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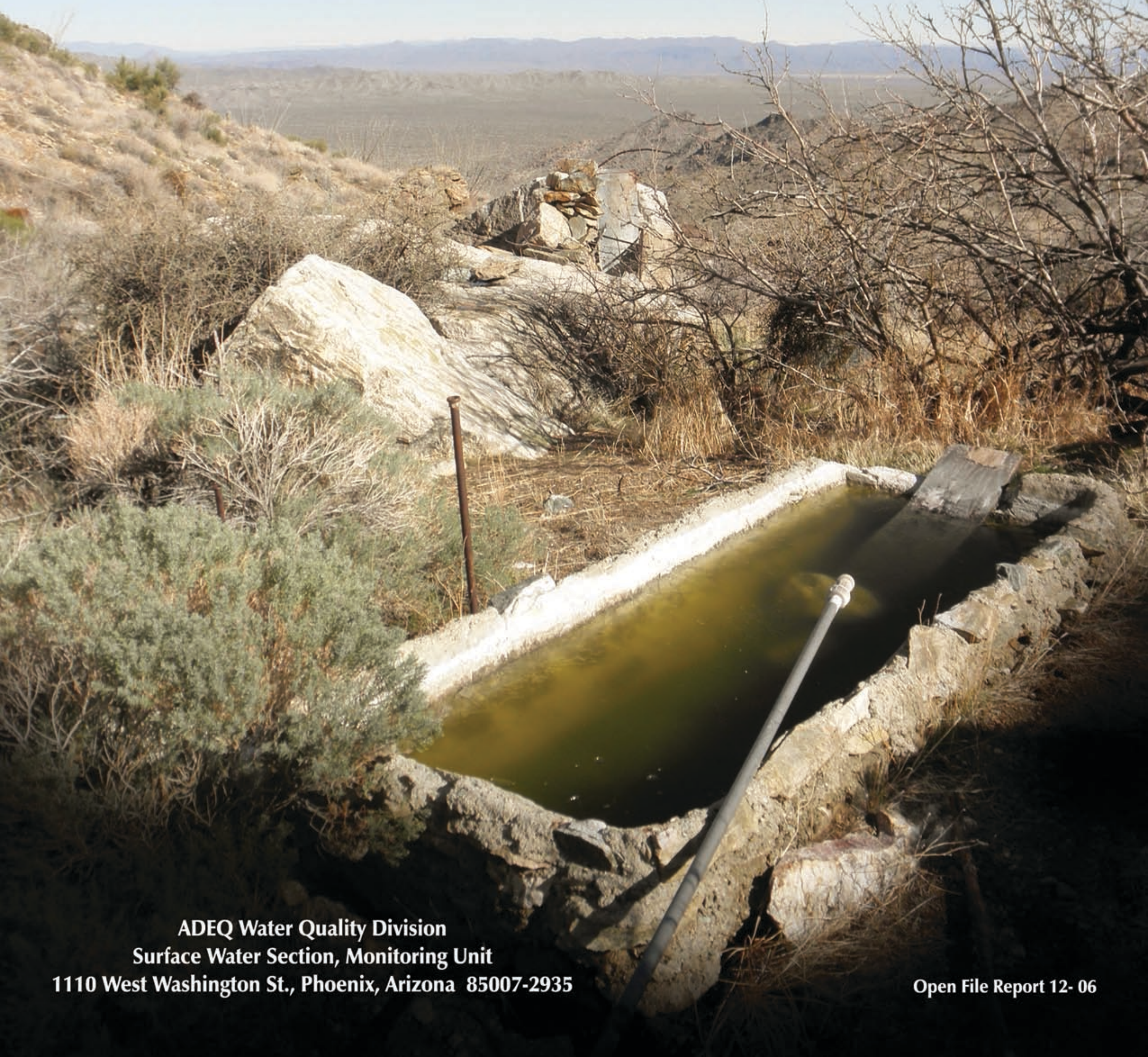
Ambient Groundwater Quality of the Butler Valley Basin
A 2008 - 2012 Baseline Study

By Douglas C. Towne
Maps by Jean Ann Rodine



ADEQ Water Quality Division
Surface Water Section, Monitoring Unit
1110 West Washington St., Phoenix, Arizona 85007-2935

Open File Report 12- 06

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Thanks:

Field Assistance: Elizabeth Boettcher and Susan Determann. Special recognition is extended to the many well owners who were kind enough to give permission to collect groundwater data on their property.

