4.0	**4**	9.4	skeletal damage
Lead (Pb)	0.015	**1**	0.016	developmental effects kidney damage
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	**16**	200	cancer
Ra-226+Ra-228	5	**4**	9.2	cancer
Radon **	300	**28**	1,122	cancer
Radon **	4,000	0	-	-
Uranium	30	**7**	270	cancer and kidney toxicity

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.[23]
** Proposed EPA Safe Drinking Water Act standards for radon in drinking water.[23]

Table 5. Bill Williams 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 ; >8.5	**4**	6.25; 9.52	*low pH:* bitter metallic taste; corrosion *high pH:* slippery feel; soda taste; deposits
General Mineral Characteristics				
TDS	500	**32**	2,800	hardness; deposits; colored water; staining; salty taste
Major Ions				
Chloride (Cl)	250	**5**	340	salty taste
Sulfate (SO_4)	250	**6**	1,400	salty taste
Trace Elements				
Fluoride (F)	2.0	**23**	9.4	tooth discoloration
Iron (Fe)	0.3	**2**	11	rusty color; sediment; metallic taste; reddish or orange staining
Manganese (Mn)	0.05	**11**	11.5	black staining; bitter metallic taste
Silver (Ag)	0.1	0	-	-
Zinc (Zn)	5.0	0	-	-

All units mg/L except pH is in standard units (su). Source: [23]

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. [24] Irrigation water may be classified using specific conductivity (SC) and the Sodium Adsorption Ratio (SAR) in conjunction with one another. [24]

Groundwater sites in the Bill Williams Basin display a narrow range of irrigation water classifications (Diagram 1). The 100 sample sites are divided into the following salinity hazards expressed in SC values: low - 1 site (< 249 uS/cm), medium – 58 sites (250 - 749 uS/cm), high – 38 sites (750-2250 uS/cm), and very high – 3 sites (> 2,250 uS/cm).

The 100 sample sites are divided into the following sodium or alkali hazards expressed in SAR values: low - 96 sites (0-10), medium – 1 site (11 – 18), high – 1 site (19 – 26) and very high – 2 sites (> 26).

Analytical Results

Analytical inorganic and radiochemistry results of the Bill Williams 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.[25] Specific constituent information for each groundwater site is found in Appendix B.

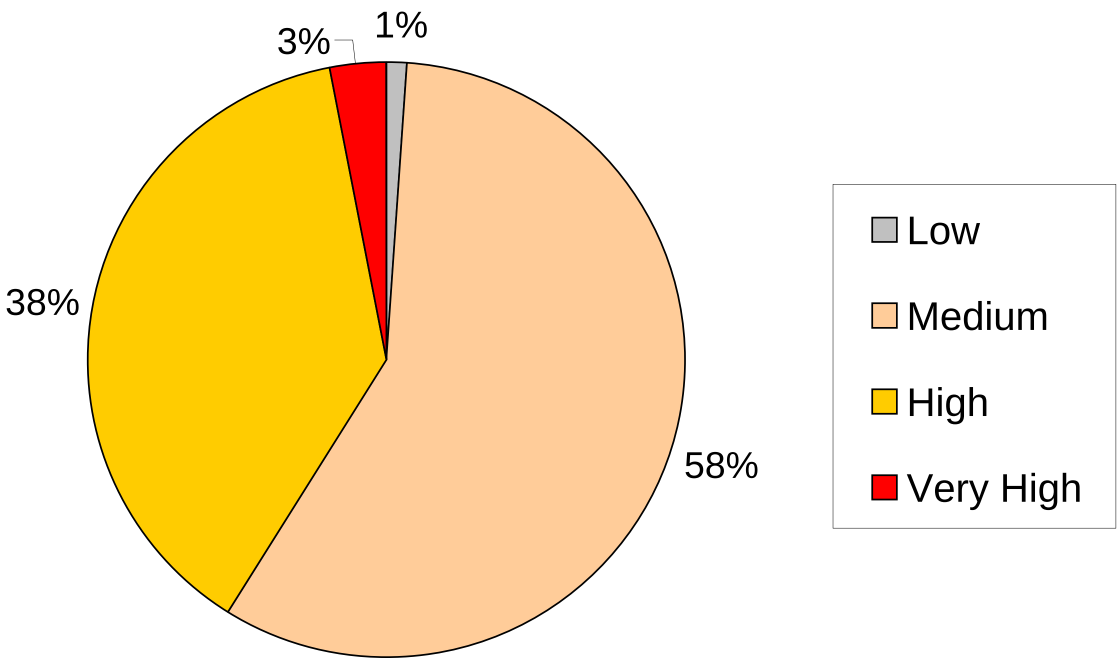


Diagram 1. Salinity Hazard of Bill Williams Basin Sample Sites

Table 6. Summary Statistics for Bill Williams Basin Groundwater Quality Data

Constituent	Minimum Reporting Limit (MRL)	# of Samples / Samples Over MRL	Median	Lower 95% Confidence Interval	Mean	Upper 95% Confidence Interval
			Physical Parameters			
Temperature (C)	0.1	83 / 83	22.1	22.0	22.9	26.8
pH-field (su)	0.01	100 / 100	7.40	7.40	7.48	7.57
pH-lab (su)	0.01	100 / 100	8.00	7.86	7.93	8.00
Turbidity (ntu)	0.01	100 / 100	0.54	0.86	3.42	5.99
			General Mineral Characteristics			
T. Alkalinity	2.0	100 / 100	215	215	229	243
Phenol. Alk.	2.0	100 / 3		> 50% of data below MRL		
SC-field (uS/cm)	N/A	100 / 100	706	755	857	960
SC-lab (uS/cm)	N/A	100 / 100	680	725	827	928
Hardness-lab	10.0	100 / 100	233	236	284	333
TDS	10.0	100 / 100	413	457	537	617
			Major Ions			
Calcium	5.0	100 / 99	63	64	76	89
Magnesium	1.0	100 / 98	17	19	24	28
Sodium	5.0	100 / 100	50	58	70	82
Potassium	0.5	100 / 97	2.6	2.8	3.6	4.4
Bicarbonate	2.0	100 / 100	260	259	276	293
Carbonate	2.0	100 / 3		> 50% of data below MRL		
Chloride	1.0	100 / 99	43	54	69	83
Sulfate	10.0	100 / 100	40	54	96	138
			Nutrients			
Nitrate (as N)	0.02	100 / 94	1.4	1.2	4.3	7.3
Nitrite (as N)	0.02	78 / 3		> 50% of data below MRL		
TKN	0.05	100 / 29		> 50% of data below MRL		
Ammonia		100 / 16		> 50% of data below MRL		
T. Phosphorus	0.02	100 / 47		> 50% of data below MRL		

Table 6. Summary Statistics for Bill Williams Basin Groundwater Quality Data— Continued

Constituent	Minimum Reporting Limit (MRL)	# of Samples / Samples Over MRL	Median	Lower 95% Confidence Interval	Mean	Upper 95% Confidence Interval
Trace Elements						
Aluminum		78 / 0		> 50% of data below MRL		
Antimony	0.005	100 / 0		> 50% of data below MRL		
Arsenic	0.01	100 / 23		> 50% of data below MRL		
Barium	0.1	100 / 57	0.024	0.035	0.047	0.059
Beryllium	0.0005	100 / 2		> 50% of data below MRL		
Boron	0.1	100 / 46		> 50% of data below MRL		
Cadmium	0.001	100 / 1		> 50% of data below MRL		
Chromium	0.01	100 / 6		> 50% of data below MRL		
Copper	0.01	100 / 16		> 50% of data below MRL		
Fluoride	0.20	100/ 100	1.1	1.2	1.5	1.8
Iron	0.1	100 / 8		> 50% of data below MRL		
Lead	0.005	100/ 1		> 50% of data below MRL		
Manganese	0.05	100 / 11		> 50% of data below MRL		
Mercury	0.0005	100 / 0		> 50% of data below MRL		
Nickel	0.1	100 / 0		> 50% of data below MRL		
Selenium	0.005	100 / 1		>50% of data below MRL		
Silver	0.001	100 / 0		> 50% of data below MRL		
Thallium	0.002	100 / 0		> 50% of data below MRL		
Strontium		46 / 28				
Zinc	0.05	100 / 51	0.06	0.13	0.25	0.36
Radiochemical						
Gross Alpha	Varies		7.1	8.4	17.9	27.5
Gross Beta	Varies		6.7	9.6	14.4	19.1
Radon	Varies	45 / 45	377	330	419	508
Isotopes						
Oxygen-18	Varies	100 / 100	- 9.3	- 9.3	- 9.0	- 8.7
Deuterium	Varies	100/ 100	- 67.0	- 69.9	- 66.3	- 64.7

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

GROUNDWATER COMPOSITION

General Summary

Groundwater in the Bill Williams basin was predominantly of calcium, mixed or sodium-bicarbonate chemistry (Diagram 2) (Map 4). A previous study found similar groundwater chemistry prevalent in the basin.[21]

The water chemistry at the 100 sample sites, in decreasing frequency, includes calcium-bicarbonate (35 sites), mixed-bicarbonate (30 sites), sodium-bicarbonate (14 sites), mixed-mixed and sodium-mixed (seven sites apiece), calcium-mixed, calcium-sulfate, and mixed-sulfate (two sites apiece), and mixed-chloride (one site) (Diagram 2 – middle diagram).

Of the 100 sample sites in the Bill Williams basin, the dominant cation was calcium at 39 sites and sodium at 21 sites; at 40 sites there was no dominant cation and was classified as “mixed” (Diagram 2 – left diagram).

The dominant anion was bicarbonate at 79 sites, sulfate at four sites and chloride at one site; at 16 sites there was no dominant anion and was classified as “mixed” (Diagram 2 – right diagram).

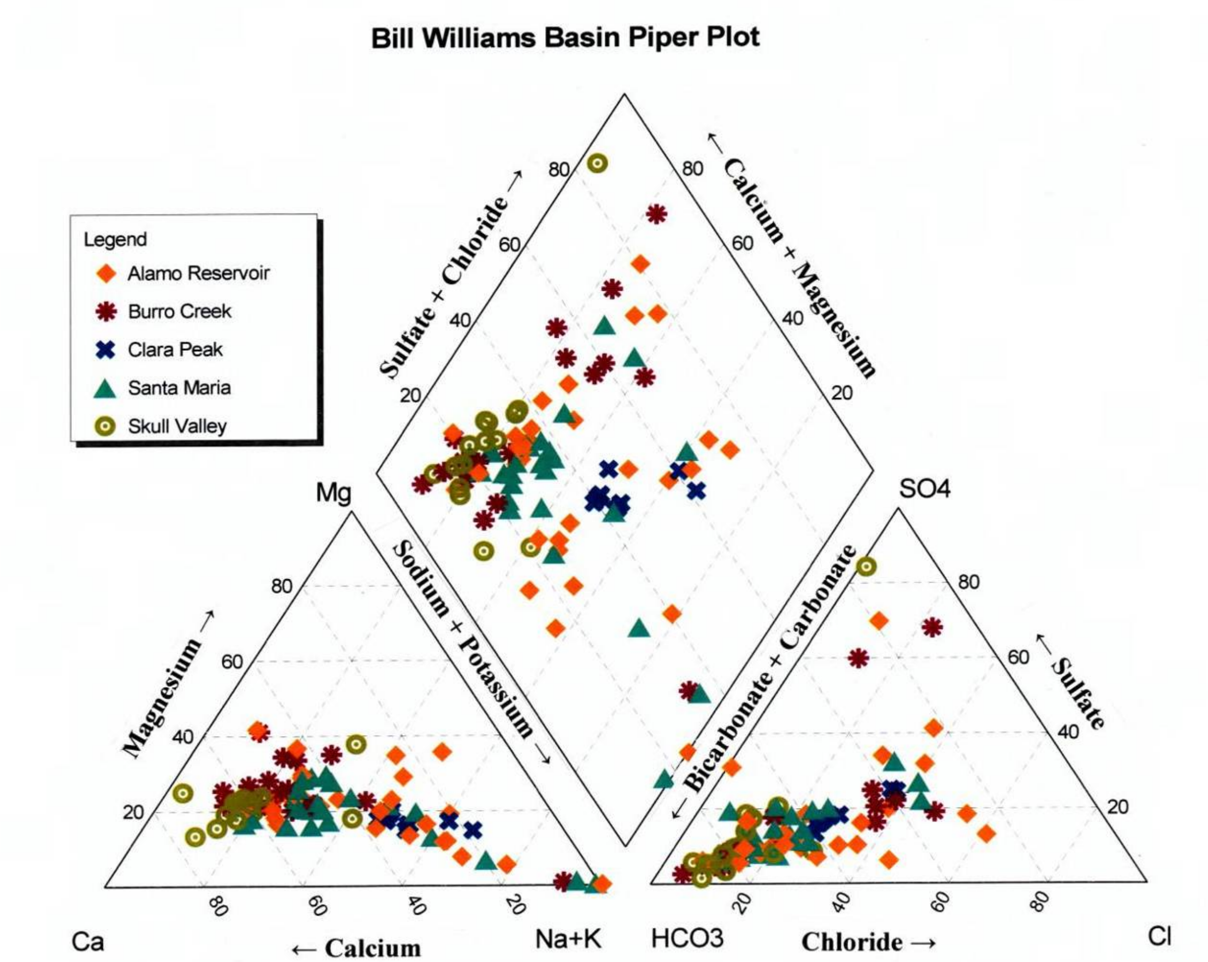
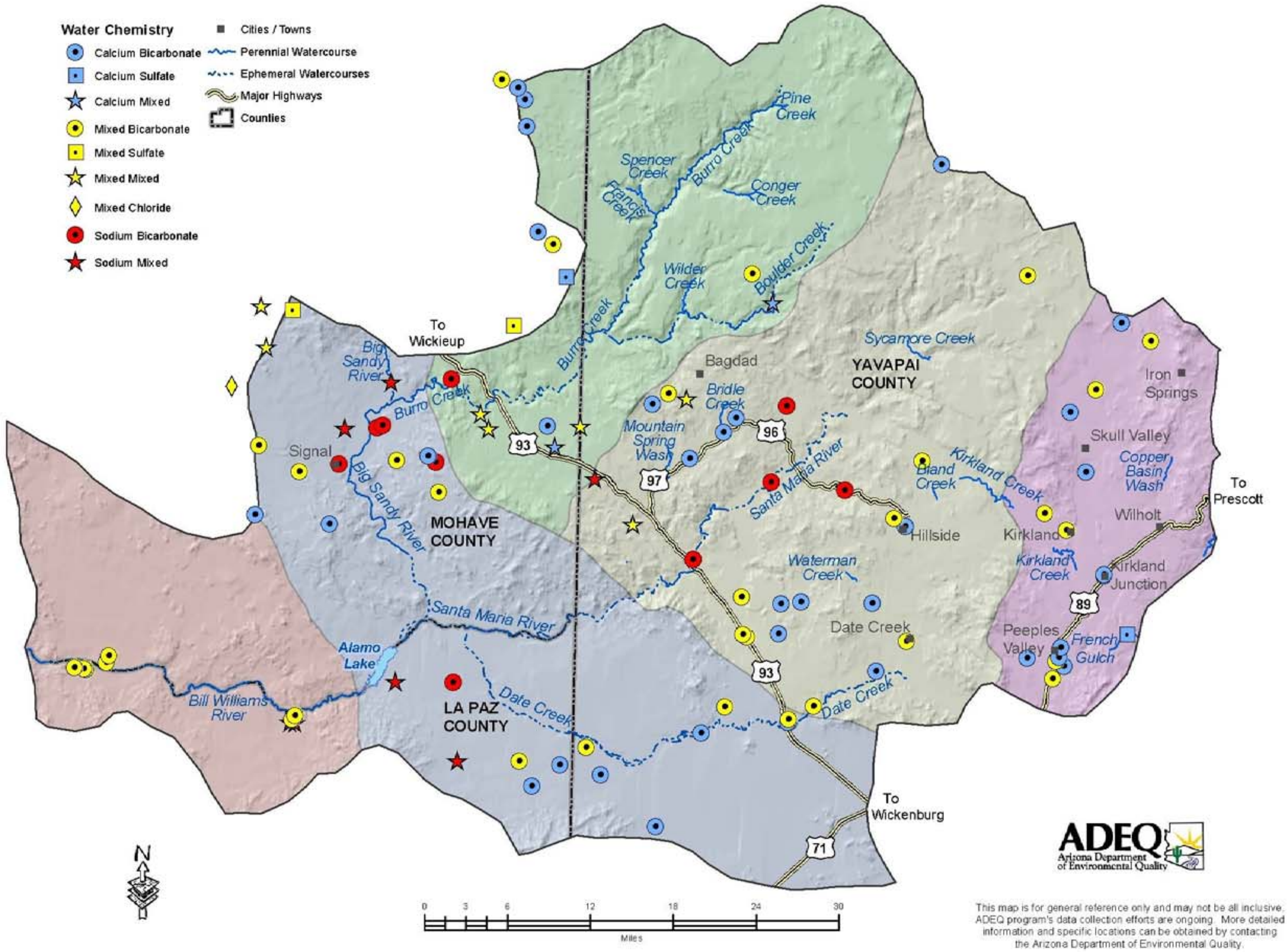


Diagram 2 – Groundwater in the Bill Williams basin evolves as it moves through the basin. Recharge occurring in the higher elevation areas of the basin such as the Skull Valley sub-basin starts as a calcium-bicarbonate chemistry and, on a flowpath through the basin, evolves into a mixed-bicarbonate or sodium-mixed chemistry when it reaches lower elevation areas such as the Clara Peak sub-basin. Some outliers such as the Skull Valley sub-basin sample with a pronounced sulfate chemistry can be explained by the presence of nearby historic copper mining activity at the Zonia Mine.

Map 4 - Water Chemistry



This map is for general reference only and may not be all inclusive. ADEQ program's data collection efforts are ongoing. More detailed information and specific locations can be obtained by contacting the Arizona Department of Environmental Quality.

At 100 sites, levels of pH-field were *slightly alkaline* (above 7 su) at 96 sites and *slightly acidic* (below 7 su) at four sites.[12] Of the 96 sites above 7 su, 10 sites had pH-field levels over 8 su and two sites had pH-field levels over 9 su.