Photo Credits: Douglas Towne

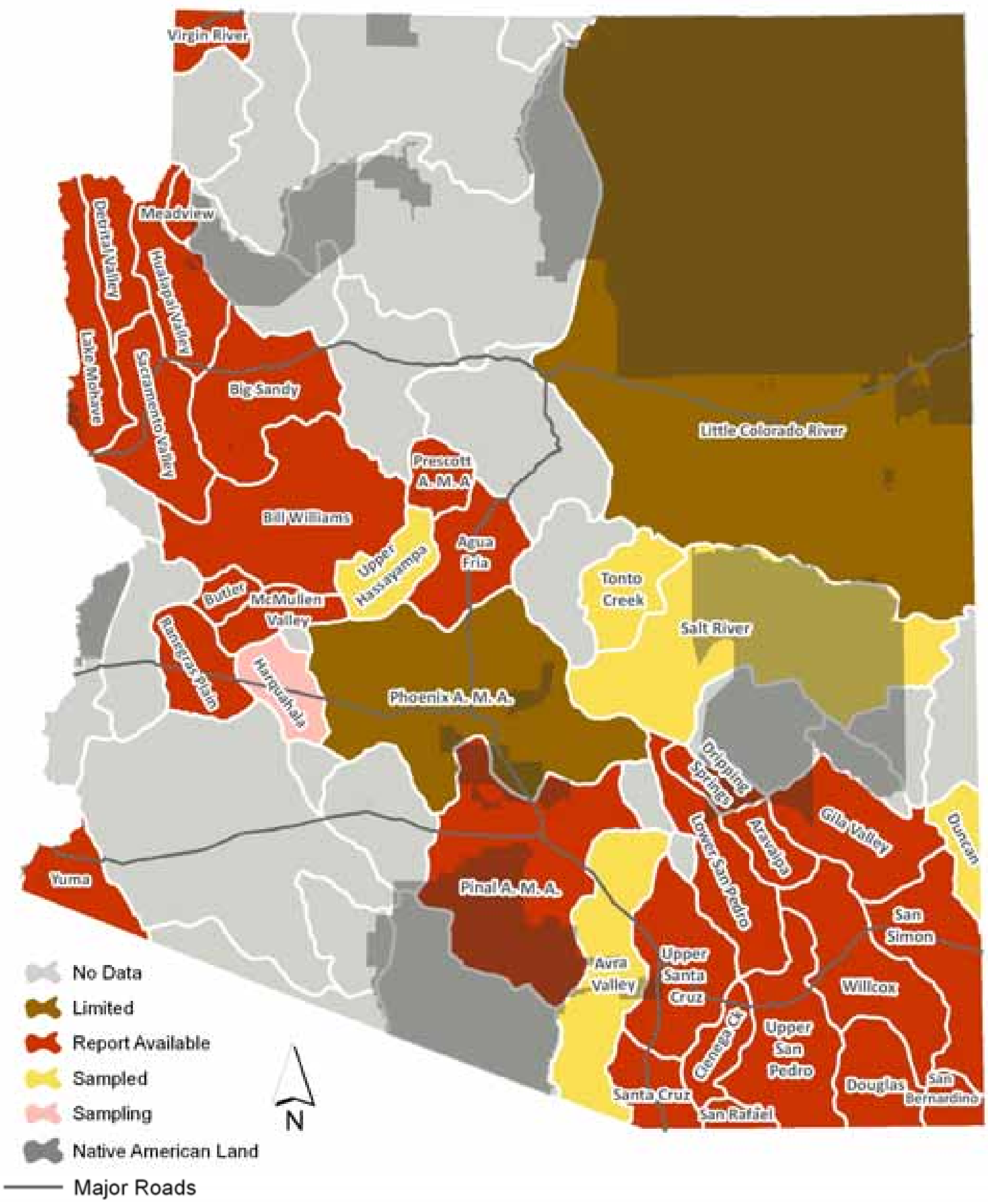
Report Cover: Situated high above Butler Valley, a stock watering trough served by Dripping Springs in the Harcuvar Mountains is stagnant because of a frozen water line. A fresh sample (BUT-3) from the spring was obtained higher up the pipeline met all water quality standards except total dissolved solids (TDS).

Other Publications of the ADEQ Ambient Groundwater Monitoring Program

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

Butler Valley Basin	OFR 12-06, 44 p.	FS 12-10, 5.p.
Cienega Creek Basin	OFR 12-02, 46 p.	FS 12-05, 4.p.
Ranegras Plain Basin	OFR 11-07, 63 p.	FS 12-01, 4.p.
Groundwater Quality in Arizona	OFR 11-04, 26 p.	-
Bill Williams Basin	OFR 11-06, 77 p.	FS 12-01, 4.p.
San Bernardino Valley Basin	OFR 10-03, 43 p.	FS 10-31, 4 p.
Dripping Springs Wash Basin	OFR 10-02, 33 p.	FS 11-02, 4 p.
McMullen Valley Basin	OFR 11-02, 94 p.	FS 11-03, 6 p.
Gila Valley Sub-basin	OFR 09-12, 99 p.	FS 09-28, 8 p.
Agua Fria Basin	OFR 08-02, 60 p.	FS 08-15, 4 p.
Pinal Active Management Area	OFR 08-01, 97 p.	FS 07-27, 7 p.
Hualapai Valley Basin	OFR 07-05, 53 p.	FS 07-10, 4 p.
Big Sandy Basin	OFR 06-09, 66 p.	FS 06-24, 4 p.
Lake Mohave Basin	OFR 05-08, 66 p.	FS 05-21, 4 p.
Meadview Basin	OFR 05-01, 29 p.	FS 05-01, 4 p.
San Simon Sub-Basin	OFR 04-02, 78 p.	FS 04-06, 4 p.
Detrital Valley Basin	OFR 03-03, 65 p.	FS 03-07, 4 p.
San Rafael Basin	OFR 03-01, 42 p.	FS 03-03, 4 p.
Lower San Pedro Basin	OFR 02-01, 74 p.	FS 02-09, 4 p.
Willcox Basin	OFR 01-09, 55 p.	FS 01-13, 4 p.
Sacramento Valley Basin	OFR 01-04, 77 p.	FS 01-10, 4 p
Upper Santa Cruz Basin (w/ USGS)	OFR 00-06, 55 p.	-
Prescott Active Management Area	OFR 00-01, 77 p.	FS 00-13, 4 p.
Upper San Pedro Basin (w/ USGS)	OFR 99-12, 50 p.	FS 97-08, 2 p.
Douglas Basin	OFR 99-11, 155 p.	FS 00-08, 4 p.
Virgin River Basin	OFR 99-04, 98 p.	FS 01-02, 4 p.
Yuma Basin	OFR 98-07, 121 p.	FS 01-03, 4 p.

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



Map I. ADEQ Ambient Groundwater Monitoring Program Studies

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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
BUT	Butler Valley Groundwater Basin
CAP	Central Arizona Project
^oC	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
GWPL	Groundwater Protection List pesticide
HCl	hydrochloric acid
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 Butler Valley Basin: A 2008-2012 Baseline Study

Abstract - In 2008-2011, the Arizona Department of Environmental Quality (ADEQ) conducted a baseline groundwater quality study of the Butler Valley basin located in west-central Arizona. The basin comprises 288 square miles within La Paz County.[4] Only approximately a dozen residents live within the remote basin. [4] The only major access to the basin is via Alamo Dam Road. The majority of land is used for low-intensity livestock grazing. Approximately 800 acres of farmland are irrigated near the boundary with the Ranegras Plain basin[4]. Land ownership in the basin consists of federal lands managed by the Bureau of Land Management (55 percent), State Trust lands (44 percent), and private land (1 percent). [3, 4]

The basin's main drainage is the ephemeral Cunningham Wash which begins in the Buckskin Mountains and flows toward the southwest eventually crossing into the Ranegras Plain basin near "the Narrows." Alluvial deposits are the main aquifer is the basin. Groundwater occurs primarily in basin-fill sediments composed of silt, sand, clay and gravel beds.[16] Limited information indicates the aquifer ranges in thickness from 525 feet to 1,450 feet. [16] The surrounding mountains sometimes produce small quantities of groundwater. Groundwater is used for all domestic, stock and irrigation purposes. Most groundwater is used for irrigation. [4]

There has been very limited groundwater development in the basin. Wells are numerous only at Butler Valley Farm located near the Narrows. All operational wells or flowing springs in other parts of the basin were sampled for the study. No samples were able to be collected from the large portions of the basin in or near the Buckskin Mountains to the north. Altogether, samples were collected from 9 sites (8 wells and 1 spring). The wells were used for stock (6 wells) and irrigation (2 wells) purposes. The spring provides water for stock. Inorganic constituents and two isotopes (oxygen and deuterium) were collected from all nine sites. At selected sites, radon (6 sites), radiochemistry (3 sites) and nitrogen isotope (6 sites) samples were also collected.