TDS concentrations were considered *fresh* (below 1,000 mg/L) at 92 sites, *slightly saline* (1,000 to 3,000 mg/L) at eight sites (Map 5).[12]

Hardness concentrations were *soft* (below 75 mg/L) at six sites, *moderately hard* (75 – 150 mg/L) at 16 sites, *hard* (150 – 300 mg/L) at 49 sites, *very hard* (300 - 600 mg/L) at 22 sites, *extremely hard* (> 600 mg/L) at seven sites (Diagram 3 and Map 6).[8]

Nitrate (as nitrogen) concentrations at most sites may have been influenced by human activities (Map 7). Nitrate concentrations were divided into natural background (15 sites at <0.2 mg/L), may or may not indicate human influence (59 sites at 0.2 – 3.0 mg/L), may result from human activities (23 sites at 3.0 – 10 mg/L), and probably result from human activities (three sites >10mg/L).[16]

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

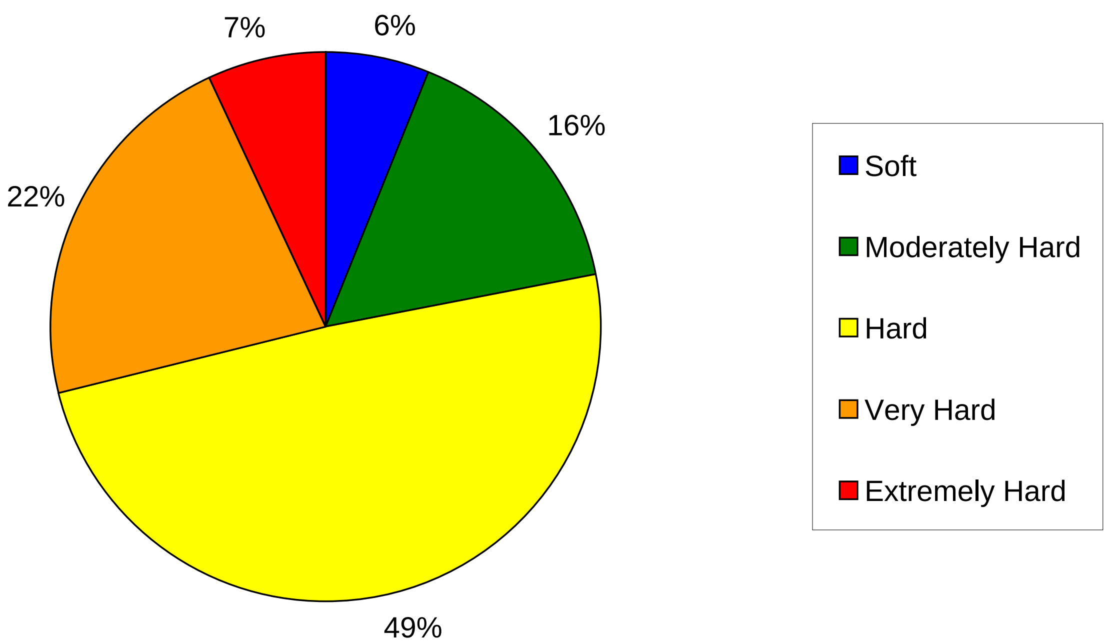
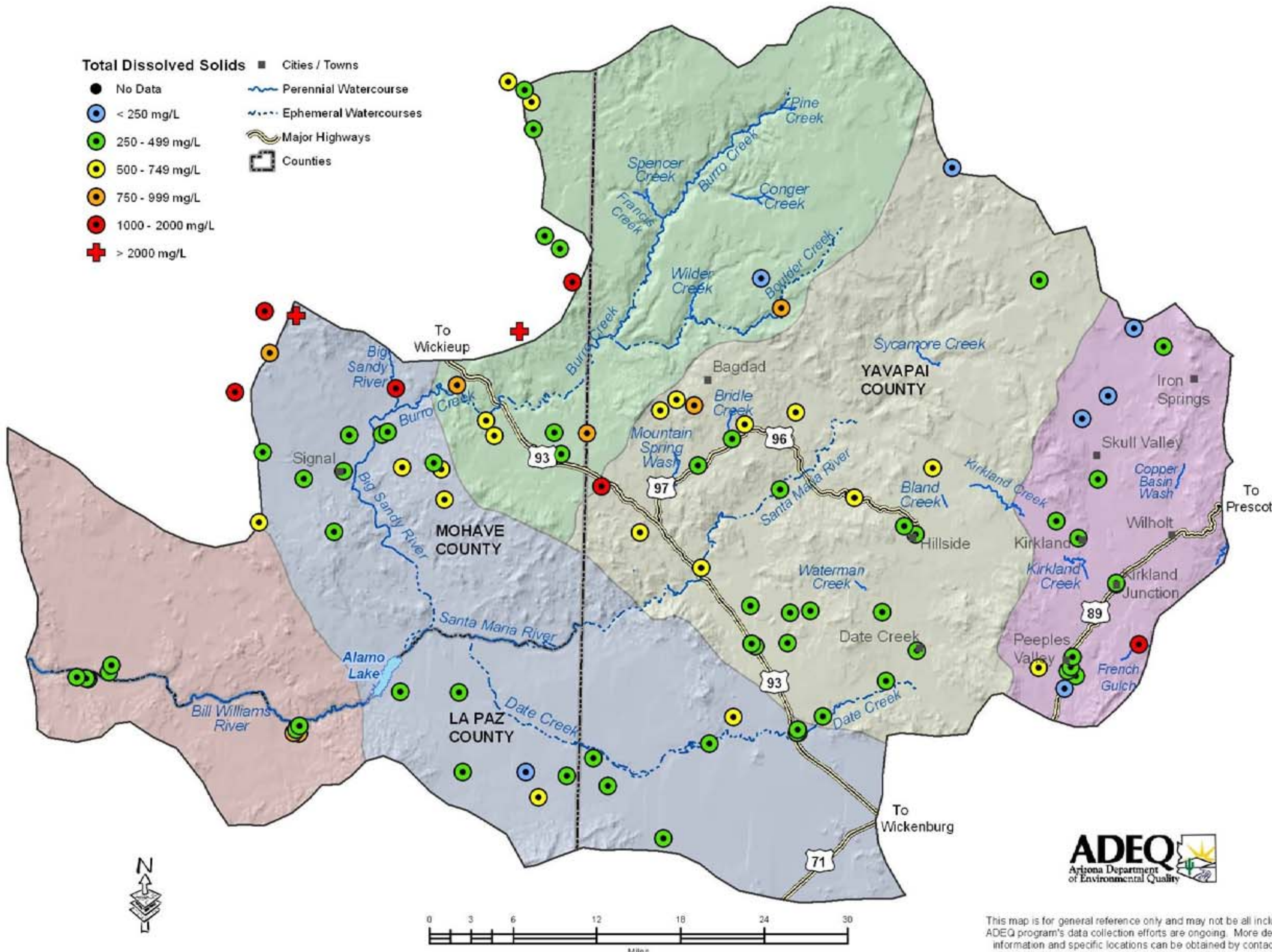


Diagram 3. Hardness Concentrations of Bill Williams Basin Sample Sites

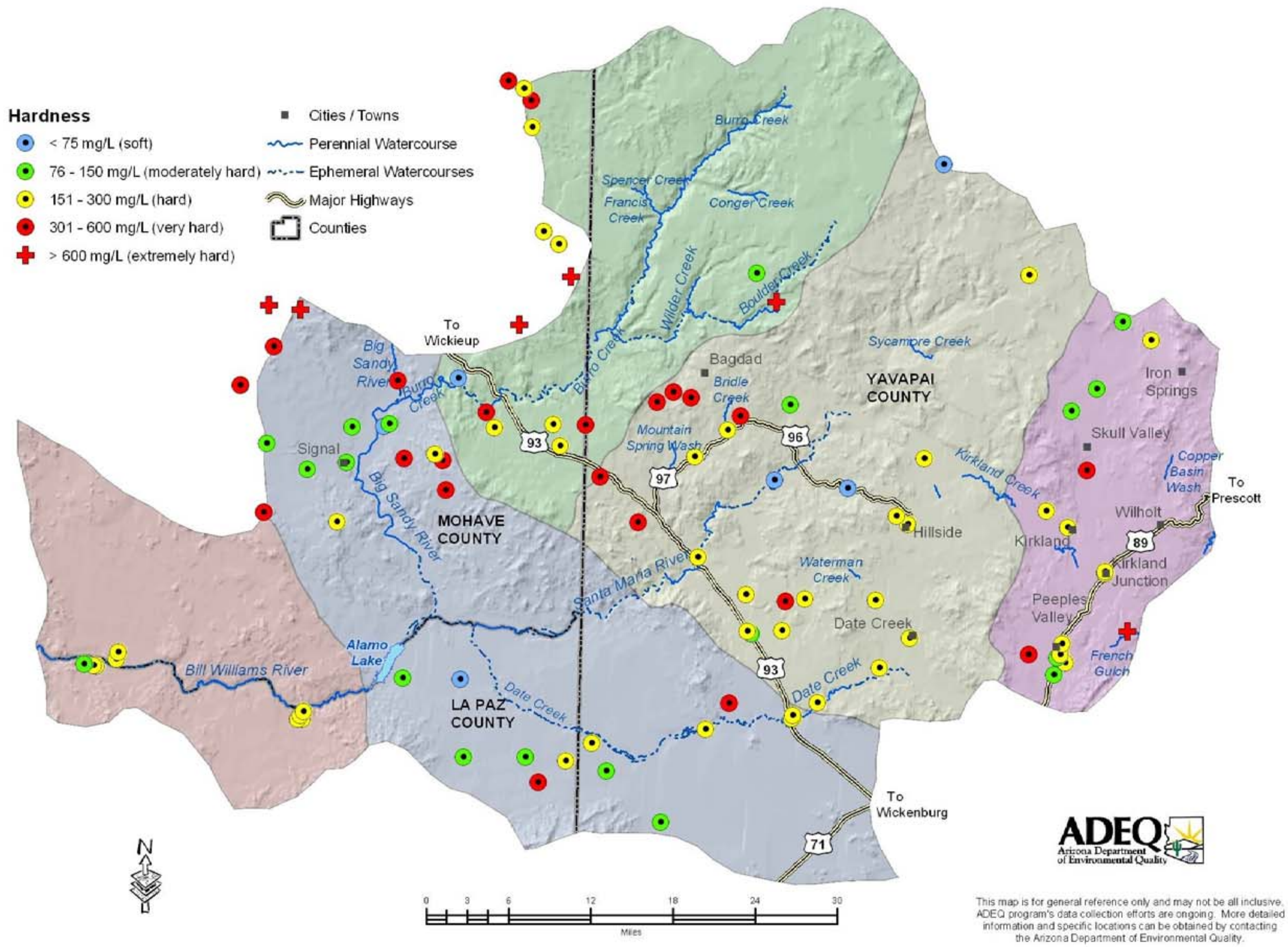
Map 5 - Total Dissolved Solids (TDS)



ADEQ Arizona Department of Environmental Quality

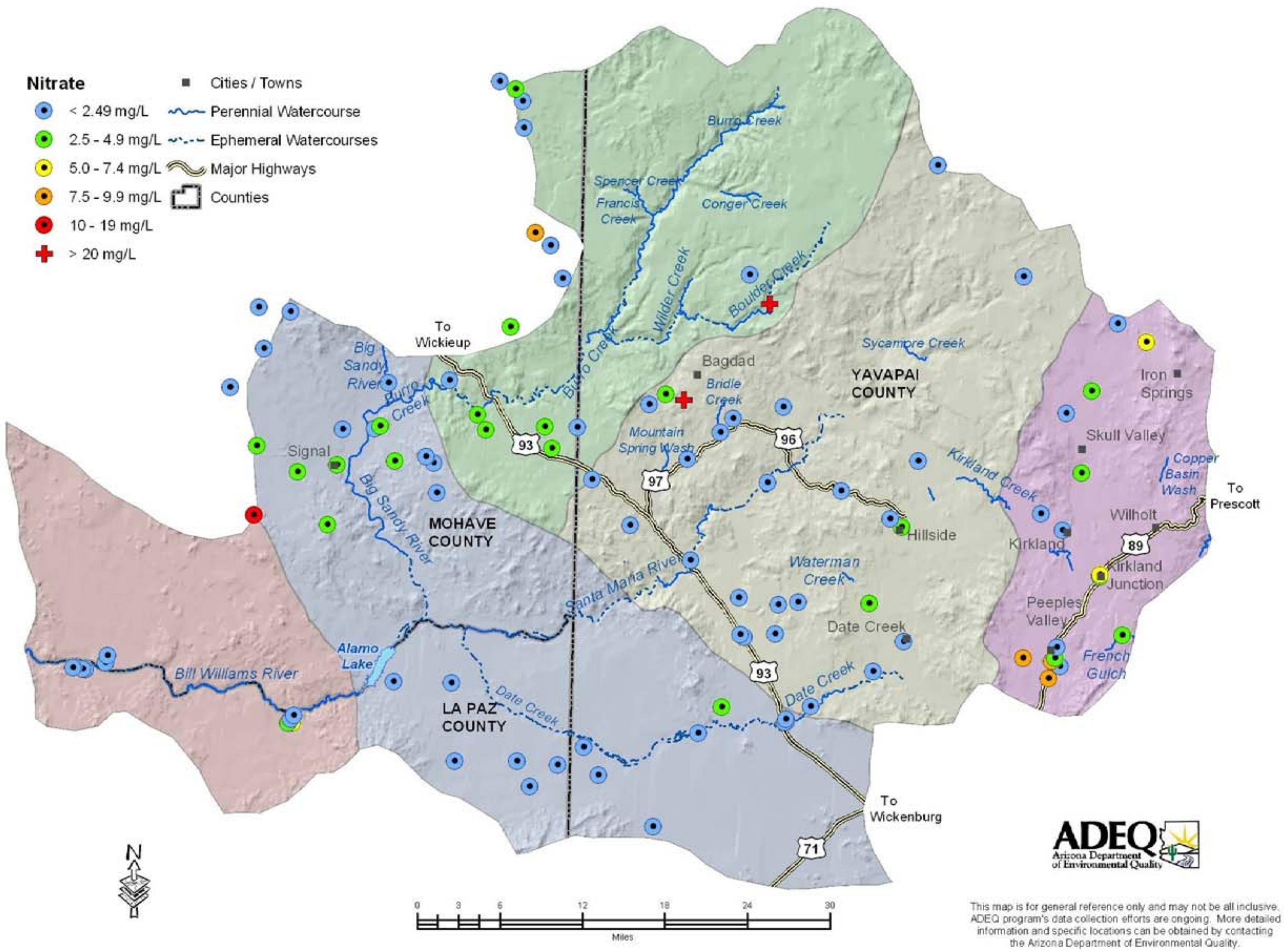
This map is for general reference only and may not be all inclusive. ADEQ program's data collection efforts are ongoing. More detailed information and specific locations can be obtained by contacting the Arizona Department of Environmental Quality.

Map 6 - Hardness



This map is for general reference only and may not be all inclusive. ADEQ program's data collection efforts are ongoing. More detailed information and specific locations can be obtained by contacting the Arizona Department of Environmental Quality.

Map 7 - Nitrate (as N)



Isotope Evaluation

The data for the Bill Williams basin roughly conforms to what would be expected in an arid environment, having a slope of 5.3 (Diagram 4), with the Local Meteoric Water Line (LMWL described by the linear equation:

$$\delta D = 5.3\ \delta^{18}O - 18.7$$

The LMWL for the Bill Williams basin (5.3) falls within the range of other basins in Arizona including Dripping Springs Wash (4.4), Detrital Valley (5.2), Agua Fria (5.3), Sacramento Valley (5.5), Big Sandy (6.1), Pinal Active Management Area (6.4), Gila Valley (6.4), San Simon (6.5), San Bernardino Valley (6.8), McMullen Valley (7.4) and Lake Mohave (7.8).

The most depleted isotope sample is Warm Spring (BWM-38) located in the Burro Creek sub-basin; the other most depleted samples are a mixture of wells and springs collected from Burro Creek, Santa Maria and Skull Valley sub-basins. The light signatures of these approximately 25 samples were much more depleted than would be expected from mountain recharge within the basin. The extreme depletion suggests that these samples may consist of paleowater that was recharged during cooler climatic conditions roughly 8,000 - 12,000 years ago.[7, 10]

The most enriched isotope samples include those collected at the Lincoln Ranch (BWM-105 to BWM-109) along the Bill Williams River. These likely consist of water recently recharged by the river that may also have suffered evaporation while stored upstream in Alamo Reservoir.

These enriched groundwater isotope values are similar to the two surface water isotope samples collected in the basin during the autumn along Burro Creek (BWM-36) and the Big Sandy River (BWM-44).

The majority of samples have values located between these two groups which suggest that they are a result of high elevation recent recharge in the basin, with paleowater contributing to some samples depending on where they lie along the Local Meteoric Water Line.

Oxygen and Hydrogen Isotopes

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.[7] 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.[7] The GMWL is the standard by which water samples are compared and is a universal reference standard based on worldwide precipitation without the effects of evaporation.

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.[7] The LMWL created by $\delta^{18}O$ and δD values for samples collected at sites in the Bill Williams basin plot to the right of the GMWL.

Meteoric waters exposed to evaporation are enriched and 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. In contrast, meteoric waters that experience little evaporation are depleted and tend to plot increasing to the left of the GMWL and are isotopically lighter.[7]

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.[7]

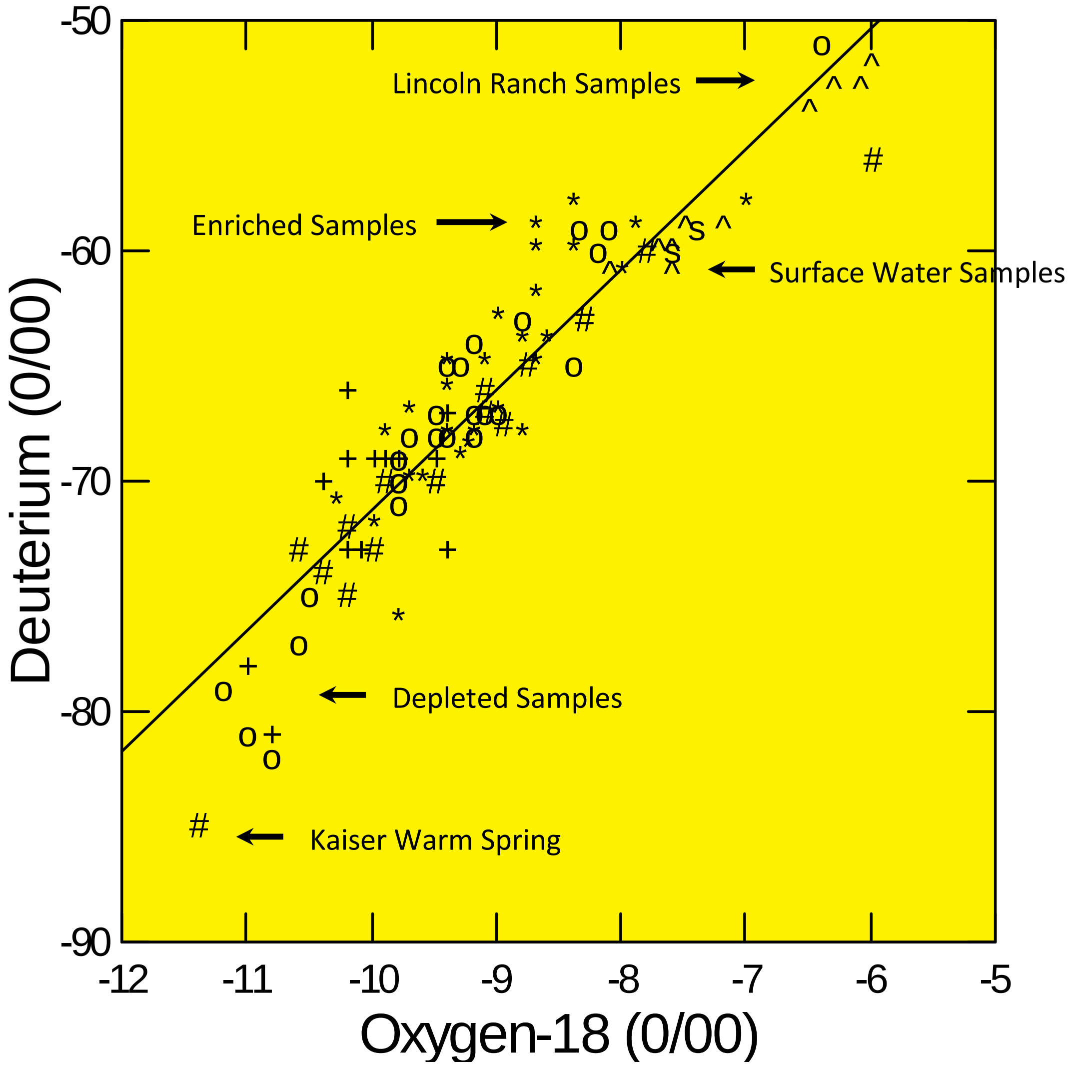


Diagram 4 - Isotope Graph

*	= Alamo Reservoir sub-basin sample site
#	= Burro Creek sub-basin sample site
^	= Clara Peak sub-basin sample site
o	= Santa Maria sub-basin sample site
+	= Skull Valley sub-basin sample site
S	= Surface Water sample
____	= Local Meteoric Water Line

Groundwater Quality Variation

Among Five Sub-basins - Twenty-five (25) groundwater quality constituent concentrations were compared between five sub-basins: Alamo Reservoir (30 sites), Burro Creek (17 sites), Clara Peak (10 sites), Santa Maria (27 sites) and Skull Valley (16 sites).