Health-based, Primary Maximum Contaminant Levels (MCLs) were exceeded at 2 of the 9 sites (22 percent). These enforceable standards define the maximum concentrations of constituents allowed in water supplied for drinking water purposes by a public water system and are based on a lifetime daily consumption of two liters. [25] Constituents exceeding Primary MCLs include fluoride (1 site), and uranium (1 site). Although earlier assessments of groundwater quality in the Butler Valley basin reported arsenic, fluoride, lead, and nitrate concentrations exceeding drinking water quality standards, this study only confirmed that fluoride exceeded standards.[4] Elevated concentrations of fluoride and uranium likely occur naturally. [16] Aesthetics-based, Secondary MCLs were exceeded at 7 of the 9 sites (78 percent). These are unenforceable guidelines that define the maximum constituent concentration that can be present in drinking water without an unpleasant taste, color, or odor.[25] Constituents above Secondary MCLs include chloride (3 sites), fluoride (2 sites), manganese (1 site), sulfate (3 sites), and total dissolved solids (TDS) (5 sites).

Oxygen and deuterium isotope values at six sites were generally lighter and more depleted than would be expected from recharge originating at the basin's elevation. These "old recharge" sites appear to consist of paleowater predominantly recharged 8,000-12,000 years ago when the basin was cooler and subject to much less evaporation. [9] Two "mixed recharge" sites had slightly less depleted isotope values and may contain small amounts of more recently recharged groundwater. Enriched isotope values were found at one site that is a former mine shaft now used as a stock well and appears to consist of "recent" mountain front recharge occurring in the Harcuvar range.

Despite collecting few samples, the study was still able to make some limited characterizations concerning groundwater quality in the basin. Groundwater in the basin is typically *slightly-alkaline*, *fresh*, and *soft* to *extremely hard*, based on pH levels along with TDS and hardness concentrations. [8, 12] Sodium was the dominant cation in most samples while the anion composition varied from a mixture to one dominated by either bicarbonate or chloride.

Groundwater constituent concentrations were influenced by recharge age and geology. Constituents such as magnesium, bicarbonate, copper, oxygen-18 and deuterium had significantly greater concentrations in "recent/mixed recharge" than "old recharge". Constituents such as hardness, calcium, magnesium, and bicarbonate had significantly greater concentrations in sites located in hard rock than in alluvium; the opposite pattern occurred with temperature (Kruskal-Wallis test, $p \leq 0.05$). Groundwater, especially in alluvial areas, generally is suitable for drinking water use based on the results of this ADEQ study.

INTRODUCTION

Purpose and Scope

The Butler Valley basin (BUT) comprises approximately 288 square miles within La Paz County in west central Arizona (Map 1).[4] The basin is located about 120 miles west of Phoenix in the northeastern part of La Paz County. The remote basin, situated about 10 miles north of the town of Wenden, is lightly populated having an estimated dozen residents in 2000.[4] Alamo Dam Road traverses the basin from south to north. There has been limited groundwater development in the basin. Groundwater is the only dependable source for domestic, irrigation, and stock water supply within the basin. The vast majority of water pumped in the basin is used for irrigation.[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 characterization of regional groundwater quality conditions in the Butler Valley basin identifying water quality variations between groundwater of different ages.
- A process for evaluating potential groundwater quality impacts arising from mineralization, mining, livestock, septic tanks, and poor well construction.
- A guide for determining areas where further groundwater quality research is needed.

Physical Characteristics

Geography – The Butler Valley basin is a southwest-trending plain surrounded by low block-faulted mountains within the Basin and Range physiographic province. The valley floor covers roughly 160 square miles and slopes gently southwestward and is drained by Cunningham Wash, an ephemeral stream that begins in the Buckskin Mountains and is a tributary to the Colorado River.[4] There are no perennial or intermittent streams or large reservoirs in the basin.[4] Vegetation types include Sonoran desert scrub and interior chaparral.

The basin is bounded on the north by the Bouse Hills and Buckskin Mountains, on the east by the Little Buckskin Mountains, on the south by the Harcuvar Mountains, and on the west by the Granite Wash Mountains. Elevations in the basin range from a high of 4,957 feet above mean sea level (amsl) at Smith Peak and a low of approximately 1,345 feet amsl at the 1.5-mile-wide "Narrows" where Cunningham Wash flows into the Ranegras Plain basin at a gap between the Granite Wash Mountains and the Bouse Hills.[4]

The Butler Valley basin consists of federal land (56 percent) managed by the Bureau of Land Management, State Trust land (44 percent), and less than 1 percent private land which mostly consists of small parcels of patented mining claims (Map 11).[3, 4]