Significant concentration differences were found with 6 constituents: temperature, sodium (Diagram 6), fluoride (Diagram 7), boron, oxygen-18 and deuterium (Diagram 8) (Kruskal-Wallis with Tukey test, $p \leq 0.05$). Complete results are found in Table 7.

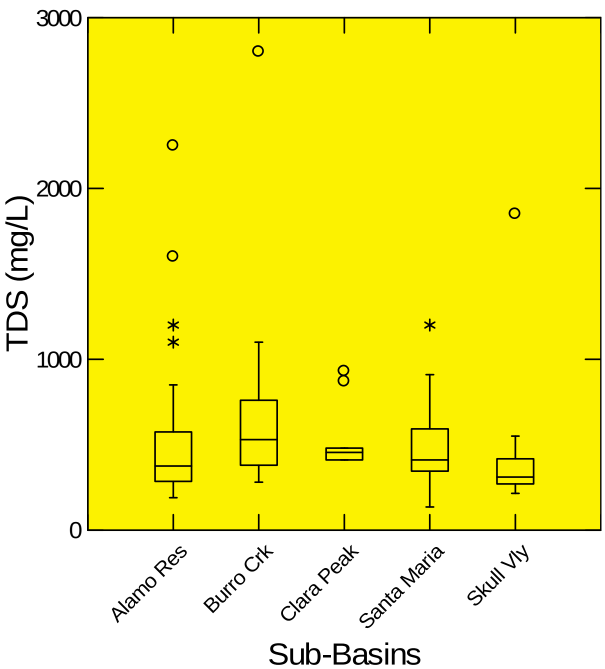


Diagram 5. Although median concentrations are lowest in the Skull Valley sub-basin and highest in the Burro Creek sub-basin, there are no significant differences in total dissolved solid (TDS) concentrations among sub-basins in the Bill Williams Basin (Kruskal-Wallis with Tukey test, $p \geq 0.05$). The TDS concentration for the vast majority of the 100 collected samples is below 1,000 mg/L and is considered *fresh* water. [12]

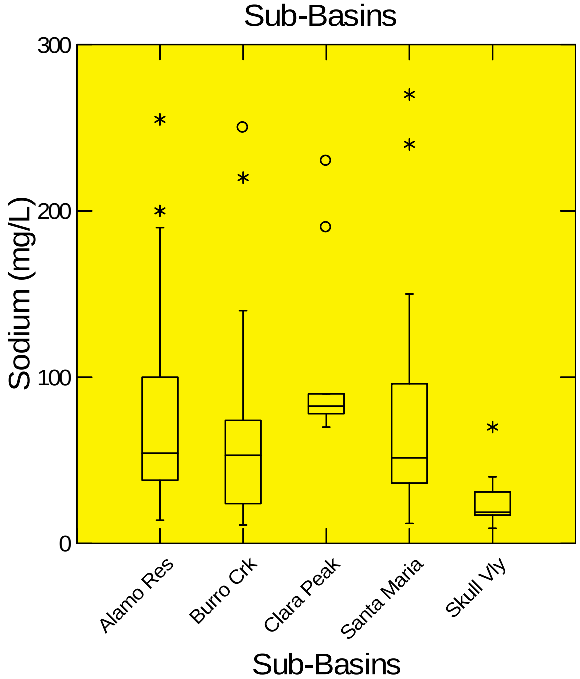


Diagram 6. Samples collected from sites in the Alamo Reservoir, Clara Peak and Santa Maria sub-basins have significantly higher sodium concentrations than samples collected from sites in the Skull Valley sub-basin (Kruskal-Wallis with Tukey test, $p \leq 0.05$). Skull Valley is the most upgradient sub-basin. In recharge areas, there are typically low sodium concentrations though in downgradient areas, sodium is often the dominant cation as a result of silicate weathering, halite dissolution and ion exchange. [20]

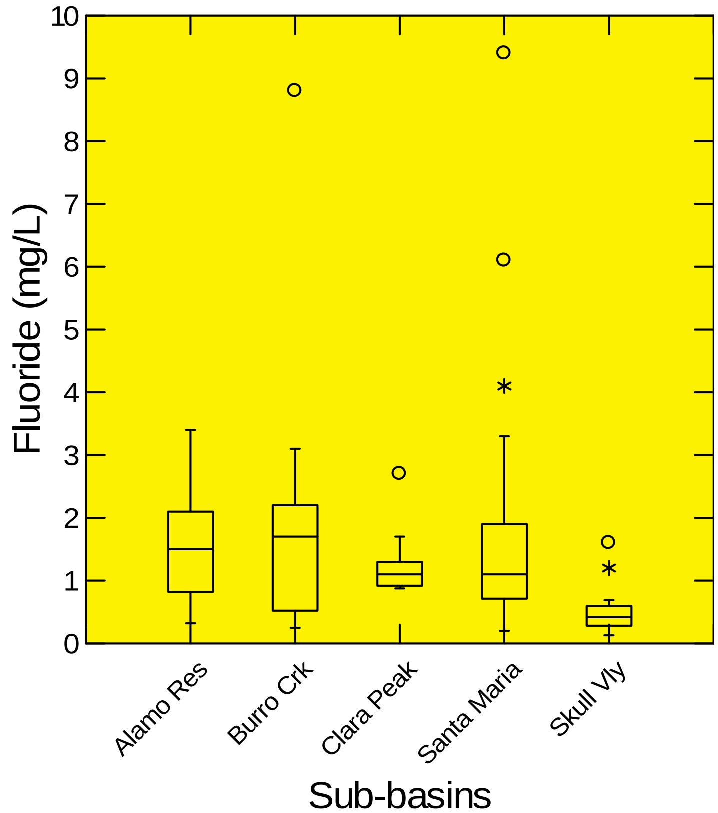


Diagram 7. Samples collected from sites in the Skull Valley sub-basin had significantly lower fluoride concentrations than samples collected in the Santa Maria sub-basin. Although other comparisons involving Skull Valley sites came close, there were no other significant differences among sub-basins (Kruskal-Wallis with Tukey test, $p \leq 0.05$). Fluoride concentrations are usually low in upgradient areas and increase downgradient through an exchange of hydroxyl ions for fluoride ions. [20]

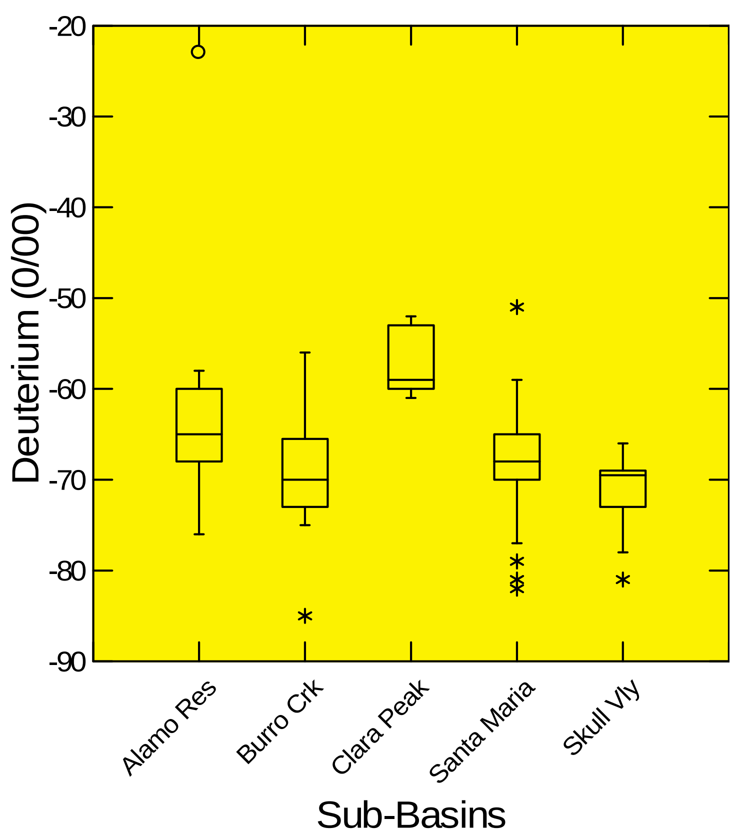


Diagram 8. Samples collected from sites in the Clara Peak sub-basin had significantly higher (or more enriched) deuterium levels than sample sites collected from the other four sub-basins. Samples collected from the Alamo Reservoir sub-basin had significantly higher (or enriched) deuterium levels that sample sites in Skull Valley (Kruskal-Wallis with Tukey test, $p \leq 0.05$). Recharge in higher elevation areas such as the Skull Valley sub-basin tend to be more depleted than lower elevation areas such as the Clara Peak sub-basin. [7] Recharge in the latter sub-basin may also experience additional evaporation from storage in Alamo Reservoir.

Table 7. Variation in Groundwater Quality Constituent Concentrations among Five Sub-basins Using Kruskal-Wallis Test with the Tukey Test

Constituent	Significance	Significant Differences Among Aquifers
Temperature - field	**	Alamo Reservoir > Burro Creek, Santa Maria & Skull Valley
pH – field	ns	-
pH – lab	ns	-
SC - field	ns	-
SC - lab	ns	-
TDS	ns	-
Turbidity	ns	-
Hardness	ns	-
Calcium	ns	-
Magnesium	ns	-
Sodium	**	Alamo Reservoir, Clara Peak & Santa Maria > Skull Valley
Potassium	ns	-
Bicarbonate	ns	-
Chloride	ns	-
Sulfate	ns	-
Nitrate (as N)	ns	-
Barium	ns	-
Boron	**	Clara Peak > Burro Creek, Santa Maria & Skull Valley
Fluoride	**	Santa Maria > Skull Valley
Zinc	ns	-
Oxygen	**	Clara Peak > Alamo Reservoir, Burro Creek, Santa Maria & Skull Valley Alamo Reservoir > Skull Valley
Deuterium	**	Clara Peak > Burro Creek, Santa Maria & Skull Valley Alamo Reservoir > Skull Valley
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

Between Alluvium and Hardrock - Twenty-five (25) groundwater quality constituent concentrations were compared between samples collected in alluvium (25 samples) and hardrock areas (75 samples).

Significant concentration differences were found with 10 constituents: pH-lab (Diagram 9), hardness, calcium (Diagram 10), magnesium, potassium, bicarbonate, boron, zinc, oxygen-18, and deuterium (Kruskal-Wallis with Tukey test, $p \leq 0.05$). Complete results are found in Table 8.

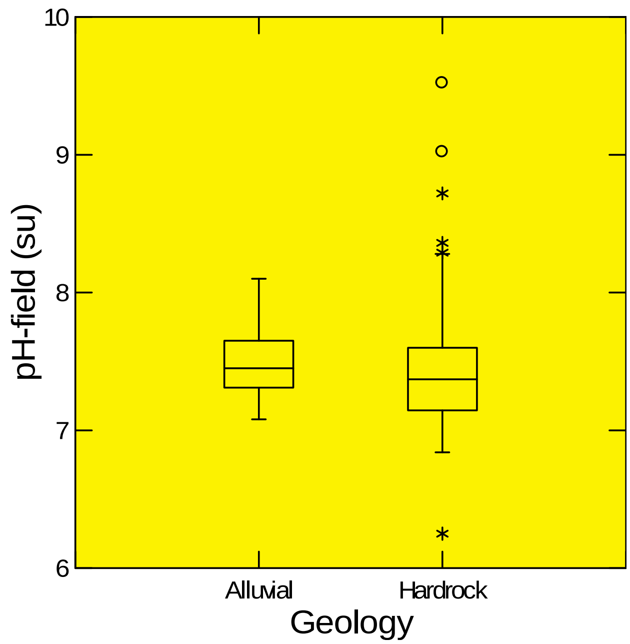


Diagram 9. Samples collected from the sites in alluvium have significantly higher pH-lab values than samples collected from sites in hardrock; however, pH-field values between alluvium and hardrock are not significantly different (Kruskal-Wallis test, $p \geq 0.05$). In hardrock areas, acidic precipitation averaging 5.8 su percolates into faults and crevices. The recharged groundwater gradually increases in pH downgradient through silicate hydrolysis reactions [20]

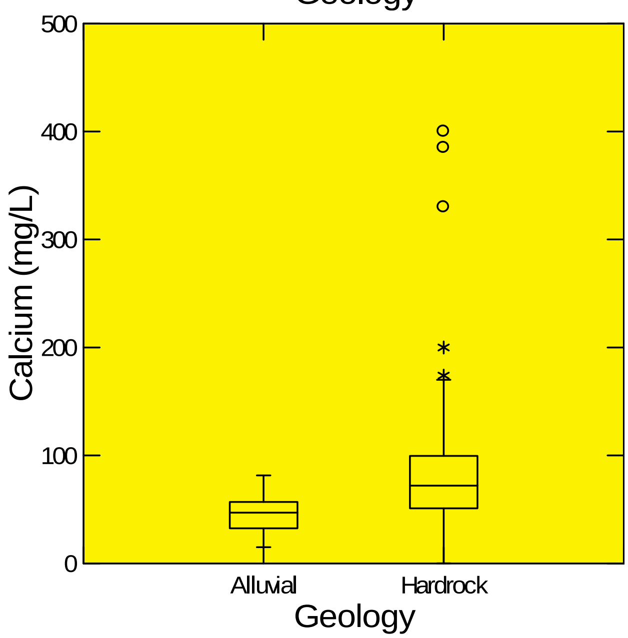


Diagram 10. Samples collected from sites in hardrock have significantly higher calcium concentrations than samples collected from alluvium (Kruskal-Wallis test, $p \leq 0.01$). The calcium differences may be due to the calcium-bicarbonate chemistry frequently associated with recharge areas as well as natural softening that often occurs as water moves downgradient to alluvial areas. [20]

Table 8. Variation in Groundwater Quality Constituent Concentrations between Two Geologic Classifications Using Kruskal-Wallis Test

Constituent	Significance	Significant Differences Between Geologic Classifications
Temperature - field	ns	-
pH – field	ns	-
pH – lab	**	Alluvium > Hardrock
SC - field	ns	-
SC - lab	ns	-
TDS	ns	-
Turbidity	ns	-
Hardness	**	Hardrock > Alluvium
Calcium	**	Hardrock > Alluvium
Magnesium	**	Hardrock > Alluvium
Sodium	ns	-
Potassium	*	Alluvium > Hardrock
Bicarbonate	*	Hardrock > Alluvium
Chloride	ns	-
Sulfate	ns	-
Nitrate (as N)	ns	-
Barium	ns	-
Boron	*	Alluvium > Hardrock
Fluoride	ns	-
Zinc	**	Hardrock > Alluvium
Oxygen	*	Alluvium > Hardrock
Deuterium	**	Alluvium > Hardrock
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

Among Geologic Classifications - Twenty-five (25) groundwater quality constituent concentrations were compared between five geologic classifications: alluvium (38 sites), basalt (34 sites), granitic (29 sites), sedimentary (six sites) and volcanic (11 sites).[18]

Significant concentration differences were found with 9 constituents: pH-lab, SC-field, SC-lab, TDS (Diagram 11), hardness, calcium (Diagram 12), magnesium, bicarbonate and fluoride (Kruskal-Wallis with Tukey test, $p \leq 0.05$).

In most cases, samples collected from sites in granitic rock were significantly higher than samples collected from sites in alluvium and/or sedimentary rock. Complete results are found in Table 9.

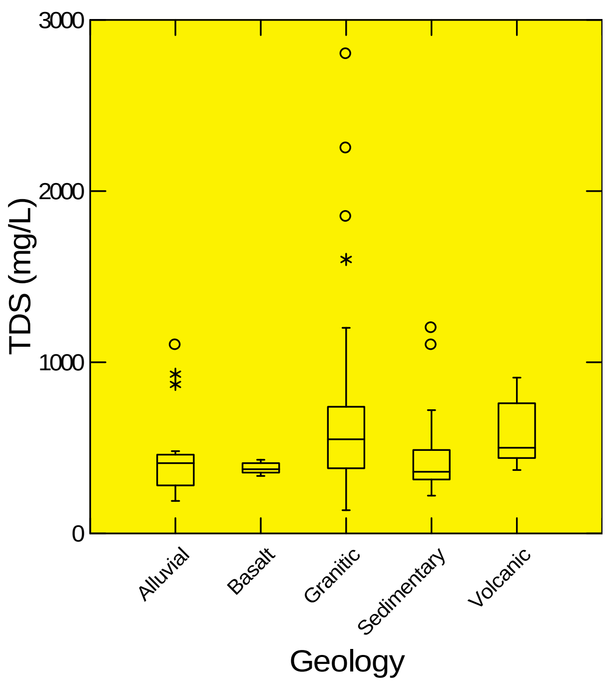


Diagram 11. Samples collected from sites in granitic rock have significantly higher TDS concentrations than samples collected from sites in alluvium or sedimentary rock (Kruskal-Wallis with Tukey test, $p \leq 0.01$). Decreasing groundwater concentrations as water moves downgradient into alluvial areas may be due to precipitation reactions including calcite and the removal of calcium and magnesium by clays.[20]

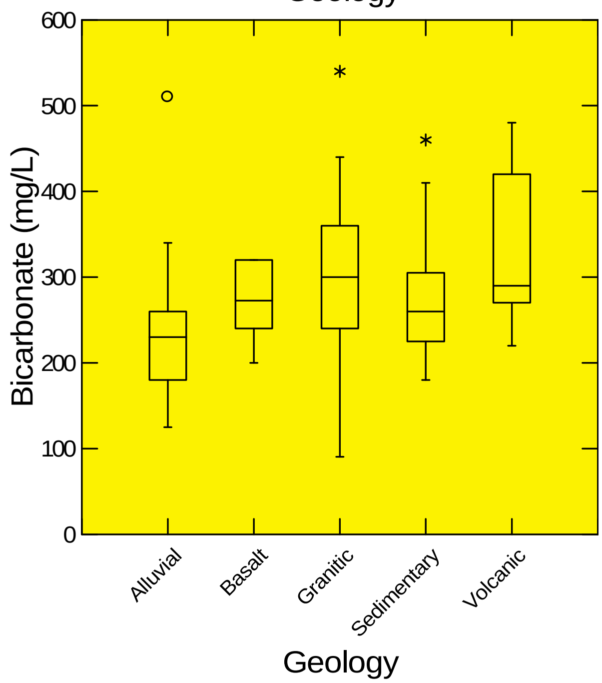


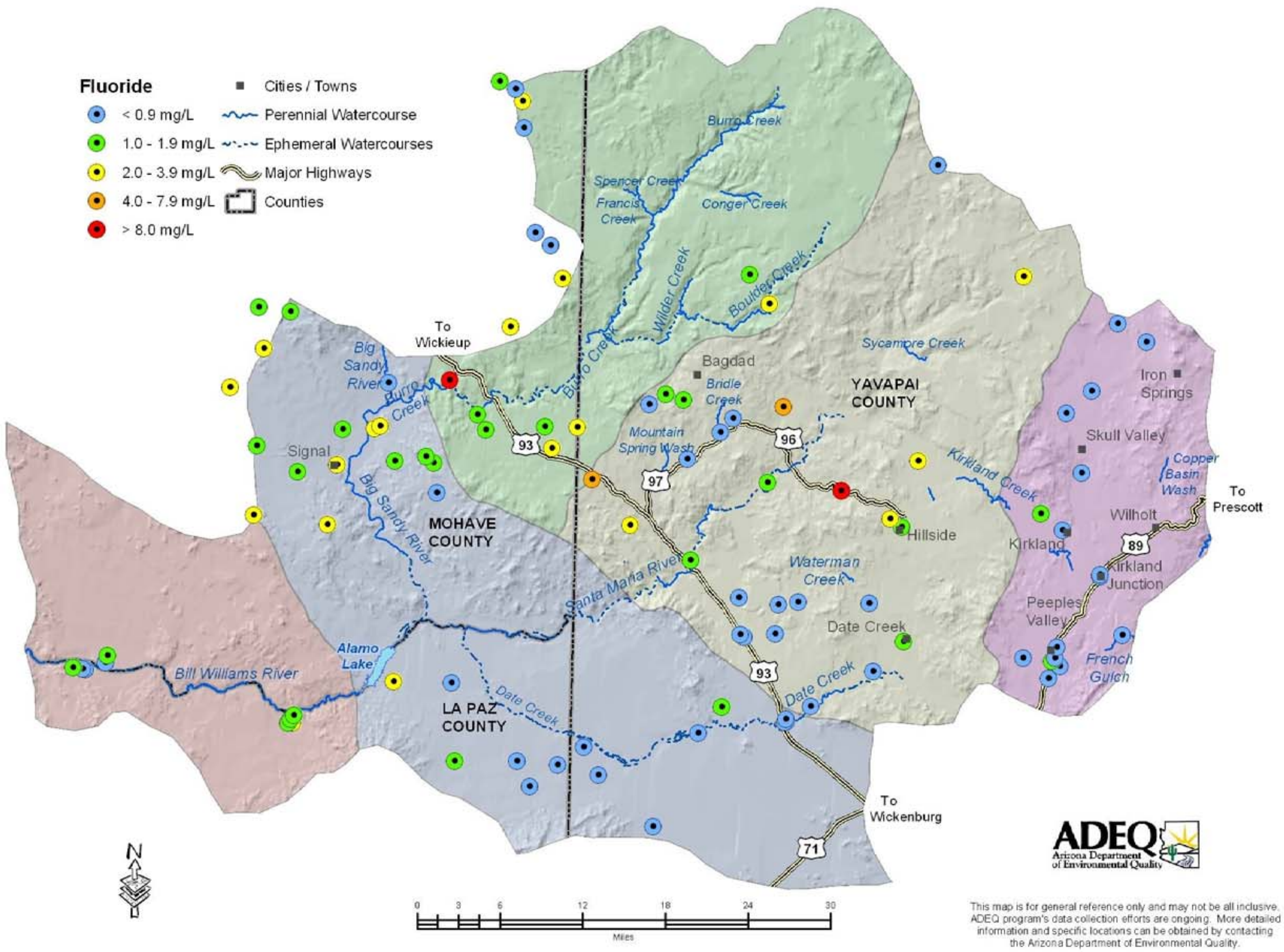
Diagram 12. Samples collected from sites located in granitic rock have significantly higher bicarbonate concentrations than samples collected from sites in alluvium (Kruskal-Wallis with Tukey test, $p \leq 0.01$). Bicarbonate concentrations are frequently higher in recharge areas and decrease as groundwater flows downgradient.[20]

Table 9. Variation in Groundwater Quality Constituent Concentrations among Five Geologic Classifications Using Kruskal-Wallis Test with the Tukey Test

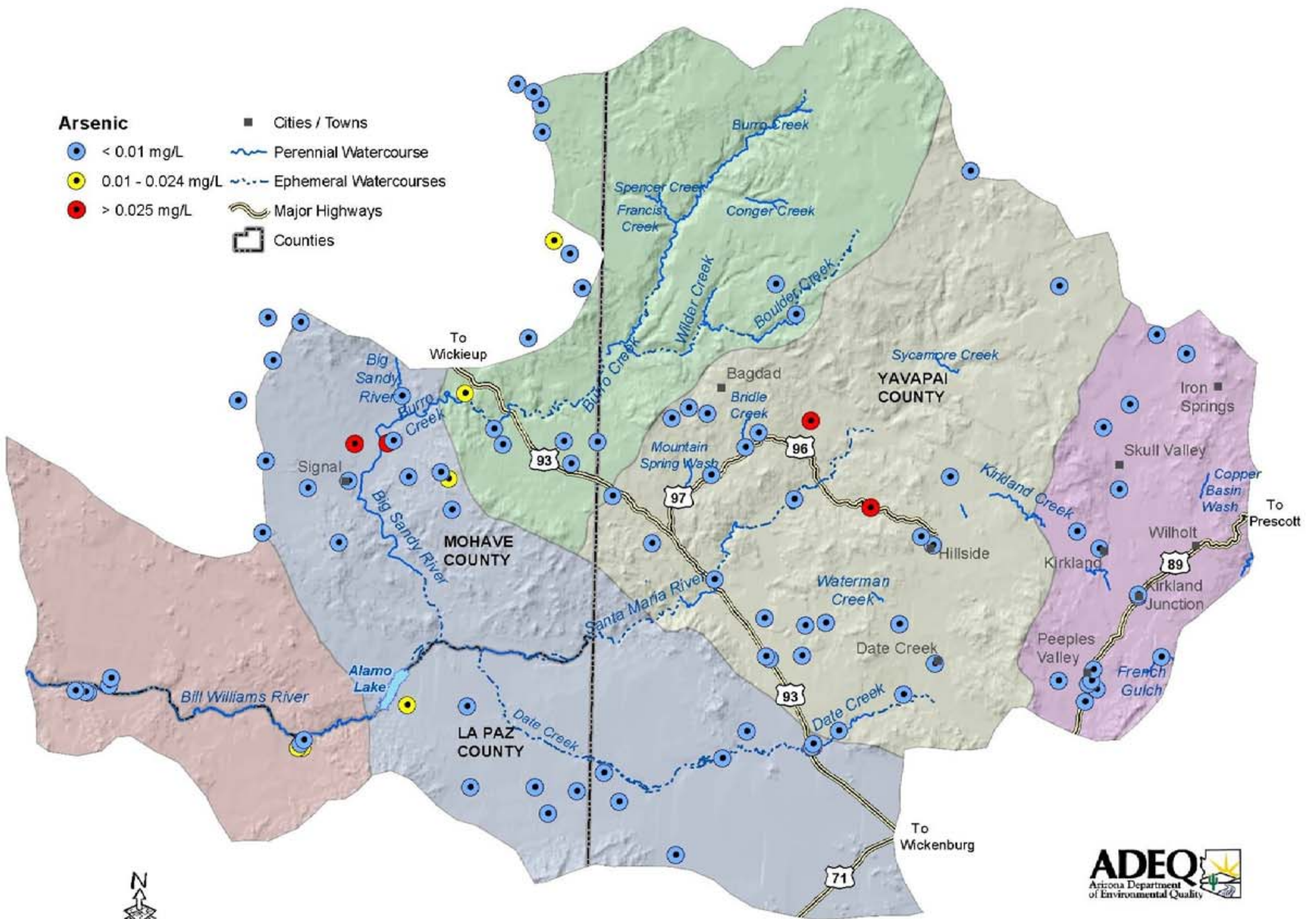
Constituent	Significance	Significant Differences Among Aquifers
Temperature - field	ns	-
pH – field	ns	-
pH – lab	**	Alluvial & Basalt > Granitic
SC - field	*	Granitic > Alluvium & Sedimentary
SC - lab	*	Granitic > Sedimentary
TDS	*	Granitic > Alluvium & Sedimentary
Turbidity	ns	-
Hardness	**	Granitic > Alluvium
Calcium	**	Granitic > Alluvium
Magnesium	** / *	Granitic > Alluvium & Sedimentary
Sodium	ns	-
Potassium	ns	-
Bicarbonate	**	Granitic > Alluvium
Chloride	ns	-
Sulfate	ns	-
Nitrate (as N)	ns	-
Barium	ns	-
Boron	ns	-
Fluoride	*	Granitic > Alluvium & Sedimentary
Zinc	ns	-
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

Map 8 - Fluoride



Map 9 - Arsenic



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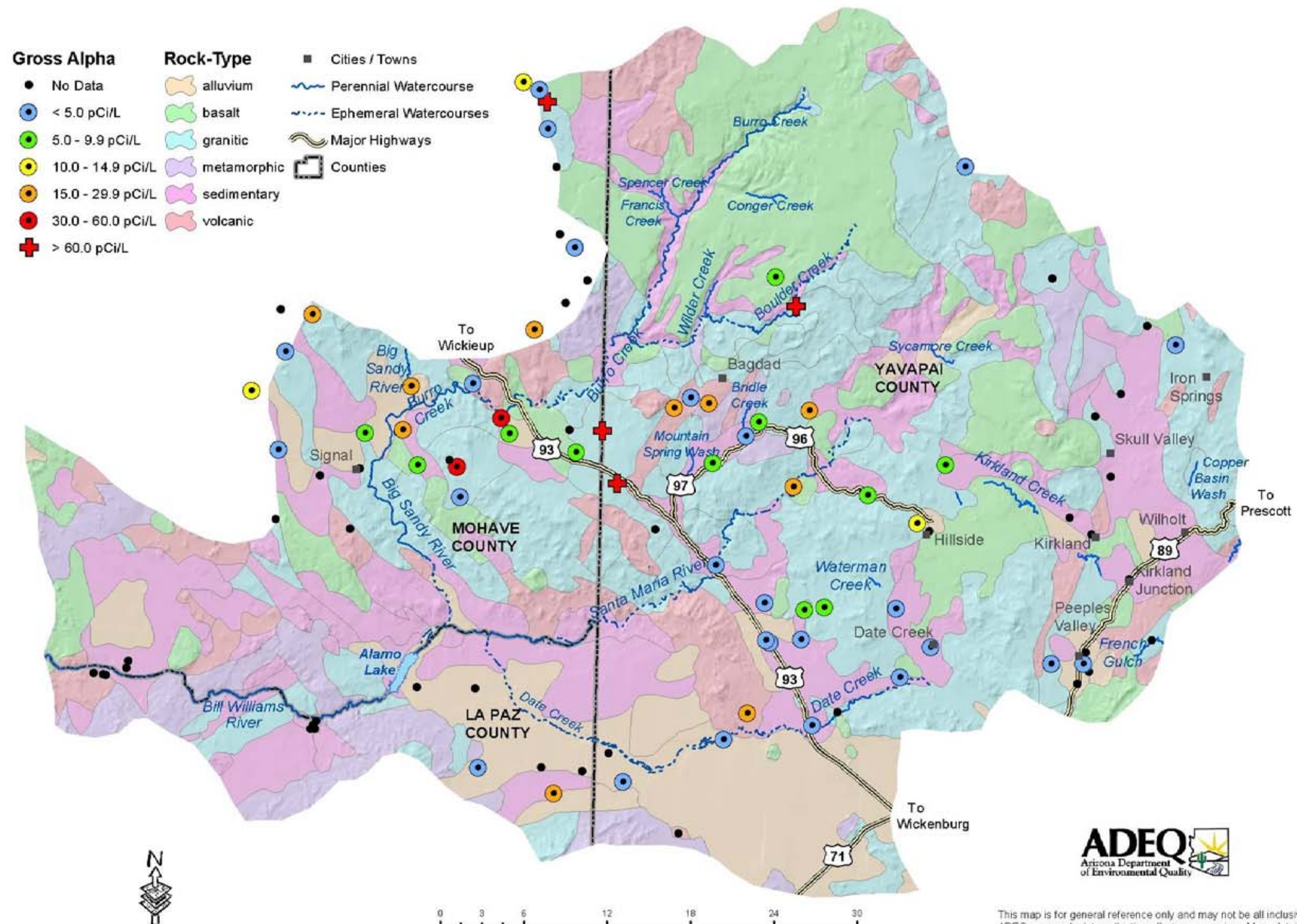
Map 10 - Gross Alpha



This map is for general reference only and may not be all inclusive. ADEQ program's data collection efforts are ongoing. More detailed information and specific locations can be obtained by contacting the Arizona Department of Environmental Quality.

DISCUSSION

The Bill Williams Basin occupies an extensive amount of land, almost 3,200 square miles, in west-central Arizona. The basin is remote, sparsely populated, and large portions are inaccessible to vehicles. In many parts of the basin, there are limited wells and springs available for sampling.

These factors resulted in extensive areas of the basin without any sample sites as well as clustering of sample sites in some developed areas. Although the ADEQ report represents the most complete, current water quality analysis of the Bill Williams Basin, the results and conclusions of the study should be used cautiously because of the basin's inherent size, complexity and remoteness.

Despite the studies inherent weaknesses, there is much to be gleaned from the collected groundwater quality data that was collected for this study. The data was considered acceptable for further analysis based on the results of blank, duplicate and split samples along with various quality assurance and quality control measurements.

Groundwater Quality - Overall, the water quality of the Bill Williams Basin was considered fair to good; almost half of the sites (48 percent) at which samples were collected met all health-based and aesthetics-based water quality standards. Forty-nine sites (49 percent) exceeded aesthetics-based water quality standards and 28 (28 percent) exceeded health-based water quality standards. In comparison, state-wide results over a 15 year period beginning in 1995 revealed 42 percent of sample sites met all health-based and aesthetics-based water quality standards, 31 percent exceeded aesthetics-based water quality standards and 27 percent exceeded health-based water quality standards.

Health-based, water quality standard exceedances would likely have increased if radionuclide samples were collected at all 100 sites instead of only at 55 sites. Whether evaluated by number or frequency, gross alpha most commonly exceeded health-based standards with 16 sites or at 29 percent of sites where radionuclide samples were collected. In addition, at the 16 sites where gross alpha exceeded water quality standards, uranium (7 sites) and radium 226+228 (4 sites) also exceeded their respective standards.

The most common inorganic constituents exceeding water quality standards included arsenic (10 sites), fluoride (4 sites) and nitrate (3 sites).

Only 3 of the 10 sites exceeding the arsenic standard had concentrations high enough to have exceeded the former standard of 0.05 mg/L that was subsequently lowered to 0.01 mg/L in 2006. The highest arsenic concentrations were from samples collected from a 180-foot deep well by Alamo Reservoir (0.30 mg/L) and from Kaiser Warm Spring in Burro Creek (0.12 mg/L). Arsenic concentrations are influenced by factors such as aquifer residence time, an oxidizing environment, and lithology. Arsenic concentrations are effected by reactions that also influence fluoride concentrations such as exchange on clays or with hydroxyl ions. [20]

Fluoride concentrations above 5 mg/L are controlled by calcium through precipitation or dissolution of the mineral, fluorite. In a chemically closed hydrologic system, calcium is removed from solution by precipitation of calcium carbonate and the formation of smectite clays. High concentrations of dissolved fluoride may occur in groundwater depleted in calcium if a source of fluoride ions is available for dissolution. [20] Three of the four sites where fluoride exceeded health-based standards, there was also an exceedance of the arsenic standard.

Of the three nitrate exceedances, two were at 110 mg/L at shallow wells located in the Bagdad area. Effluent from septic systems and waste associated with livestock corrals adjacent to water sources are likely responsible for elevated nitrate concentrations. These sources have been found to impact nitrate concentrations in isolated wells in other Arizona groundwater basins.

Cadmium, chromium and lead concentrations exceeded water quality standards at one sample site apiece. These constituents do not appear to be of concern in the basin; cadmium and lead were only detected at one sample site apiece while chromium was detected at six sites. The exceedances may have been due to unusual geochemistry at the site, sampling or lab errors.

The most common aesthetic-based water quality exceedances include TDS (32 sites) and fluoride (23 sites). Previous studies have also found TDS concentrations in the basin to be from 75 to 3,000 mg/L with most samples less than 500 mg/L.[21]

Controls on concentrations of fluoride below 5 mg/L include hydroxyl ion exchange and sorption-desorption reactions. As pH values increase, greater levels of hydroxyl ions may affect an exchange of hydroxyl for fluoride ions, thereby increasing the concentrations of fluoride in solution. [20] Previous studies revealed about one-third of the water samples exceeded 1.6 mg/L.[21]

Groundwater Composition - Groundwater in the basin evolves as it slowly moves through the basin from upgradient areas in the northeast to downgradient areas west part of the basin. Recharge occurring in the higher elevation areas of the basin such as the Skull Valley sub-basin start as a calcium-bicarbonate chemistry and, on a flowpath, evolves into a mixed-bicarbonate or sodium-mixed chemistry when it reaches lower elevation areas such as the Clara Peak sub-basin.

Isotope results reveal some samples collected from sites in the Bill Williams basin are much lighter and more depleted than would be expected from recharge originating in even the highest elevations of the basin.[10] Samples from the depleted wells and springs probably consist of paleowater that was recharged 8,000 – 12,000 years ago when climate in the basin was wetter and cooler.[10] Most sample sites appear to consist of recently recharged precipitation though some sites may have paleowater influences. Samples collected from wells along the Bill Williams River have heavy, enriched isotope values that show the influences of evaporation perhaps while the water was stored in Alamo Reservoir before being released into the river channel.

Few broad, water quality patterns could be gleaned from the data using factors such as sub-basins or geology. The basin's heterogeneous geology and the clustering of sample sites may have contributed to the lack of basin-wide, water quality patterns.