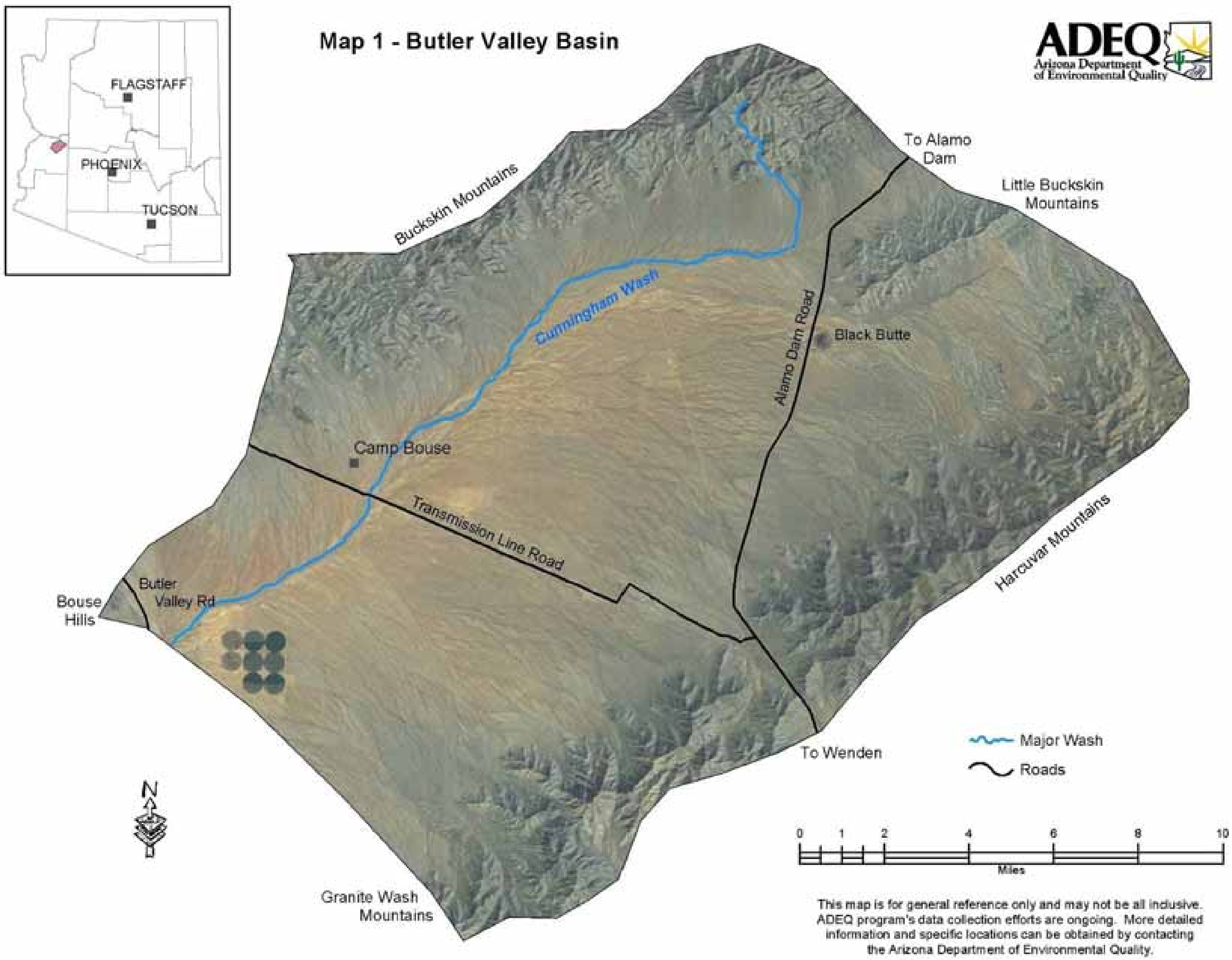
Climate – The Butler Valley has an arid climate characterized by hot, dry summers and mild winters. Precipitation ranges annually from 5 inches in the valley to 14 inches in high mountain elevations. It occurs predominantly as rain in either late summer, localized monsoon thunderstorms or, less often, as widespread, low intensity winter rain that occasionally includes snow at higher elevations.[4]

Geology – The mountains surrounding the alluvium-filled Butler Valley are predominantly composed of the following rock types (Map 10): Granite Wash Mountains (granite), the Bouse Hills (volcanic and granite), the Buckskin Mountains (granite and metamorphic), the Little Buckskin Mountains (metamorphic), and the Harcuvar Mountains (granite, metamorphic, and sedimentary).[17]

Groundwater Characteristics

Groundwater occurs primarily in the basin-fill sediments composed of silt, sand, clay, and gravel beds found in the valley. Based on limited data, these deposits range in thickness from 525 feet to 1,450 feet.[16] Depths to groundwater range from 145 feet below land surface (bls) to 513 feet bls.[16] Alluvial deposits are the principal aquifer in the basin. Small volumes of groundwater may also occur in mountain areas in thin alluvium, and in fractured and weathered volcanic, granitic, metamorphic, and sedimentary rocks.[4]