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Appendix A. Data for Sample Sites, Bill Williams Basin, 2003-09

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Sub-Basin / Geology
1st Field Trip, August 12, 2003 – Towne & Sutter									
BWM-0	B(14-13)13bad submersible	34°33'29.809" 113°34'23.793"	627863	20187	Rohr Rnch Well	Inorganic, Radiochem Radon, Isotopes	250'	50'	Alamo Res Alluvial
2nd Field Trip, October 1, 2003 - Lucci & Boettcher (Travel Blank #1)									
BWM-1/1D duplicate	B(12-4)06dcd submersible	34°25'05.095" 112°42'43.810"	593261	62695	Durrey Well	Inorganic, Radon O & H Isotopes	202'	85'	Skull Valley Sedimentary
BWM-2	B(13-4)09cbd submersible	34°28'45.324" 112°41'20.945"	643329	62696	Pearson Well	Inorganic, Radon O, H isotopes	-	-	Skull Valley Sedimentary
BWM-3	B(13-6)31b submersible	34°25'38.289" 112°55'52.678"	594559	62697	Blackmore Well	Inorganic, Radiochem O, H isotopes	257’	-	Santa Maria Granitic
BWM-4	B(13-7)21acb windmill	34°27'18.895" 112°59'46.705"	637157	20034	Blackmore Windmill	Inorganic, Radiochem O, H isotopes	65’	-	Santa Maria Granitic
BWM-5/5S split	B(13-5)25cbc submersible	34°26'06.689" 112°44'25.928"	570319	62698	Levin Well	Inorganic, Radon O, H isotopes	385’	-	Skull Valley Sedimentary
BWM-6	B(13-6)04ccd submersible	34°29'17.966" 112°53'49.929"	622775	62699	Low Well	Inorganic, Radiochem O, H isotopes	-	-	Santa Maria Sedimentary
3rd Field Trip, October 22-23, 2003 - Lucci & Fitch (Travel Blank #2)									
BWM-7	B(14-9)16ddd submersible	34°32'52.329" 113°11'52.262"	600895	62743	Kellis Ranch Well	Inorganic, Radiochem O, H isotopes	125’	-	Santa Maria Volcanic
BWM-8	B(15-8)27cbc windmill	34°39'01.848" 113°05'27.478"	533940	62744	Wildhorse Windmill	Inorganic, Radiochem O, H isotopes	-	-	Burro Creek Granitic
BWM-9	B(14-8)23bbd spring / well	34°32'35.814" 113°04'12.677"	644849	62745	S.H. Spring / Well	Inorganic, Radiochem O, H isotopes	-	-	Santa Maria Granitic
BWM-10/10s split	B(14-4)20bcc submersible	34°32'30.249" 112°42'35.457"	646595	62746	Gardner Well	Inorganic, Radon O, H isotopes	60’	-	Skull Valley Granitic
BWM-11	B(11-7)25cbd submersible	34°15'58.141" 112°57'00.609"	625483	62747	Browning Well	Inorganic, Radiochem O, H isotopes	375’	75’	Santa Maria Sedimentary
4th Field Trip, December 2, 2003 – Lucci & Fitch									
BWM-12/12S split	B(11-4)12cbb submersible	34°18'31.946" 112°38'02.658"	589474	62832	Zonia Mine Well	Inorganic, Radon O, H isotopes	200’	-	Skull Valley Granitic
BWM-13/13D duplicate	B(11-5)22abc submersible	34°16'58.619" 112°45'34.744"	517263	62833	Reeves Well	Inorganic, Radiochem, O, H isotopes	310’	-	Skull Valley Granitic
BWM-14	B(13-9)10bcb Submersible	34°29'07.416" 113°11'28.963"	578784	62834	Walley Well	Inorganic, Radiochem, O, H isotopes	225’	-	Santa Maria Sedimentary
BWM-15	B(12-7)35ddb submersible	34°20'15.219" 112°57'23.299"	613954	62835	Hawkins Well	Inorganic, Radiochem O, H isotopes	100’	-	Santa Maria Sedimentary
BWM-16	B(11-6)17bdd submersible	34°17'53.325" 112°54'43.137"	582666	62836	Austin Well	Inorganic, Radiochem O, H isotopes	216’	-	Santa Maria Sedimentary
5th Field Trip, January 29, 2004 – Lucci & Yu (Travel Blank #3)									
BWM-17/17D duplicate	B(10-7)7bbd submersible	34°13'40.451" 113°01'41.806"	621453	19668	Knight Well	Inorganic, Radon O, H isotopes	150’	-	Santa Maria Basalt
6th Field Trip, March 1-2, 2004 – Lucci & Fitch									
BWM-18/18D duplicate	B(10-13)01aaa submersible	34°14'38.304" 113°33'27.392"	520524	63002	Cholla Cmp Well	Inorganic, Radon O, H isotopes	480’	-	Alamo Res Alluvial
BWM-19/19S/82 split	B(10-12)02bbb submersible	34°14'39.600" 113°29'02.783"	617732	19692	Wayside Inn Well	Inorganic, Radon O, H isotopes	580’	-	Alamo Res Alluvial
BWM-20	B(12-9)24bda submersible	34°22'45.313" 113°11'04.134"	614692	63003	Barnes Well	Inorganic, Radiochem, O, H isotopes	60’	-	Santa Maria Sedimentary
BWM-21	B(15-5)03 submersible	34°41'05.782" 112°46'01.445"	626009	63001	Polk Well	Inorganic, Radon O, H isotopes	180’	-	Santa Maria Granitic
BWM-22	B(15-4)14d submersible	34°38'11.605" 112°38'48.624"	526675	20278	Denton Well	Inorganic, Radon O, H isotopes	293’	-	Skull Valley Sedimentary

Appendix A. Data for Sample Sites, Bill Williams Basin, 2003-09---Continued

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Sub-Basin / Geology
7th Field Trip, April 12-13, 2004 – Lucci & Yu (Travel Blank #4)									
BWM-23/23D duplicate	B(13-8)15cca submersible	34°27'45.586" 113°05'17.515"	610910	63400	Sanderson Well	Inorganic, Radiochem O, H isotopes	-	-	Santa Maria Basalt
BWM-24/24S split	B(13-6)32ccb submersible	34°25'06.710" 112°55'01.100"	511989	63401	Daniel Well	Inorganic, Radon O, H isotopes	-	-	Santa Maria Basalt
BWM-25	B(13-11)01caa windmill	34°29'39.189" 113°21'49.727"	642250	63213	Olea Well	Inorganic, Radiochem O, H isotopes	220'	-	Burro Creek Granitic
BWM-26	B(14-11)35aaa windmill	34°30'58.175" 113°22'23.461"	632254	63402	New Olea Well	Inorganic, Radon O, H isotopes	220'	-	Burro Creek Granitic
BWM-27	B(14-10)32bab windmill	34°31'00.658" 113°19'53.398"	614776	63676	Pack Rat Windmill	Inorganic, Radiochem O, H isotopes	200'	-	Burro Creek Granitic
BWM-28	B(13-10)16cda windmill	34°27'43.297" 113°18'42.316"	614722	63675	Middle Well	Inorganic, Radiochem O, H isotopes	200'	-	Santa Maria Granitic
8th Field Trip, May 11, 2004 – Lucci & Taunt (Travel Blank #5)									
BWM-29/29S/ 112 split	B(11-16)32cdb turbine	34°14'56.056" 113°57'08.079"	619420	63836	Well #4	Inorganic, Radon Perc, O, H isotopes	130'	-	Clara Peak Alluvial
9th Field Trip, May 25-26, 2004 – Lucci & Fitch (Travel Blank #6)									
BWM-30/30S split	B(12-13)06ddb submersible	34°24'27.712" 113°38'45.960"	642286	63585	Eagle Point Well	Inorganic, Radon O, H isotopes	300'	180'	Alamo Res Volcanic
BWM-31	B(13-10)16cda windmill	34°27'43.585" 112°03'04.892"	649965	63586	Rupley Well	Inorganic, Radon O, H isotopes	220'	-	Alamo Res Sedimentary
BWM-32/32D duplicate	B(12-14)05bba windmill	34°24'56.723" 113°44'25.847"	649964	63587	Baker Well	Inorganic, Radon O, H isotopes	90'	75'	Alamo Res Granitic
BWM-33	B(13-6)32ccb submersible	34°30'36.723" 113°35'21.486"	582819	63588	Cmpgrnd Well	Inorganic, Radon O, H isotopes	180'	-	Alamo Res Basalt
BWM-34	B(12-10)02adb windmill	34°24'53.257" 113°15'43.384"	614694	63589	ASLD Windmill	Inorganic, Radon O, H isotopes	100'	30'	Santa Maria Granitic
10th Field Trip, November 14-15, 2007 – Towne (Travel Blank, BWM- 45)									
BWM-35	B(11-8)17abc spring	34°18'08.347" 113°07'10.098"	-	19780	Divide Spring	Inorganic, Radiochem, Perc, Radon, Isotopes	-	-	Santa Maria Sedimentary
BWM-36	At Burro Creek Campground	-	-	-	Burro Creek	Isotopes	-	-	-
BWM-37	B(14-11)31acd hillside spring	34°30'42.256" 113°26'52.127"	-	69278	Wildhorse Spring	Inorganic, Radiochem, Perc, Radon, Isotopes	-	-	Burro Creek Granitic
BWM-38	B(14-12)10ddb adit hot spring	34°33'47." 113°29'46."	-	20184	Kaiser Warm Spr	Inorganic, Radiochem, Perc, Radon, Isotopes	-	-	Burro Creek Volcanic
BWM-39/40	B(14-12)25ada hillside spring	34°31'38." 113°27'32."	-	69282	Snake Spring	Inorganic, Radiochem, Perc, Isotopes	-	-	Burro Creek Granitic
BWM-41	B(14-13)35ada submersible	34°30'47.071" 113°34'56.201"	646799	69279	Smith Well	Inorganic, Radiochem, Perc, Radon, Isotopes	310'	168'	Alamo Res Sedimentary
BWM-42/43 duplicate	B(14-13)33cba submersible	34°30'31.202" 113°37'47.413"	906969	69280	Dieterich Well	Inorganic, Radiochem, Perc, Radon, Isotopes	488'	303'	Alamo Res Alluvial
BWM-44	At Signal Road Crossing	-	-	-	Big Sandy River	Isotopes	-	-	-
11th Field Trip, December 7, 2007 – Towne									
BWM-46/47 duplicate	B(15-11)21cdd windmill	34°37'14.071" 113°25'11.187"	612829	69281	Red Knob Windmill	Inorganic, Radiochem, Perc, Radon, Isotopes	-	-	Burro Creek Granitic

Appendix A. Data for Sample Sites, Bill Williams Basin, 2003-09---Continued

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Sub-Basin / Geology
12th Field Trip, December 19, 2007 – Towne (Travel Blank, BWM- 49)									
BWM-48	B(13-12)09dda channel spring	34°28’31.585" 113°30'47.236"	-	69758	Alamo Spring	Inorganic, Radiochem, Perc, Isotopes	-	-	Alamo Res Granitic
BWM-50	B(13-12)07ccb hillside spring	34°28'35.196" 113°33'48.538"	-	69759	Hackberry Spring	Inorganic, Radiochem, Perc, Isotopes	-	-	Alamo Res Granitic
BWM-51	B(13-12)09bdc channel spring	34°28'54.165" 113°31'27.555"	-	69760	Big Sandy Spring	Perchlorate O, H isotopes	-	-	Alamo Res Granitic
13th Field Trip, January, 16-17, 2008 – Towne & Harmon (Travel Blank, BWM-63)									
BWM-52/53 duplicate	B(11-8)17adb windmill	34°17'58.429" 113°06'52.114"	643176	19781	Lower Hackberry	Inorganic, Radiochem, Perc, Radon, Isotopes	130’	-	Santa Maria Sedimentary
BWM-54/55 duplicate	B(11-8)14bbb windmill	34°18'13.511" 113°04'28.414"	643179	19779	Upper Hackberry	Inorganic, Radiochem, Perc, Radon, Isotopes	120’	61’	Santa Maria Sedimentary
BWM-56	B(12-8)36cad submersible	34°20'15.473" 113°02'49.369"	643169	19906	Grullo Windmill	Inorganic, Radiochem, Perc, Radon, Isotopes			Santa Maria Granitic
BWM-57	B(12-8)35cca spring	34°20'05.044" 113°04'19.288"	-	70058	Up Black Canyon Sp	Inorganic, Perc Isotopes	-	-	Santa Maria Sedimentary
BWM-58	B(12-8)32bdc windmill	34°20'27.647" 113°07'19.955"	643173	19904	Broken Windmill	Inorganic, Radiochem, Perc, Radon, Isotopes	-	-	Santa Maria Sedimentary
BWM-59	B(17-11)11bcd submersible	34°52'14.733" 113°25'12.671"	630658	20908	Unnamed Windmill	Inorganic, Radiochem, Perc, Radon, Isotopes	150’	89’	Burro Creek Granitic
BWM-60	B(17-11)14aca windmill	34°51'30.657" 113°24'40.681"	619684	70078	BLM Willow Spr	Inorganic, Radiochem, Perc, Radon, Isotopes	100’	16’	Burro Creek Granitic
BWM-61/62 split	B(17-11)3ccc submersible	34°52'43.469" 113°26'28.925"	630666	20905	Williams Windmill	Inorganic, Radiochem, Perc, Radon, Isotopes	190’	45’	Burro Creek Granitic
BWM-64	B(13-12)27bba spring	34°26'38.873" 113°30'30.698"	-	70079	Arroweed Spring	Inorganic, Radiochem, Perc, Isotopes	-	-	Alamo Res Granitic
14th Field Trip, March 18-19, 2008 – Towne (Travel Blank, BWM- 75)									
BWM-65/66 split	B(10-9)23bcb submersible	34°11'49.923" 113°10'12.055"	805811	19684	Pipeline RanchWell	Inorganic, Radiochem, Perc, Radon, Isotopes	220’	180’	Alamo Res Alluvial
BWM-67	B(10-9)12adb spring	34°13'31.850" 113°08'26.309"	-	70921	Tres Alamos Sp	Inorganic, Radiochem, Perc, Radon, Isotopes	-	-	Alamo Res Volcanic
BWM-68	B(14-9)17adc windmill	34°33'11.354" 113°13'11.955"	600896	70940	Mtn Spring Windmill	Inorganic, Radiochem, Perc, Radon, Isotopes	115’	50’	Santa Maria Sedimentary
BWM-69	B(14-9)19bdd windmill	34°32'31.665" 113°14'26.361"	600899	70941	Grayback Windmill	Inorganic, Radiochem, Perc, Radon, Isotopes	200’	-	Santa Maria Sedimentary
BWM-70/71 radiochem split	B(14-8)30cba windmill	34°31'46.054." 113°08'02.081"	599893	70942	Ed Kellis Windmill	Inorganic, Radiochem, Perc, Radon, Isotopes	150’	60’	Santa Maria Sedimentary
BWM-72	B(15-8)17dbd windmill	34°40'51.455." 113°07'00.978"	614794	70943	Denny Moore Mill	Perc, Isotopes	293’	183’	Santa Maria Basalt
BWM-73/74 duplicate	B(14-9)36abd windmill	34°30'51.250" 113°08’58.463"	614768	70944	Red Flat Windmill	Inorganic, Radiochem, Perc, Radon, Isotopes	140’	93’	Santa Maria Sedimentary
15th Field Trip, July 29-30, 2008 – Towne									
BWM-76	B(14-3)06dbd hillside spring	34°32'31.665" 113°14'26.361"	631929	71482	Up Pasture Spring	Inorganic, Radiochem, Isotopes	-	-	Skull Valley Granitic
BWM-77/78 duplicate	B(16-6)03acc hillside spring	34°31'46.054." 113°08'02.081"	-	20704	Merritt Spring	Inorganic, Radiochem, Isotopes	-	-	Santa Maria Granitic
BWM-79/80 split	B(14-4)09dda hillsidespring	34°40'51.455." 113°07'00.978"	-	71483	Woolsey Spring	Inorganic, Radiochem, Radon, Isotopes	-	-	Skull Valley Sedimentary
16th Field Trip, October 29, 2008 – Towne (Travel Blank, MMU- 126)									
BWM-81	B(10-12)35ccd submersible	34°09'43.958." 113°28'40.162"	521572	19695	Connelly Well	Inorganic, Radiochem, Radon, Isotopes	480’	255’	Alamo Res Alluvial
BWM-19/82	B(17-11)3ccc submersible	34°14'39.898." 113°29'05.650"	617732	19692	Wayside Inn	Inorganic, Radon O & H Isotopes	580’	200’	Alamo Res Alluvial

Appendix A. Data for Sample Sites, Bill Williams Basin, 2003-09---Continued

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Sub-Basin / Geology
17th Field Trip, November 6, 2008 – Towne & Jones									
BWM-83	B(9-9)29bbb submersible	34°05'52.996" 113°13'31.003"	638790	72344	Summer Camp Well	Inorganic, Radiochem, Radon, Isotopes	186'	-	Alamo Res Volcanic
BWM-84	B(9-10)4daa submersible	34°09'04.268" 113°17'45.813"	514668	72345	Bullard Well	Inorganic, Radon O & H Isotopes	600'	550'	Alamo Res Alluvial
18th Field Trip, January, 21, 2009 – Towne (Travel Blank, BWM-85 and BWM-96)									
BWM-86	B(12-4)22bda submersible	34°22'13.646" 112°39'51.547"	643855	72865	Tufa Well	Inorganic, Radon O & H Isotopes	125'	90'	Skull Valley Sedimentary
BWM-87/88 duplicate	B(12-4)22bda submersible	34°22'18.892" 112°39'52.939"	808464	72866	Junction IR Well	Inorganic, Radiochem, O & H Isotopes	120'	61'	Skull Valley Sedimentary
BWM-89/90 split	B(11-4)18bdc submersible	34°17'41.331" 112°43'04.381"	609598	72867	East Fork House Wl	Inorganic Radon	80'	19'	Skull Valley Alluvial
BWM-91	B(11-4)19dcb spring	34°20'05.044" 113°04'19.288"	-	44474	Genug Spring	Inorganic O & H Isotopes	-	-	Skull Valley Alluvial
BWM-92	B(11-4)19b submersible	34°17'02.099" 112°43'12.678"	901444	72868	East Fork Barn Well	Inorganic Radon	-	-	Skull Valley Alluvial
BWM-93	B(11-5)25dad submersible	34°15'42.872" 112°43'39.505"	-	72869	McCrea Windmill	Inorganic, Radon O & H Isotopes	150'	89'	Skull Valley Alluvial
BWM-94/95 duplicate	B(11-5)24add submersible	34°16'47.899" 112°43'26.609"	-	72870	West Fork House Wl	Inorganic, Radiochem, O & H Isotopes	-	-	Skull Valley Alluvial
19th Field Trip, April 20-22, 2009 – Towne (Travel Blank, BWM- 110)									
BWM-97	B(10-10)29dab submersible	34°11'47.407" 113°18'55.361"	645595	73600	Date Creek Well	Inorganic O & H Isotopes	450'	-	Alamo Res Alluvial
BWM-98	B(11-10)36dda submersible	34°09'38.928" 113°20'52.715"	645596	73601	HQ Well	Inorganic O & H Isotopes	435'	334'	Alamo Res Alluvial
BWM-99/100 duplicate	B(10-11)34cbb submersible	34°09'49.157" 113°23'56.436"	633307	19691	East Well	Inorganic O & H Isotopes	-	-	Alamo Res Alluvial
BWM-101	B(9-11)10add submersible	34°08'15.244" 113°22'58.239"	645593	73620	Weber Well	Inorganic O & H Isotopes	520'	450'	Alamo Res Sedimentary
BWM-102	B(10-8)14bdd submersible	34°12'38.262" 113°03'34.834"	612047	19680	Garden Well	Inorganic O & H Isotopes	150'	80'	Alamo Res Sedimentary
BWM-103	B(10-8)14bdd submersible	34°12'38.440." 113°03'39.311"	612048	19679	Corral Well	Inorganic	220'	50'	Alamo Res Sedimentary
BWM-104	B(10-8)14bad submersible	34°12'51.016" 113°03'36.440"	590250	73640	House Well	Inorganic O & H Isotopes			Santa Maria Sedimentary
BWM-105	B(10-14)23bac turbine	34°11'53.159." 113°41'26.498"	608746	19710	Main Meter Well	Inorganic O & H Isotopes	165'	18'	Clara Peak Alluvial
BWM-106	B(10-14)23abd turbine	34°11'53.029" 113°41'03.791"	608743	19708	Corral Field	Inorganic O & H Isotopes	101'	13'	Clara Peak Alluvial
BWM-107	B(10-14)14cdd turbine	34°12'06.345" 113°41'14.951"	608747	19706	House Well	Inorganic O & H Isotopes	91'	21'	Clara Peak Alluvial
BWM-108	Bill Williams River at Lincoln Ranch	-	-	-	-	O & H Isotopes	-	-	-
BWM-109	B(10-14)14dac turbine	34°12'21.435." 113°41'00.535"	-	19705	River Well	Inorganic O & H Isotopes	86'	15'	Clara Peak Alluvial
20th Field Trip, June 3-4, 2009 – Towne									
BWM-111	B(11-16)31dcb submersible	34°14'59.015" 113°57'51.584"	619427	51365	Trailer Well	Inorganic O & H Isotopes	80'	20'	Clara Peak Alluvial
BWM-112	B(11-16)32cdb turbine	34°14'56.056" 113°57'08.079"	619420	63836	Well #4	Inorganic O & H Isotopes	130'	25'	Clara Peak Alluvial
BWM-113	B(11-16)32cda submersible	34°14'54.241" 113°56'57.661"	619413	19826	Shed Well	Inorganic O & H Isotopes	100'	40'	Clara Peak Alluvial
BWM-114	B(11-16)27cbc turbine	34°14'48.779" 113°55'16.282"	619410	19816	Well #7	Inorganic O & H Isotopes	115'		Clara Peak Alluvial

Appendix A. Data for Sample Sites, Bill Williams Basin, 2003-09---Continued

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Sub-Basin / Geology
BWM-115	B(11-16)33ada turbine	34°15'22.114" 113°55'26.007"	619417	19827	Well #9	Inorganic O & H Isotopes	148’		Clara Peak Alluvial
21st Field Trip, June 22-24, 2009 – Towne									
BWM-116	B(15-14)20aab windmill	34°38'03.94" 113°44'31.04"	642277	57934	Halfway Windmill	Inorganic O & H Isotopes	-	-	Alamo Res Granitic
BWM-117/118 duplicate	B(15-14)23bbd windmill	34°37'51.30" 113°42'03.69"	645961	20318	Devils Cyn Windmill	Inorganic, Radiochem O & H Isotopes	150’	20’	Alamo Res Granitic
BWM-119	B(15-14)33cdc spring	34°35'28.55" 113°44'01.95"	-	20319	Groom Spring	Inorganic, Radiochem O & H Isotopes	-	-	Alamo Res Granitic
BWM-120	B(14-15)13dda windmill	34°32'59.21" 113°46'32.20"	645965	57942	Banks Windmill	Inorganic, Radiochem O & H Isotopes	142’	80’	Alamo Res Sedimentary
BWM-121	B(13-14)08aaa windmill	34°29'18.38" 113°44'20.59"	627862	20047	Misery Windmill	Inorganic, Radiochem O & H Isotopes	300’	220’	Alamo Res Sedimentary
BWM-122	B(13-13)18aaa submersible	34°28'15.413" 113°38'12.108"	-	20045	Signal Spring	Inorganic O & H Isotopes	-	-	Alamo Res Granitic
BWM-123	B(16.5-11)27abc submersible	34°47'26.72" 113°23'52.32"	619690	74432	Francis Ck Ranch HQ	Inorganic, Radiochem O & H Isotopes	110’	75’	Burro Creek Granitic
BWM-124	B(17-11)26aac windmill	34°49'50.82" 113°24'33.36"	625630	74427	Blue Windmill	Inorganic, Radiochem O & H Isotopes	230’	-	Burro Creek Granitic
BWM-125	B(16-11)22aab submersible	34°43'12.47" 113°23'30.10"	619683	74428	Sycamore Camp Well	Inorganic, Radiochem O & H Isotopes	150’	25’	Burro Creek Basalt
BWM-126	B(15-11)01ada windmill	34°40'23.31" 113°21'19.19"	642273	74429	Pine Flat Windmill	Inorganic, Radiochem O & H Isotopes	-	-	Burro Creek Granitic
BWM-127	B(16-11)23ddd windmill	34°42'26.81" 113°22'20.17"	619687	74430	Butte Windmill	Inorganic O & H Isotopes	65’	45’	Burro Creek Basalt
BWM-128	B(11-16)33ada windmill	34°38'55.56" 113°22'55.31"	642360	74431	Upper Cornwall	Inorganic O & H Isotopes	-	-	Burro Creek sedimentary

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09

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)
BWM-0	TDS, Cl Gross α, Pb	21.4	7.08	*7.83*	1832	2050	**1100**	385	390	*4.2*
BWM-1/1D	-	21.6	7.23	*7.7*	613	625	415	240	250	0.185
BWM-2	Radon	19.2	7.03	*7.6*	777	700	420	310	320	0.06
BWM-3	F	21.8	7.07	*7.5*	671	690	440	260	270	1.3
BWM-4	TDS, As, **F**, Mn	29.5	7.94	*8.1*	1007	1000	630	26	30	*0.23*
BWM-5/5S	Radon	24.0	7.00	*7.65*	701	735	465	230	230	0.06
BWM-6	TDS, F	17.8	7.07	*7.6*	804	840	**510**	240	250	0.58
BWM-7	TDS, NO_3 Gross α	28.7	7.40	7.7	1510	1400	**910**	580	610	0.54
BWM-8	TDS, F, NO_3 Gross α, U	26.8	7.59	*7.3*	1472	1400	**940**	600	600	5.3
BWM-9	TDS, **F**, As Gross α	25.3	7.23	*7.3*	862	840	**540**	120	120	0.04
BWM-10/10S	Mn, Radon	21.3	7.08	*7.5*	335	340	215	135	140	1.2
BWM-11	-	24.2	8.28	*7.7*	573	500	330	200	210	0.01
BWM-12/12S	TDS, SO_4, Cd, Mn, Radon	16.2	7.31	*6.73*	2420	1950	**1850**	1350	1300	0.86
BWM-13/13D	TDS	16.8	7.11	*7.4*	1036	885	**550**	390	370	1.5
BWM-14	-	22.6	8.28	*7.6*	819	670	430	280	270	0.72
BWM-15	-	19.4	8.29	*7.5*	656	560	360	270	260	0.25
BWM-16	pH	21.3	**8.72**	*8.1*	540	460	300	170	180	0.20
BWM-17/17D	Mn, Radon	15.4	7.46	*7.65*	693	690	410	235	250	2.1
BWM-18/18D	F, As, Radon	18.2	7.29	*7.8*	560	635	385	110	120	1.0
BWM-19/19S	Cr, Radon	28.8	8.09	*8.23*	453	455	285	49.5	50	0.45
BWM-20	TDS	21.1	7.37	*7.5*	870	880	**530**	220	220	0.17
BWM-21	F, Mn	-	7.28	*7.5*	677	700	410	270	280	22
BWM-22	Radon	-	7.48	*7.9*	329	340	220	150	160	0.28
BWM-23/23D	pH, Gross α	27.2	**9.02**	*9.0*	550	550	335	ND	ND	0.165
BWM-24/24S	-	17.1	7.36	*7.87*	546	570	355	230	220	0.13
BWM-25	F	22.3	7.37	*7.6*	763	780	470	280	290	4.4
BWM-26	Radon	24.6	7.24	*7.5*	549	520	360	250	250	1.3
BWM-27	TDS, Cl, F Gross α, Radium, U	25.3	7.32	*7.4*	1514	1500	**910**	430	440	0.96

italics = constituent exceeded holding time

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---Continued

Site #	**MCL Exceedances**	**Temp** (°C)	**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)
BWM-28	TDS, SO_4, **F** Gross α, Radium, U	24.0	7.17	*7.4*	1877	1900	**1200**	410	400	7.8
BWM-29/29S/112	-	22.1/ 21.8	7.66 / 7.54	*7.84*	751 / 729	765	460	200	200	0.08
BWM-30/30S	F, Radon	26.6	7.16	*7.57*	749	720	440	290	290	ND
BWM-31	-	26.0	7.81	*7.8*	476	420	280	120	130	0.25
BWM-32/32D	TDS, F, NO_3	24.2	7.25	*7.5*	962	875	**575**	365	390	0.54/ ND
BWM-33	pH, F, As, Radon	27.8	**9.52**	9.5	635	560	370	ND	ND	0.26
BWM-34	TDS, F, Radon	29.4	7.78	8.0	1049	950	**630**	320	340	1.0
BWM-35	-	21.9	7.21	8.1	514	510	330	200	200	0.23
BWM-37	TDS	22.1	7.66	8.3	857	860	**530**	300	300	0.83
BWM-38	TDS, As, **F**	35.4	7.39	8.2	1158	1200	**760**	50	50	0.02
BWM-39/40	TDS, Gross α, U	19.7	7.07	8.05	1025	1000	**680**	375	375	0.07
BWM-41	F, Gross α, Radon	27.5	7.44	8.3	427	420	270	98	99	0.03
BWM-42/43	As, Radon	28.3	7.30	8.2	720	720	450	120	120	1.05
BWM-46/47	TDS, Cl, SO_4, F, Fe, Mn, Gross α, Radium, Radon	20.7	7.26	7.8	3222	3400	**2800**	1700	1700	32
BWM-48	TDS, As, Gross α	10.1	8.36	8.2	1205	1200	**740**	440	480	0.42
BWM-50	TDS	12.7	7.98	8.0	1014	1000	**600**	380	390	0.94
BWM-51	-	12.3	8.18	-	748	-	-	-	-	-
BWM-52/53	Radon	19.9	7.75	8.15	453	440	265	140	140	1.2
BWM-54/55	Mn	10.5	7.77	8.15	667	670	380	230	235	5.7
BWM-56	-	21.7	7.49	8.1	617	610	380	260	250	0.31
BWM-57	-	14.6	7.45	8.1	644	640	410	280	270	1.0
BWM-58	Radon	21.0	7.60	8.1	515	510	310	170	170	0.21
BWM-59	-	15.9	7.59	8.1	517	510	340	250	250	0.35
BWM-60	-	17.6	7.45	8.1	747	740	470	330	340	0.25
BWM-61/62	TDS,	15.1	7.42	7.94	982	1000	**560**	420	400	0.10
BWM-64	TDS, F, Gross α, Radium, U	18.2	7.04	8.0	876	860	**550**	340	350	16
BWM-65/66	Radon	21.2	7.35	7.86	485	470	280	210	210	1.3
BWM-67	Radon	19.7	7.18	8.0	832	810	500	360	360	3.7

italics = constituent exceeded holding time

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---Continued

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)
BWM-68	TDS, Gross α, U, Radon	19.7	7.01	*7.8*	1200	1200	**720**	440	440	1.8
BWM-69	TDS	20.4	7.46	*8.0*	1036	1000	**620**	380	380	0.23
BWM-70/71	TDS, Gross α, U, Radon	22.2	7.01	*7.9*	1039	1000	**610**	360	360	0.36
BWM-73/74	TDS	21.8	7.60	*8.15*	915	895	**575**	350	350	0.775
BWM-76	-	32.9	7.94	*8.2*	435	370	220	130	130	1.9
BWM-77/78	pH	16.1	**6.25**	7.0	262	200	135	72	76.5	3.6
BWM-79/80	Mn, Radon	25.6	7.11	7.6	603	540	335	250	250	0.66
BWM-81	-	26.7	7.82	8.1	818	800	470	130	130	0.46
BWM-82	Radon	29.6	8.20	8.3	472	450	290	43	46	0.17
BWM-83	Radon	22.2	7.26	8.0	628	620	370	260	290	ND
BWM-84	Radon	26.3	7.91	8.2	329	320	190	84	82	0.17
BWM-86	Radon	21.5	7.52	8.1	452	420	280	180	180	0.98
BWM-87/88	-	20.4	7.43	8.2	462	440	290	180	185	0.035
BWM-89/90	Radon	-	7.31	7.94	564	550	310	240	240	0.26
BWM-91	-	-	7.23	8.1	507	490	310	200	210	0.75
BWM-92	Radon	16.4	7.43	8.2	479	450	280	190	190	0.69
BWM-93	-	17.8	7.63	8.3	427	400	260	170	180	1.9
BWM-94/95	-	16.2	7.22	8.1	526	500	320	220	220	0.11
BWM-97	-	27.0	8.10	8.3	399	360	220	99	100	0.54
BWM-98	-	27.2	7.95	8.2	473	440	280	130	130	0.58
BWM-99/100	-	29.3	7.73	8.2	449	415	250	110	110	0.335
BWM-101	Mn	25.3	7.51	8.2	628	590	340	180	200	29
BWM-102	-	19.3	7.13	8.0	643	610	380	220	240	0.12
BWM-103	-	19.1	6.99	8.0	623	610	360	230	230	0.30
BWM-104	-	23.4	7.38	8.1	627	600	360	230	240	0.05
BWM-105	TDS, As	21.8	7.40	8.2	1461	1400	**870**	280	270	ND
BWM-106	TDS, As, F	21.8	7.32	8.1	1565	1500	**930**	260	250	ND
BWM-107	-	19.9	7.12	8.2	798	780	450	200	200	0.05

italics = constituent exceeded holding time

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---Continued

Site #	**MCL Exceedances**	**Temp** (°C)	**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)
BWM-109	-	19.9	7.65	*8.2*	836	820	470	230	210	0.95
BWM-111	-	25.0	7.41	*8.0*	742	670	410	150	160	1.0
BWM-112	-	21.8	7.54	*8.0*	729	680	410	180	170	0.48
BWM-113	-	22.1	7.57	*8.0*	718	680	410	170	170	0.05
BWM-114	-	24.7	7.45	*8.0*	830	790	480	180	180	0.99
BWM-115	-	24.9	7.65	8.0	777	730	440	170	170	1.0
BWM-116	TDS, Cl, SO_4,	24.7	7.10	7.7	2383	2300	**1600**	810	780	0.68
BWM-117/118	TDS, SO_4, Fe, Mn Gross α,	24.3	6.88	7.65	2790	2650	**2250**	1200	1350	115
BWM-119	TDS, F, Mn	29.7	8.22	8.6	1523	1500	**850**	330	380	40
BWM-120	TDS, Cl, F	33.4	7.30	7.8	1817	1700	**1200**	590	550	0.51
BWM-121	-	28.7	7.90	8.1	547	480	320	120	160	1.5
BWM-122	F	28.8	7.90	8.0	576	530	330	120	110	0.04
BWM-123	-	24.2	7.34	8.0	601	540	380	280	230	0.08
BWM-124	TDS, Gross α,	20.2	7.06	7.9	1035	970	**610**	390	380	0.88
BWM-125	-	22.7	7.36	8.0	645	600	380	260	250	0.18
BWM-126	-	20.7	6.95	7.7	501	450	280	170	170	1.8
BWM-127	As	21.0	6.84	7.8	711	670	430	280	260	5.6
BWM-128	TDS, SO_4, F	29.9	7.36	8.1	1507	1400	**1100**	630	630	0.09

italics = constituent exceeded holding time

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---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)
BWM-0	81.5	44	255	11.25	425	510	ND	**260**	185
BWM-1/1D	61	23	37	6.9	210	260	ND	36	57
BWM-2	90	22	35	2.5	210	260	ND	36	65
BWM-3	75	18.8	51.7	0.90	270	330	ND	33	31
BWM-4	9.8	1.5	240	2.7	330	400	ND	54	99
BWM-5/5S	64.5	17	70	5.9	300	370	ND	32	33.5
BWM-6	60	24	98	1.4	340	410	ND	39	53
BWM-7	160	52	99	1.8	180	220	ND	160	110
BWM-8	174	42	55	1.6	180	220	ND	99	78
BWM-9	36	7.4	150	3.6	280	340	ND	51	57
BWM-10	39	9.6	14.5	1.65	120	150	ND	12	30.5
BWM-11	63	14	22	2.5	200	240	ND	25	17
BWM-12/12S	385	81	19.5	1.5	200	240	ND	12	**1100**
BWM-13/13D	110	22	40	3.5	265	325	ND	84	34.5
BWM-14	75	21	43	6.4	240	290	ND	58	39
BWM-15	78	16	22	1.8	220	270	ND	25	23
BWM-16	51	13	37	2.3	190	230	ND	21	22
BWM-17/17D	60	25	51.5	4.5	240	290	ND	55.5	43.5
BWM-18/18D	32.5	9.1	90	3.05	155	125	ND	58	90.5
BWM-19/19S	15	2.9	79	2.4	130	160	ND	33.5	38.5
BWM-20	51	22	110	4.2	260	320	ND	73	85
BWM-21	67	27	47	1.2	260	320	ND	35	45
BWM-22	55	5.8	9.1	1.2	150	180	ND	6.7	9.0
BWM-23/23D	1.1	ND	130	0.995	240	255	18	19	15
BWM-24/24S	73.5	11.5	25.5	1.4	205	240	ND	33	20
BWM-25	85	19	37	3.7	180	220	ND	100	59
BWM-26	76	15	16	2.6	250	300	ND	18	12
BWM-27	110	41	140	3.6	260	320	ND	**260**	140

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---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)
BWM-28	110	31	270	3.5	360	440	ND	240	**320**
BWM-29/29S	56	16.5	78	6.3	205	260	ND	81.5	70
BWM-30/30S	88.5	17	42	4.3	225	270	ND	73	23
BWM-31	37	9.0	49	5.1	160	200	ND	22	14
BWM-32/32D	115	25	53.5	2.45	245	295	ND	96.5	40.5
BWM-33	ND	ND	150	ND	240	200	39	22	19
BWM-34	99	22	87	3.7	230	280	ND	200	180
BWM-35	54	17	32	3.3	190	230	ND	41	19
BWM-37	83	23	60	4.4	170	200	ND	110	86
BWM-38	18	1.1	250	7.3	390	480	ND	65	99
BWM-39/40	105	28	74	4.4	220	270	ND	115	120
BWM-41	25	9.0	55	7.1	180	220	ND	14	11
BWM-42/43	36	6.6	110	6.7	180	220	ND	56	97
BWM-46/47	400	180	220	3.4	210	255	ND	**340**	**1400**
BWM-48	130	38	77	5.1	310	380	ND	150	95
BWM-50	94	37	56	4.1	180	220	ND	ND	78
BWM-52/53	35	13	37.5	3.05	150	190	ND	31.5	16.5
BWM-54/55	67.5	17	42	3.1	175	205	ND	9.85	42
BWM-56	79	14	28	3.6	230	280	ND	31	35
BWM-57	85	15	32	1.3	270	320	ND	27	30
BWM-58	48	13	39	2.2	160	200	ND	38	31
BWM-59	71	17	13	1.7	210	250	ND	25	15
BWM-60	88	28	34	2.4	310	380	ND	35	34
BWM-61/62	86	49	73.5	1.75	450	540	ND	45	43.5
BWM-64	110	19	57	2.0	300	360	ND	62	56
BWM-65/66	63	12.5	19.5	2.1	205	250	ND	12	13.5
BWM-67	78	40	41	1.4	350	420	ND	45	22