Groundwater flows from the northeast to the southwest.[16] The water-level gradient is low throughout most of the basin but increases in the southwestern


Map 1 - Butler Valley Basin
ADEQ
Arizona Department of Environmental Quality
FLAGSTAFF
PHOENIX
TUCSON
Buckskin Mountains
To Alamo Dam
Little Buckskin Mountains
Cunningham Wash
Alamo Dam Road
Black Butte
Camp Bouse
Transmission Line Road
Harcuvar Mountains
Butler Valley Rd
Bouse Hills
To Wenden
Major Wash
Roads
N
0 1 2 4 6 8 10
Miles
Granite Wash Mountains
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.

portion as a result of a cone of depression caused by a cluster of irrigation wells at Butler Valley Farm. Water levels in the basin generally are stable except for small declines in the southwest part of the basin due to irrigation withdrawals. [16]

INVESTIGATION METHODS

ADEQ collected samples from nine groundwater sites to characterize regional groundwater quality in the Butler Valley basin (Map 2). The following types of samples were collected:

- oxygen and deuterium isotopes at nine sites
- inorganic suites at nine sites
- nitrogen isotopes at six sites
- radon at six sites
- radionuclide at three sites

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 irrigation and stock purposes were sampled for the study, provided each well met ADEQ requirements. A well was considered suitable for sampling when: the owner has given permission to sample, a sampling point existed near the wellhead, and the well casing and surface seal appeared to be intact and undamaged.[1, 5] Because of the few operational wells in the basin, an exception was made with sample BUT-6 which was a former mine shaft and the cement casing was covered by wooden planks which may have allowed a small amount of precipitation into the well.

For this study, ADEQ personnel sampled 8 wells all served by submersible pumps except for 2 turbine pumps at irrigation wells. One spring was also sampled for the study. Of the 8 wells sampled, their primary purposes were stock (6 wells) and irrigation (2 wells). The spring also provided water for stock use. 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) [1] and the *Field Manual for Water Quality Sampling*. [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.

After obtaining permission from the well owner, 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 (SC)—were monitored at least every five minutes using either a Hach or YSI multi-parameter instrument.

To assure obtaining fresh water from the aquifer, 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. In certain instances, it was not possible to purge three bore volumes. In these cases, at least one bore volume was evacuated and the physical parameters had stabilized within 10 percent. Sample bottles were filled in the following order:

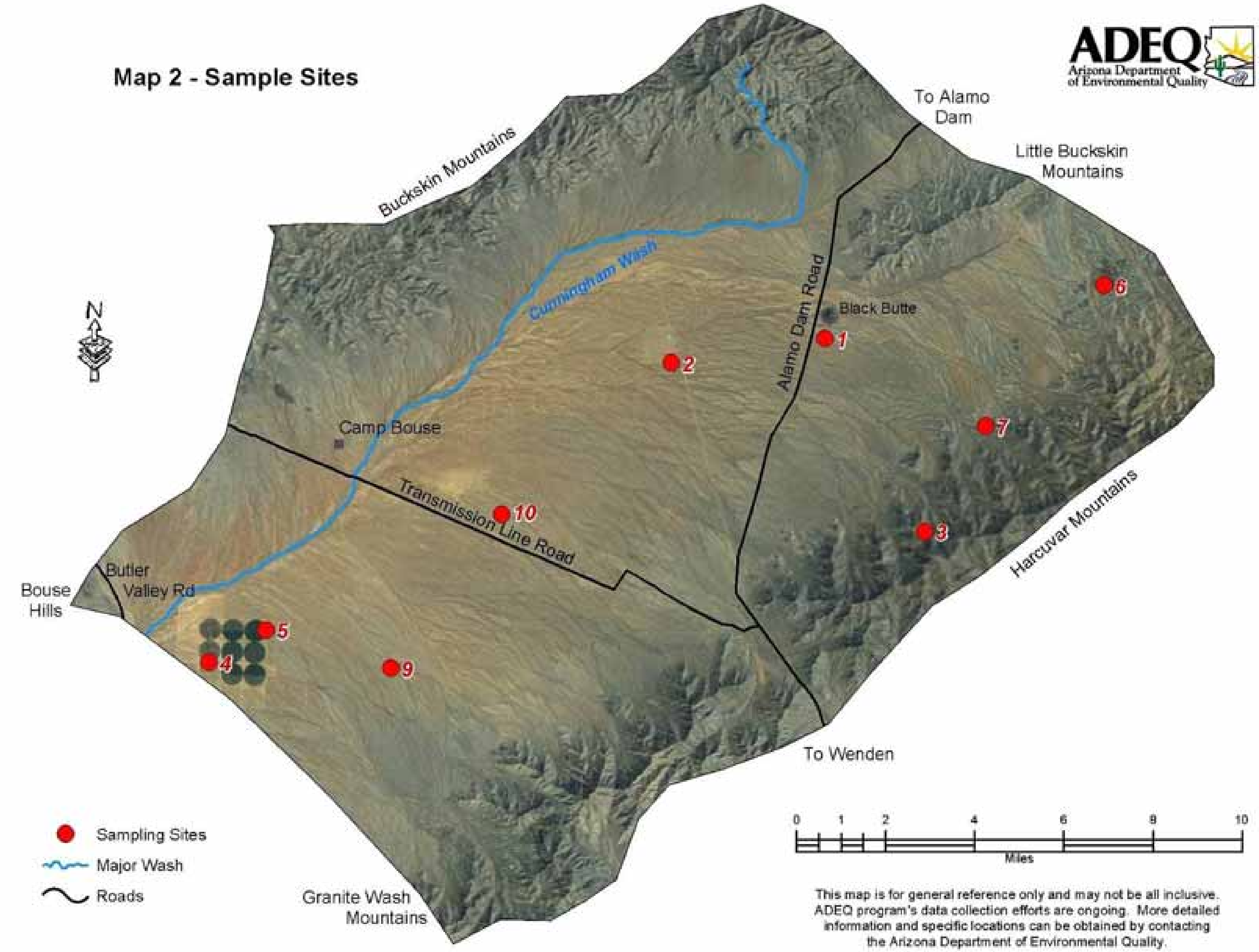
1. Radon
2. Inorganics
3. Radionuclides
4. Isotopes