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---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)
BWM-68	120	35	94	1.9	380	460	ND	100	83
BWM-69	88	39	74	0.38	280	340	ND	93	99
BWM-70/71	110	21	83	1.9	330	400	ND	97	56
BWM-73/74	110	19	64.5	1.4	290	360	ND	64	81.5
BWM-76	24	18	27	3.1	170	210	ND	13	2.6
BWM-77/78	19	7.1	12	ND	74	90.5	ND	11	9.4
BWM-79/80	82.5	11	19.5	1.2	245	290	ND	27	8.85
BWM-81	37	10	100	2.7	100	130	ND	100	110
BWM-82	14	2.8	74	1.9	130	160	ND	32	40
BWM-83	62	32	14	ND	240	290	ND	28	20
BWM-84	19	8.5	31	2.3	120	150	ND	10	6.6
BWM-86	51	13	19	2.3	190	230	ND	13	11
BWM-87/88	54	12	18	2.3	190	230	ND	15	10.5
BWM-89/90	74.5	13	18.5	1.3	195	230	ND	38.5	20.5
BWM-91	63	14	17	2.1	180	220	ND	21	42
BWM-92	60	10	18	1.3	160	190	ND	18	28
BWM-93	51	12	15	1.1	160	200	ND	15	15
BWM-94/95	65.5	14	17	1.4	195	235	ND	22	23
BWM-97	19	13	37	2.7	120	140	ND	12	25
BWM-98	22	19	41	2.7	150	180	ND	19	17
BWM-99/100	29	10	42	2.25	140	170	ND	31	20
BWM-101	54	15	42	2.4	160	190	ND	74	28
BWM-102	66	17	38	2.9	220	260	ND	43	31
BWM-103	64	17	37	2.4	220	270	ND	42	29
BWM-104	66	18	31	2.3	200	250	ND	43	36
BWM-105	62	29	190	6.8	280	340	ND	180	170
BWM-106	57	27	230	6.5	280	340	ND	190	170
BWM-107	52	18	82	6.0	230	280	ND	69	59

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---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)
BWM-109	53	20	86	6.4	240	290	ND	73	50
BWM-111	43	12	79	4.7	180	230	ND	62	55
BWM-112	47	14	71	4.8	190	240	ND	62	52
BWM-113	46	14	70	4.9	190	240	ND	61	51
BWM-114	47	15	90	5.8	210	260	ND	74	66
BWM-115	44	14	83	5.6	200	250	ND	66	57
BWM-116	200	67	190	5.7	300	360	ND	**330**	**510**
BWM-117/118	330	125	200	10.5	330	410	ND	130	**1150**
BWM-119	44	65	150	40	380	420	20	220	40
BWM-120	150	42	110	3.7	240	290	ND	**330**	150
BWM-121	44	13	27	2.2	150	180	ND	40	20
BWM-122	30	7.5	56	3.6	190	230	ND	26	22
BWM-123	49	25	11	1.9	270	330	ND	10	6.9
BWM-124	100	31	53	2.3	360	440	ND	74	41
BWM-125	59	26	24	4.5	260	320	ND	27	13
BWM-126	48	11	28	1.5	200	240	ND	17	10
BWM-127	72	20	21	1.8	260	320	ND	24	25
BWM-128	170	50	84	2.0	230	280	ND	66	**460**

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---Continued

Site #	Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	T. Phosphorus (mg/L)	SAR (value)	Irrigation Quality	Perchlorate (ug/L)	Aluminum (mg/L)
BWM-0	ND	ND	ND	ND	ND	5.3	C3-S1	-	-
BWM-1/1D	1.55	ND	ND	ND	0.0455	1.0	C2-S1	-	ND
BWM-2	2.9	ND	ND	ND	ND	0.9	C2-S1	-	ND
BWM-3	2.0	ND	0.058	ND	0.024	1.4	C2-S1	-	ND
BWM-4	ND	ND	ND	ND	ND	18.9	C3-S4	-	ND
BWM-5/5S	0.59 (< 0.50)	ND	ND	ND	ND	2.0	C2-S1	-	ND
BWM-6	0.27	ND	ND	ND	0.069	2.7	C3-S1	-	ND
BWM-7	**110**	ND	0.17	ND	ND	1.7	C3-S1	-	ND
BWM-8	**110**	ND	0.21	0.11	ND	1.0	C3-S1	-	ND
BWM-9	0.48	ND	ND	0.056	0.026	5.9	C3-S2	-	ND
BWM-10	ND	ND	ND	0.037	0.0744	0.5	C2-S1	-	ND
BWM-11	2.3	ND	ND	ND	ND	0.7	C2-S1	-	ND
BWM-12/12S	3.05	0.20	0.21	0.076	ND	0.3	C3-S1	-	ND
BWM-13/13D	9.35	ND	0.16	ND	0.425	0.9	C3-S1	-	ND
BWM-14	0.59	ND	ND	ND	ND	1.1	C3-S1	-	ND
BWM-15	3.8	ND	ND	ND	0.066	0.6	C2-S1	-	ND
BWM-16	0.94	ND	ND	0.027	ND	1.2	C2-S1	-	ND
BWM-17/17D	0.0456	ND	ND/ 0.062	ND	ND/ 0.033	1.4	C2-S1	-	ND
BWM-18/18D	1.7	ND	ND	ND	ND	3.6	C2-S1	-	ND
BWM-19/19S	1.35	ND	ND	ND	ND/ 0.06	5.0	C2-S1	-	ND
BWM-20	0.51	ND	0.062	ND	0.090	3.2	C3-S1	-	ND
BWM-21	1.1	0.026	0.071	0.51	ND	1.2	C2-S1	-	ND
BWM-22	1.6	ND	0.076	ND	ND	0.3	C2-S1	-	ND
BWM-23/23D	1.2	ND	ND	ND	0.022	34.1	C2-S4	-	ND
BWM-24/24S	4.3	ND	ND	ND	ND	0.7	C2-S1	-	ND
BWM-25	2.5	ND	ND	ND	ND	0.9	C3-S1	-	ND
BWM-26	3.8	ND	ND	ND	ND	0.4	C2-S1	-	ND
BWM-27	1.2	ND	ND	ND	ND	2.9	C3-S1	-	ND

italics = constituent exceeded holding time

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---Continued

Site #	Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	T. Phosphorus (mg/L)	SAR (value)	Irrigation Quality	Perchlorate (ug/L)	Aluminum (mg/L)
BWM-28	1.6	*ND*	0.067	ND	ND	5.4	C3-S1	-	
BWM-29/29S	0.43	*ND*	ND	ND	0.039	2.4	C3-S1	ND	
BWM-30/30S	4.15	ND	*ND*	ND	ND	1.0	C2-S1	-	ND
BWM-31	3.4	ND	*ND*	ND	ND	0.1	C2-S1	-	ND
BWM-32/32D	**12**	ND	ND	0.12/ ND	0.025/ ND	1.2	C3-S1	-	ND
BWM-33	1.2	0.027	0.058	ND	ND	292	C2-S4	-	ND
BWM-34	0.85	ND	ND	ND	ND	2.1	C3-S1	-	ND
BWM-35	1.17	-	0.3	0.04	0.025	1.0	C2-S1	1.38	
BWM-37	4.39	-	ND	ND	0.039	1.5	C3-S1	3.34	
BWM-38	0.15	-	ND	0.03	0.011	15.5	C3-S3	0.216	
BWM-39/40	4.33	-	ND	ND	ND	1.6	C3-S1	3.09	
BWM-41	2.81	-	ND	ND	ND	2.4	C2-S1	3.09	
BWM-42/43	2.03	-	ND	ND	0.0085	4.4	C2-S1	0.707	
BWM-46/47	2.60	-	0.2	0.04	0.0085	2.3	C4-S1	1.16	
BWM-48	0.38	-	0.2	ND	0.017	1.5	C3-S1	1.34	
BWM-50	3.85	-	ND	ND	0.073	1.2	C3-S1	1.31	
BWM-52/53	1.78	-	ND	ND	0.012	1.4	C2-S1	1.535	
BWM-54/55	0.015	-	0.2	0.0125	0.013	1.2	C2-S1	0.0911	
BWM-56	1.78	-	ND	0.03	0.021	0.8	C2-S1	1.09	
BWM-57	0.33	-	ND	ND	0.324	1.3	C2-S1	0.05	
BWM-58	1.47	-	ND	ND	ND	1.3	C2-S1	1.28	
BWM-59	2.72	-	ND	ND	0.042	0.4	C2-S1	2.59	
BWM-60	0.74	-	ND	ND	0.073	0.8	C2-S1	0.671	
BWM-61/62	ND	-	ND	-	ND	1.6	C3-S1	0.837	
BWM-64	2.40	-	0.6	0.09	0.191	1.3	C3-S1	1.23	
BWM-65/66	2.4	ND	0.2	0.04	0.062	0.6	C2-S1	0.31	
BWM-67	1.99	-	ND	0.03	0.042	0.9	C3-S1	0.21	

italics = constituent exceeded holding time

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---Continued

Site #	T. Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	T. Phosphorus (mg/L)	SAR (value)	Irrigation Quality	Aluminum (mg/L)	Perc / Stron (mg/L)
BWM-68	3.91	-	ND	0.03	0.007	1.9	C3-S1		1.62
BWM-69	4.82	-	ND	ND	0.021	1.7	C3-S1		0.22
BWM-70/71	1.73	-	ND	ND	0.059	1.9	C3-S1		0.80
BWM-72	-	-	-	-	-	-	-		0.91
BWM-73/74	0.92	-	ND	ND	0.018	1.5	C3-S1		0.44
BWM-76	0.53	ND	0.55	ND	0.027	1.0	C2-S1	-	-
BWM-77/78	0.41	ND	0.235	ND	0.039	0.6	C1-S1	-	-
BWM-79/80	0.053	ND	ND	ND	ND	0.5	C2-S1	-	-
BWM-81	1.8	ND	ND	ND	ND	3.8	C3-S1		-
BWM-82	1.3	ND	ND	ND	ND	4.7	C2-S1		-
BWM-83	5.3	ND	ND	ND	ND	0.4	C2-S1		-
BWM-84	3.6	ND	ND	ND	ND	1.5	C2-S1		-
BWM-86	1.1	ND	ND	ND	ND	0.4	C2-S1		-
BWM-87/88	1.4	ND	ND	ND	ND	0.6	C2-S1		-
BWM-89/90	3.3	ND	ND	ND	ND	0.5	C2-S1		-
BWM-91	0.093	ND	0.17	ND	0.062	0.5	C2-S1		-
BWM-92	5.5	ND	ND	ND	ND	0.6	C2-S1		-
BWM-93	1.8	ND	ND	ND	0.05	0.5	C2-S1		-
BWM-94/95	3.5	ND	ND	ND	ND	0.5	C2-S1		-
BWM-97	8.9	ND	ND	ND	ND	1.6	C2-S1	ND	0.42
BWM-98	9.2	ND	ND	ND	ND	1.5	C2-S1	ND	0.52
BWM-99/100	1.65	ND	ND	ND	ND	1.8	C2-S1	ND	0.375
BWM-101	0.20	ND	ND	ND	ND	1.3	C2-S1	ND	0.43
BWM-102	1.4	ND	ND	ND	0.051	1.1	C2-S1	ND	0.26
BWM-103	1.1	ND	0.11	ND	0.041	1.1	C2-S1	ND	0.30
BWM-104	2.4	ND	ND	ND	ND	0.9	C2-S1	ND	0.35
BWM-105	3.8	ND	0.15	ND	0.034	5.0	C3-S1	ND	1.2
BWM-106	6.7	ND	ND	ND	0.031	6.3	C3-S1	ND	0.92
BWM-107	ND	ND	0.18	ND	0.050	2.5	C3-S1	ND	0.53

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

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---Continued

Site #	T. Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	T. Phosphorus (mg/L)	SAR (value)	Irrigation Quality	Aluminum (mg/L)	Strontium (mg/L)
BWM-109	0.10	ND	0.25	ND	0.077	2.6	C3-S1	ND	0.54
BWM-111	0.23	ND	0.16	ND	ND	2.7	C2-S1	ND	0.25
BWM-112	0.49	ND	0.98	ND	0.020	2.3	C2-S1	ND	0.54
BWM-113	0.46	ND	0.99	ND	0.042	2.3	C2-S1	ND	0.54
BWM-114	1.0	ND	ND	ND	0.049	2.9	C3-S1	ND	0.60
BWM-115	1.1	ND	ND	ND	0.056	2.8	C2-S1	ND	0.52
BWM-116	0.86	ND	ND	ND	ND	3.0	C4-S1	ND	1.1
BWM-117/118	ND	ND	0.12	0.035	ND	2.3	C4-S1	ND	2.3
BWM-119	0.021	ND	1.5	ND	0.16	3.4	C3-S1	ND	0.65
BWM-120	0.74	ND	0.26	ND	ND	2.0	C3-S1	ND	0.65
BWM-121	2.9	ND	ND	ND	ND	0.9	C2-S1	ND	0.37
BWM-122	3.1	ND	ND	ND	ND	2.4	C2-S1	ND	0.63
BWM-123	0.78	ND	ND	ND	0.059	0.3	C2-S1	ND	0.35
BWM-124	0.83	ND	ND	ND	0.031	1.2	C3-S1	ND	0.84
BWM-125	0.83	ND	ND	ND	ND	0.7	C2-S1	ND	0.43
BWM-126	1.4	ND	ND	ND	ND	0.9	C2-S1	ND	0.18
BWM-127	7.8	ND	ND	ND	ND	0.6	C2-S1	ND	0.56
BWM-128	0.035	ND	ND	ND	ND	1.5	C3-S1	ND	1.8

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---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)
BWM-0	ND	ND	ND	ND	0.845	ND	ND	ND	0.84
BWM-1/1D	ND	ND	ND	ND	0.18	ND	ND	ND	0.595
BWM-2	ND	ND	ND	ND	ND	ND	ND	ND	0.41
BWM-3	ND	ND	ND	ND	ND	ND	ND	0.068	**3.3**
BWM-4	ND	**0.037**	ND	ND	0.67	ND	ND	ND	**9.4**
BWM-5/5S	ND	ND	0.185	ND	0.39	ND	ND	0.01	1.6
BWM-6	ND	ND	0.10	ND	0.31	ND	ND	0.012	**2.3**
BWM-7	ND	ND	ND	ND	0.13	ND	ND	ND	1.5
BWM-8	ND	ND	ND	0.0016	ND	ND	ND	ND	**3.1**
BWM-9	ND	**0.056**	ND	0.00054	0.45	ND	ND	ND	**6.1**
BWM-10	ND	ND	ND	ND	ND	ND	ND	ND	0.42
BWM-11	ND	ND	ND	ND	ND	ND	ND	0.018	0.64
BWM-12/12S	ND	ND	ND	ND	ND	**0.00735**	ND	0.046	0.69
BWM-13/13D	ND	ND	0.225	ND	0.14/ ND	ND	ND	ND	0.495
BWM-14	ND	ND	ND	ND	ND	ND	ND	ND	0.60
BWM-15	ND	ND	ND	ND	ND	ND	ND	ND	0.49
BWM-16	ND	ND	ND	ND	0.11	ND	ND	ND	1.2
BWM-17/17D	ND	ND	ND	ND	0.105	ND	ND	ND	0.825
BWM-18/18D	ND	**0.013**	ND	ND	0.215	ND	ND	ND	**3.25**
BWM-19/19S	ND	ND	ND	ND	0.12	ND	**0.11**	ND	0.68
BWM-20	ND	ND	ND	ND	0.24	ND	ND	ND	1.5
BWM-21	ND	ND	0.11	ND	ND	ND	ND	ND	**2.9**
BWM-22	ND	ND	ND	ND	ND	ND	ND	ND	0.13
BWM-23/23D	ND	ND	ND	ND	0.14	ND	0.0475	ND	1.1
BWM-24/24S	ND	ND	ND	ND	ND	ND	ND	ND	1.15
BWM-25	ND	ND	0.052	ND	ND	ND	ND	0.026	**2.9**
BWM-26	ND	ND	0.33	ND	ND	ND	ND	ND	1.3
BWM-27	ND	ND	0.051	ND	0.23	ND	ND	ND	**2.9**

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---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)
BWM-28	ND	ND	ND	ND	0.43	ND	ND	0.037	**4.1**
BWM-29/29S	ND	ND	ND	ND	0.23	ND	ND	ND	0.875
BWM-30/30S	ND	ND	0.16	ND	0.10	ND	ND	ND	**3.2**
BWM-31	ND	ND	ND	ND	0.13	ND	ND	0.031	1.7
BWM-32/32D	ND	ND	0.125	ND	0.16	ND	ND	ND	**2.85**
BWM-33	ND	**0.30**	ND	ND	0.37	ND	ND	ND	**3.1**
BWM-34	ND	ND	0.14	ND	0.13	ND	ND	0.027	**2.5**
BWM-35	ND	ND	ND	ND	ND	ND	ND	0.12	0.83
BWM-37	ND	ND	ND	ND	ND	ND	ND	ND	1.7
BWM-38	ND	**0.12**	ND	ND	1.0	ND	ND	ND	**8.8**
BWM-39/40	ND	0.0077	ND	ND	0.14	ND	ND	ND	1.9
BWM-41	ND	ND	ND	ND	0.15	ND	0.046	ND	**2.0**
BWM-42/43	ND	**0.027**	ND	ND	0.29	ND	ND	ND	1.6
BWM-46/47	ND	ND	ND	ND	0.19	ND	ND	ND	**2.0**
BWM-48	ND	**0.020**	ND	ND	0.12	ND	ND	ND	1.3
BWM-50	ND	ND	ND	ND	0.14	ND	ND	ND	1.8
BWM-52/53	ND	ND	0.0255	ND	ND	ND	ND	ND	0.765
BWM-54/55	ND	ND	0.0195	ND	ND	ND	ND	ND	0.615
BWM-56	ND	ND	ND	ND	ND	ND	ND	ND	0.79
BWM-57	ND	ND	0.073	ND	ND	ND	ND	ND	1.1
BWM-58	ND	ND	0.028	ND	ND	ND	ND	0.011	0.79
BWM-59	ND	ND	0.044	ND	ND	ND	ND	ND	0.36
BWM-60	ND	ND	0.11	ND	ND	ND	ND	ND	0.47
BWM-61/62	ND	ND	0.11	ND	ND	ND	ND	ND	1.7
BWM-64	ND	ND	0.028	ND	ND	ND	ND	ND	**3.4**
BWM-65/66	ND	ND	0.10	ND	ND	ND	ND	ND	0.485
BWM-67	ND	ND	ND	ND	ND	ND	ND	ND	0.37

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---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)
BWM-68	ND	ND	ND	ND	ND	ND	ND	ND	1.3
BWM-69	ND	ND	0.026	ND	ND	ND	ND	ND	1.5
BWM-70/71	ND	ND	0.090	ND	0.054	ND	ND	ND	0.61
BWM-73/74	ND	ND	0.093	ND	0.062	ND	ND	0.0175	0.66
BWM-76	ND	ND	0.0077	ND	ND	ND	ND	ND	1.2
BWM-77/78	ND	ND	0.033	ND	ND	ND	ND	ND	0.20
BWM-79/80	ND	ND	0.145	ND	0.40/ND	ND	ND	ND	0.595
BWM-81	ND	0.0067	0.054	ND	0.21	ND	ND	ND	1.5
BWM-82	ND	0.0066	0.053	ND	0.11	ND	0.011	ND	0.71
BWM-83	ND	ND	0.035	ND	ND	ND	ND	ND	0.32
BWM-84	ND	ND	ND	ND	ND	ND	0.025	ND	0.62
BWM-86	ND	ND	0.034	ND	ND	ND	ND	ND	0.26
BWM-87/88	ND	ND	0.0285	ND	ND	ND	ND	ND	0.25
BWM-89/90	ND	ND	0.006	ND	ND	ND	ND	ND	0.30
BWM-91	ND	ND	0.080	ND	ND	ND	ND	ND	0.22
BWM-92	ND	ND	0.018	ND	ND	ND	ND	ND	0.47
BWM-93	ND	ND	0.043	ND	ND	ND	ND	0.014	0.36
BWM-94/95	ND	ND	0.032	ND	ND	ND	ND	ND	0.315
BWM-97	ND	ND	ND	ND	ND	ND	0.012	0.011	0.82
BWM-98	ND	ND	0.057	ND	ND	ND	ND	ND	1.0
BWM-99/100	ND	ND	0.145	ND	ND	ND	0.011	ND	0.67
BWM-101	ND	ND	0.14	ND	ND	ND	ND	ND	0.40
BWM-102	ND	ND	ND	ND	ND	ND	ND	ND	0.90
BWM-103	ND	ND	0.055	ND	ND	ND	ND	ND	0.86
BWM-104	ND	ND	0.062	ND	ND	ND	ND	ND	0.91
BWM-105	ND	**0.010**	0.058	ND	0.61	ND	ND	ND	1.7
BWM-106	ND	**0.011**	ND	ND	0.74	ND	ND	ND	**2.7**
BWM-107	ND	0.0080	0.050	ND	0.23	ND	ND	ND	1.1