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.[21]

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 inorganic parameters were unpreserved. [18, 21]

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. [10]

Oxygen and hydrogen isotope samples were collected in a 250 ml polyethylene bottle with no preservative. Nitrogen isotope samples were collected in a 500 ml polyethylene bottle and filled ¾ full to allow room for expansion when frozen. [25]



Map 2 - Sample Sites
ADEQ
Arizona Department of Environmental Quality
Buckskin Mountains
Cunningham Wash
To Alamo Dam
Little Buckskin Mountains
Alamo Dam Road
Black Butte
1
2
3
4
5
6
7
9
10
Camp Bouse
Transmission Line Road
Harcuvar Mountains
Butler Valley Rd
Bouse Hills
To Wenden
Granite Wash Mountains
N
Sampling Sites
Major Wash
Roads
0
1
2
4
6
8
10
Miles
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.

Figure 1 – HQ Well at the former Conley Ranch was the first sample (BUT-1) collected in the basin. The sample met all water quality standards; Black Butte is located behind the corral.

Figure 3 – ADEQ's Susan Determann collects a sample from Hangman's Well (BUT-7) in the foothills of the Harcuvar Mountains. The former windmill is now solar powered and is used for stock watering.

Figure 2 – ADEQ's Susan Determann stands on the casing of Graham Well, a former windmill located at the Narrows where groundwater underflow from Butler Valley migrates into the Ranegras Plain basin. Several historic wells in the Butler Valley basin are no longer in use and weren't able to be sampled for the study.

Figure 4 – In Butler Valley, rancher Frank Herschkowitz watches ADEQ's Elizabeth Boettcher collect a sample (BUT-9) from Jug Head Well. The sample from the 280-foot-deep stock well met all water quality standards except for total dissolved solids (TDS).

Figure 5 – The only major water use in the basin is Butler Valley Farm which grows alfalfa using center pivots on State Trust lands near the basin outflow into the Ranegras Plain basin. Almost 10,000 acre-feet per year are pumped for irrigation annually in the basin. Many of the estimated 15 people who reside in Butler Valley basin live at the farm.

Figure 6 – Upper State Well formerly used for irrigation but now supplying water for livestock is located near the center of the valley. A submersible pump powered by a portable generator powers the well. The sample (BUT-2) collected from the well met all water quality standards. The El Paso Natural Gas Compressor Station and the Buckskin Mountains can be seen in the background.

Figure 7 – ADEQ's Elizabeth Boettcher samples the 320-foot-deep Headquarters Well located along Transmission Line Road. The sample (BUT-10) collected from the well exceeded Secondary MCLs for chloride, sulfate, and TDS.

Figure 8 – Burnt Well (BUT-6) is a mine shaft from which a solar-powered pump raises groundwater into the former underground storage tank at the top of the photo. The water is used for livestock and exceeded four Secondary MCLs.

Figure 9 – ADEQ's Susan Determann collects a sample (BUT-4) from the Butler Valley Farm Shop Well. The irrigation well powered by a diesel pump runs constantly during the growing season to provide water to an alfalfa field using a center pivot.