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---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)
BWM-109	ND	0.0074	0.053	ND	0.24	ND	ND	ND	1.1
BWM-111	ND	0.0064	0.073	ND	0.20	ND	ND	ND	1.3
BWM-112	ND	0.0079	0.076	ND	0.19	ND	ND	ND	0.96
BWM-113	ND	0.0080	0.081	ND	0.26	ND	ND	ND	0.91
BWM-114	ND	0.0077	0.061	ND	0.26	ND	ND	ND	1.3
BWM-115	ND	0.0070	0.10	ND	0.23	ND	ND	ND	0.92
BWM-116	ND	ND	ND	ND	0.23	ND	ND	0.022	1.8
BWM-117/118	ND	ND	ND	ND	ND	ND	ND	ND	1.5
BWM-119	ND	0.0087	0.17	ND	0.34	ND	ND	ND	**3.1**
BWM-120	ND	0.0054	0.068	ND	0.25	ND	ND	ND	**2.1**
BWM-121	ND	ND	0.074	ND	ND	ND	ND	ND	1.5
BWM-122	ND	0.0024	0.046	ND	0.18	ND	ND	ND	**2.4**
BWM-123	ND	ND	0.0075	ND	ND	ND	ND	ND	0.25
BWM-124	ND	ND	0.19	ND	ND	ND	ND	0.020	0.52
BWM-125	ND	0.0067	0.052	ND	ND	ND	ND	ND	0.60
BWM-126	ND	ND	0.022	ND	ND	ND	ND	ND	0.49
BWM-127	ND	**0.019**	0.15	ND	ND	ND	ND	ND	0.80
BWM-128	ND	ND	0.018	ND	ND	ND	ND	ND	**2.2**

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---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)
BWM-0	0.28	**0.016**	ND	ND	ND	ND	ND	ND	ND
BWM-1/1D	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-2	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-3	ND	ND	ND	ND	ND	ND	ND	ND	0.67
BWM-4	ND	ND	**0.064**	ND	ND	ND	ND	ND	0.64
BWM-5/5S	ND	ND	ND	ND	ND	ND	ND	ND	ND 0.076
BWM-6	ND	ND	ND	ND	ND	ND	ND	ND	0.18
BWM-7	ND	ND	ND	ND	ND	ND	ND	ND	0.16
BWM-8	0.24	ND	ND	ND	ND	ND	ND	ND	2.3
BWM-9	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-10	0.25	ND	**0.25**	ND	ND	ND	ND	ND	ND
BWM-11	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-12/12S	0.14	ND/ 0.0054	**11.5**	ND	ND	ND	ND	ND	0.26
BWM-13/13D	ND	ND	ND	ND	ND	ND	ND	ND	0.275
BWM-14	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-15	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-16	ND	ND	ND	ND	ND	ND	ND	ND	0.077
BWM-17/17D	ND	ND	**0.13**	ND	ND	ND	ND	ND	ND
BWM-18/18D	ND	ND	ND	ND	ND	ND	ND	ND	0.066
BWM-19/19S	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-20	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-21	0.22	ND	**0.14**	ND	ND	ND	ND	ND	1.3
BWM-22	ND	ND	ND	ND	ND	ND	ND	ND	0.098
BWM-23/23D	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-24/24S	ND	ND	ND	ND	ND	ND	ND	ND	0.165
BWM-25	ND	ND	ND	ND	ND	ND	ND	ND	0.42
BWM-26	ND	ND	ND	ND	ND	ND	ND	ND	0.79
BWM-27	ND	ND	ND	ND	ND	ND	ND	ND	0.30

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---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)
BWM-28	ND	ND	ND	ND	ND	ND	ND	ND	0.41
BWM-29/29S	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-30/30S	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-31	ND	ND	ND	ND	ND	ND	ND	ND	0.14
BWM-32/32D	ND	ND	ND	ND	ND	ND	ND	ND	0.135
BWM-33	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-34	ND	ND	ND	ND	ND	ND	ND	ND	3.4
BWM-35	ND	ND	ND	ND	ND	ND	ND	ND	0.086
BWM-37	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-38	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-39/40	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-41	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-42/43	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-46/47	**0.555**	ND	**0.0895**	ND	ND	ND	ND	ND	0.445
BWM-48	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-50	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-52/53	ND	ND	ND	ND	ND	ND	ND	ND	0.080
BWM-54/55	ND	ND	**0.28**	ND	ND	ND	ND	ND	0.245
BWM-56	ND	ND	ND	ND	ND	ND	ND	ND	0.46
BWM-57	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-58	ND	ND	ND	ND	ND	ND	ND	ND	0.26
BWM-59	ND	ND	ND	ND	ND	ND	ND	ND	0.069
BWM-60	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-61/62	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-64	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-65/66	ND	ND	ND	ND	ND	ND	ND	ND	0.067/ND
BWM-67	ND	ND	ND	ND	ND	ND	ND	ND	0.36
BWM-68	ND	ND	ND	ND	ND	ND	ND	ND	0.36

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---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)
BWM-69	ND	ND	ND	ND	ND	ND	ND	ND	2.0
BWM-70/71	ND	ND	ND	ND	ND	ND	ND	ND	0.54
BWM-73/74	ND	ND	ND	ND	ND	ND	ND	ND	0.26
BWM-76	ND	ND	ND	ND	ND	ND	ND	ND	0.15
BWM-77/78	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-79/80	0.095	ND	**0.099**	ND	ND	ND	ND	ND	ND
BWM-81	ND	ND	ND	ND	ND	ND	ND	ND	0.093
BWM-82	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-83	ND	ND	ND	ND	ND	ND	ND	ND	0.14
BWM-84	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-86	ND	ND	ND	ND	ND	ND	ND	ND	0.069
BWM-87/88	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-89/90	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-91	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-92	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-93	ND	ND	ND	ND	ND	ND	ND	ND	0.26
BWM-94/95	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-97	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-98	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-99/100	ND	ND	ND	ND	ND	ND	ND	ND	0.525
BWM-101	ND	ND	**0.085**	ND	ND	ND	ND	ND	0.18
BWM-102	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-103	ND	ND	ND	ND	ND	ND	ND	ND	0.072
BWM-104	ND	ND	ND	ND	ND	ND	ND	ND	0.55
BWM-105	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-106	ND	ND	ND	ND	ND	0.0052	ND	ND	ND
BWM-107	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-109	ND	ND	ND	ND	ND	ND	ND	ND	ND

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---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)
BWM-111	ND	ND	ND	ND	ND	ND	ND	ND	0.080
BWM-112	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-113	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-114	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-115	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-116	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-117/118	**11**	ND	**0.21**	ND	ND	ND	ND	ND	ND
BWM-119	ND	ND	**0.17**	ND	ND	ND	ND	ND	ND
BWM-120	ND	ND	ND	ND	ND	ND	ND	ND	0.11
BWM-121	ND	ND	ND	ND	ND	ND	ND	ND	0.21
BWM-122	ND	ND	ND	ND	ND	ND	ND	ND	0.055
BWM-123	ND	ND	ND	ND	ND	ND	ND	ND	0.12
BWM-124	ND	ND	ND	ND	ND	ND	ND	ND	0.23
BWM-125	ND	ND	ND	ND	ND	ND	ND	ND	ND
BWM-126	ND	ND	ND	ND	ND	ND	ND	ND	0.073
BWM-127	ND	ND	ND	ND	ND	ND	ND	ND	0.087
BWM-128	ND	ND	ND	ND	ND	ND	ND	ND	3.5

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---Continued

Site #	**Radon-222** (pCi/L)	**Alpha** (pCi/L)	**Beta** (pCi/L)	**Ra-226 + Ra-228** (pCi/L)	**Uranium** (µg/L)	**δ^{18} O** ($^{0}/_{00}$)	**δ D** ($^{0}/_{00}$)	**Type of Chemistry**
BWM-0	-	**20**	17	< LLD	23	- 9.2	- 69	sodium-mixed
BWM-1/1D	106	-	-	-	-	- 9.5	- 69	mixed-bicarbonate
BWM-2	**359**	-	-	-	-	- 10.2	- 73	calcium-bicarbonate
BWM-3	-	10	6.7	< LLD	-	- 9.8	-70	mixed-bicarbonate
BWM-4	-	8	3.3	0.38	-	- 11.0	- 81	sodium-bicarbonate
BWM-5/5S	**703**	-	-	-	-	- 10.8	- 81	mixed-bicarbonate
BWM-6	-	8	4	< LLD	-	- 9.2	- 68	mixed-bicarbonate
BWM-7	-	**25**	22	0.32	24	- 9.8	- 70	mixed-mixed
BWM-8	-	**89**	49	< LLD	**71**	- 9.1	- 66	calcium-mixed
BWM-9	-	**15**	15	< LLD	17	- 10.6	- 77	sodium-bicarbonate
BWM-10	**439**	-	-	-	-	- 10.1	- 73	calcium-bicarbonate
BWM-11	-	1.3	4.9	-	-	- 9.4	- 68	calcium-bicarbonate
BWM-12/12S	**377**	-	-	-	-	- 9.8	- 69	calcium-sulfate
BWM-13/13D	-	4.6	7.0	-	-	- 9.4	- 67	calcium-bicarbonate
BWM-14	-	8.6	10	< LLD	< LLD	- 9.7	- 68	calcium-bicarbonate
BWM-15	-	2.1	1.3	-	-	- 9.5	- 68	calcium-bicarbonate
BWM-16	-	0.9	1.4	-	-	-9.2	- 67	mixed-bicarbonate
BWM-17/17D	**504**	-	-	-	-	- 8.8	- 63	mixed-bicarbonate
BWM-18/18D	**457**	-	-	-	-	- 9.1	- 65	sodium-mixed
BWM-19/19S	**435**	-	-	-	-	- 9.4	- 66	sodium-bicarbonate
BWM-20	-	4.3	6.6	-	-	- 6.4	- 51	sodium-bicarbonate
BWM-21	295	-	-	-	-	- 10.5	- 75	mixed-bicarbonate
BWM-22	**405**	-	-	-	-	- 11.0	- 78	calcium-bicarbonate
BWM-23/23D	-	**16**	4.0	< LLD	23	- 10.8	- 82	sodium-bicarbonate
BWM-24/24S	152	-	-	-	-	- 9.0	- 67	calcium-bicarbonate
BWM-25	-	7.9	7.6	2.6	-	- 8.3	- 63	calcium-mixed
BWM-26	**745**	-	-	-	-	- 6.0	- 56	calcium-bicarbonate
BWM-27	-	**150**	59	**9.2**	**250**	- 9.1	-67	mixed-mixed

LLD = Lower Limit of Detection

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---Continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Ra-226 + Ra-228 (pCi/L)	Uranium (µg/L)	δ^{18} O ($^0/_{00}$)	δ D ($^0/_{00}$)	Type of Chemistry
BWM-28	-	**200**	61	**8**	**270**	- 9.1	- 67	? no sheet
BWM-29/29S	218	-	-	-	-	- 7.6	- 61	mixed-bicarbonate
BWM-30/30S	**594**	-	-	-	-	- 8.7	- 65	calcium-bicarbonate
BWM-31	96	-	-	-	-	- 8.8	- 64	mixed-bicarbonate
BWM-32/32D	279	-	-	-	-	- 8.0	- 61	calcium-bicarbonate
BWM-33	**300**	-	-	-	-	- 9.8	- 76	sodium-bicarbonate
BWM-34	**306**	-	-	-	-	- 8.2	- 60	mixed-mixed
BWM-35	234	3.9	4.4	-	-	- 8.1	- 59	mixed-bicarbonate
BWM-36	-	-	-	-	-	- 7.6	- 60	-
BWM-37	38	5.8	8.8	< LLD	-	- 7.8	- 60	mixed-mixed
BWM-38	110	1.8	6.4	< LLD	< LLD	- 11.4	- 85	sodium-bicarbonate
BWM-39/40	-	**55**	46	3.9	**82**	- 8.75	- 65	mixed-mixed
BWM-41	**712**	**19**	15	< LLD	19	- 7.9	- 59	sodium-bicarbonate
BWM-42/43	**455**	7.8	12	< LLD	-	- 9.3	- 69	sodium-mixed
BWM-44	-	-	-	-	-	- 7.4	- 59	-
BWM-46/47	**999**	**18**	12	**6.6**	13	- 8.95	- 67.5	mixed-sulfate
BWM-48	-	**39**	29	3.2	28	- 8.8	- 68	sodium-bicarbonate
BWM-50	-	8.6	10	< LLD	-	- 8.6	- 64	mixed-bicarbonate
BWM-51	-	-	-	-	-	- 8.2	- 62	-
BWM-52/53	**653**	3.2	5.9			- 8.35	- 59	mixed-bicarbonate
BWM-54/55	33.5	4.9	4.4			- 9.8	- 69	calcium-bicarbonate
BWM-56	291	7.1	8.6	<LLD	-	- 9.5	- 67	calcium-bicarbonate
BWM-57	-	-	-	-	-	- 9.4	- 65	calcium-bicarbonate
BWM-58	**423**	4.3	3.8			- 9.2	- 64	mixed-bicarbonate
BWM-59	159	0.84	3.1			- 9.5	- 70	calcium-bicarbonate
BWM-60	57	5.7	4.8	<LLD	-	- 10.0	- 73	calcium-bicarbonate
BWM-61/62	89	12	9.1	<LLD	-	- 10.4	- 74	mixed-bicarbonate
BWM-64	-	**67**	61	**6.7**	**130**	- 9.2	- 68	calcium-bicarbonate
BWM-65/66	**810**	4.2	2.8	-	-	- 9.7	- 67	calcium-bicarbonate

LLD = Lower Limit of Detection

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---Continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Ra-226 + Ra-228 (pCi/L)	Uranium (μg/L)	δ^{18} O ($^0/_{00}$)	δ D ($^0/_{00}$)	Type of Chemistry
BWM-67	**975**	3.4	2.8	-	-	- 7.0	- 58	mixed-bicarbonate
BWM-68	**960**	**27**	31	< LLD	**40**	- 9.8	- 71	mixed-bicarbonate
BWM-69	122	2.1	< LLD	-	-	- 8.4	- 65	mixed-bicarbonate
BWM-70/71	**608**	**23.9**	18	< LLD	**30.2**	- 9.8	- 69	calcium-bicarbonate
BWM-72	-	-	-	-	-	- 9.0	- 65	-
BWM-73/74	79	8.3	6.4	< LLD	-	- 9.3	- 65	calcium-bicarbonate
BWM-76	-	9.4	5.0	< LLD	-	- 9.4	- 73	mixed-bicarbonate
BWM-77/78	-	0.7	< LLD	-	-	- 11.2	- 79	calcium-bicarbonate
BWM-79/80	**974**	3.5	1.4	-	-	- 10.1	- 73	calcium-bicarbonate
BWM-81	110	3.6	5.2	-	-	- 9.7	- 70	sodium-mixed
BWM-82	**408**	-	-	-	-	- 9.7	- 68	sodium-bicarbonate
BWM-83	**1,122**	< LLD	< LLD	-	-	- 8.4	- 58	mixed-bicarbonate
BWM-84	**322**	-	-	-	-	- 8.7	- 62	mixed-bicarbonate
BWM-86	**488**	-	-	-	-	- 10.0	- 69	calcium-bicarbonate
BWM-87/88	-	1.7	2.5	-	-	- 9.9	- 69	calcium-bicarbonate
BWM-89/90	**604**	-	-	-	-	-	-	calcium-bicarbonate
BWM-91	-	-	-	-	-	- 10.2	- 66	calcium-bicarbonate
BWM-92	**485**	-	-	-	-	-	-	calcium-bicarbonate
BWM-93	176	-	-	-	-	- 10.4	- 70	calcium-bicarbonate
BWM-94/95	-	6.3	2.1	< LLD	-	- 10.2	- 69	calcium-bicarbonate
BWM-97	-	-	-	-	-	- 10.3	- 71	mixed-bicarbonate
BWM-98	-	-	-	-	-	- 8.7	- 60	mixed-bicarbonate
BWM-99/100	-	-	-	-	-	- 9.9	- 68	mixed-bicarbonate
BWM-101	-	-	-	-	-	- 9.4	- 65	mixed-bicarbonate
BWM-102	-	-	-	-	-	- 8.4	- 60	calcium-bicarbonate
BWM-103	-	-	-	-	-	-	-	calcium-bicarbonate
BWM-104	-	-	-	-	-	- 8.7	- 59	calcium-bicarbonate
BWM-105	-	-	-	-	-	- 6.0	- 52	sodium-mixed
BWM-106	-	-	-	-	-	- 6.1	- 53	sodium-mixed

LLD = Lower Limit of Detection

Appendix B. Groundwater Quality Data, Bill Williams Basin, 2003-09---Continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Ra-226 + Ra-228 (pCi/L)	Uranium (µg/L)	δ^{18} O ($^{0}/_{00}$)	δ D ($^{0}/_{00}$)	Type of Chemistry
BWM-107	-	-	-	-	-	- 6.5	- 54	mixed-bicarbonate
BWM-108	-	-	-	-	-	- 5.5	- 49	-
BWM-109	-	-	-	-	-	- 6.3	- 53	mixed-bicarbonate
BWM-111	-	-	-	-	-	- 8.1	- 61	mixed-bicarbonate
BWM-112	-	-	-	-	-	- 7.7	- 60	mixed-bicarbonate
BWM-113	-	-	-	-	-	- 7.6	- 60	mixed-bicarbonate
BWM-114	-	-	-	-	-	- 7.2	- 59	mixed-bicarbonate
BWM-115	-	-	-	-	-	- 7.5	- 59	mixed-bicarbonate
BWM-116	-	-	-	-	-	- 9.4	- 68	mixed-mixed
BWM-117/118	-	**15**	67	-	-	- 10.0	- 72	mixed-sulfate
BWM-119	-	< LLD	38	-	-	2.1	- 23	mixed-mixed
BWM-120	-	11	18	-	-	- 9.6	- 70	mixed-chloride
BWM-121	-	2.2	4.4	-	-	- 9.0	- 63	mixed-bicarbonate
BWM-122	-	-	-	-	-	- 9.0	- 67	sodium-bicarbonate
BWM-123	-	1.4	9.3	-	-	- 9.9	- 70	mixed-bicarbonate
BWM-124	-	**22**	38	< LLD	18	- 9.5	- 70	calcium-bicarbonate
BWM-125	-	2.2	7.9	-	-	- 10.2	- 72	mixed-bicarbonate
BWM-126	-	2.5	3.4	-	-	- 10.6	- 73	calcium-bicarbonate
BWM-127	-	-	-	-	-	- 8.3	- 63	calcium-bicarbonate
BWM-128	-	-	-	-	-	- 10.2	- 75	calcium-sulfate

LLD = Lower Limit of Detection