Figure 10 – Butler Valley Farm Well #1 is sampled by ADEQ's Susan Determann. The sample (BUT-5) met all water quality standards except for fluoride which exceeded the health-based, water quality standard of 4.0 mg/L. The Bouse Hills are in the background.

All samples were kept at 4°C with ice in an insulated cooler, with the exception of the oxygen and hydrogen isotope and radiochemistry samples.[10,25] Nitrogen samples were frozen upon returning from the field and shipped in dry ice to the laboratory.[25] Chain of custody procedures were followed in sample handling. Samples for this study were collected during four field trips between August 2008 and January 2012.

Laboratory Methods

The inorganic analyses for samples BUT-1 and BUT-2 were conducted by the Arizona Department of Health Services (ADHS) Laboratory in Phoenix, Arizona.

For samples BUT-3 through BUT-10, inorganic 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.

Radon samples were submitted to Test America Laboratory and analyzed by Radiation Safety Engineering, Inc. Laboratory in Chandler, Arizona.

Radionuclide analyses for sample BUT-1 was conducted by the Arizona Radiation Agency Laboratory in Phoenix. For samples BUT-3 through BUT-10, radionuclide analysis was conducted by Radiation Safety Engineering, Inc. Laboratory in Chandler, Arizona. The following EPA SDW protocols were used: Gross alpha was analyzed, and if levels exceeded 5 picocuries per liter (pCi/L), then radium-226 was measured. Radium-228 was measured if radium-226 exceeded 3 pCi/L. If gross alpha levels exceeded 15 pCi/L initially, then radium-226/228 and total uranium were measured.[10]

All isotope samples were analyzed by the Department of Geosciences, 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 Butler Valley 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] Although QC samples were not collected for this study, sampling trips to Butler Valley were combined with those in the McMullen Valley and Ranegras Plain basins.[22, 23] Based on the QA/QC results for those two basins, sampling procedures and laboratory equipment did not significantly affect the groundwater quality samples.[22, 23]

Data Validation

The analytical work for this study was subjected to four QA/QC correlations and considered valid based on the following results.[14]

Cation/Anion Balances - In theory, water samples exhibit electrical neutrality. Therefore, the sum of milliequivalents 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]

Overall, cation/anion meq/L balances of Butler Valley basin samples were significantly correlated (regression analysis, $p \leq 0.01$). Of the 9 samples, all were within +/-6 percent and had low cation/high anion sums. Dilution factors of up to 20 for both chloride and sulfate seemed to be a likely reason for the higher anion sums.[21]

SC/TDS - The SC and TDS concentrations measured by contract laboratories were significantly correlated as were SC-field and TDS concentrations (regression analysis, $r = 0.99$, $p \leq 0.01$). 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]

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, $r = 0.72$, $p \leq 0.05$).

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
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 / E 300	5 / 2
Sulfate	Colorimetric	EPA 375.4 / E 300	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 [10, 19, 21]

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 / 0.2
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
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
Strontium	ICP-AES	EPA 200.7	0.1 / 0.1
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	Kinetic phosphorimeter	EPA Laser Phosphorimetry	Varies

All units are mg/L Source [10, 19, 21]

Temperature/GW Depth/Well Depth – The groundwater temperature measured in the field was compared to well depth and groundwater depth. Groundwater temperature should increase with depth, approximately 3 degrees Celsius with every 100 meters or 328 feet. [14] Groundwater depth was significantly correlated with temperature (regression analysis, $r = 0.88$, $p \leq 0.05$). Well depth (Diagram 1) was not however, significantly correlated with temperature (regression analysis, $r = 0.73$, $p \leq 0.05$).

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.[29]

Data Normality: Data associated with 30 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 16 of the 30 constituents (temperature, pH-field, pH-lab, hardness, calcium, sodium, potassium, total alkalinity, bicarbonate, chloride, nitrate, arsenic, barium, deuterium, well depth, and groundwater depth) examined 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 having different aquifers were the same. The Kruskal-Wallis test uses the differences, but also incorporates information about the magnitude of each difference.[29] 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. The Kruskal-Wallis test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.[13]

Correlation Between Constituents: In order to assess the strength of association between constituents, their concentrations were compared to each other using the Pearson Correlation Coefficient test. The Pearson correlation coefficient varies between -1 and +1; with a value of +1 indicating that a variable can be predicted perfectly by a positive linear function of the other, and vice versa. A value of -1 indicates a perfect inverse or negative relationship. The results of the Pearson Correlation Coefficient test were then subjected to a probability test to determine which of the individual pair wise correlations were significant. [29] Like the Kruskal-Wallis test, the Pearson test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.[13]

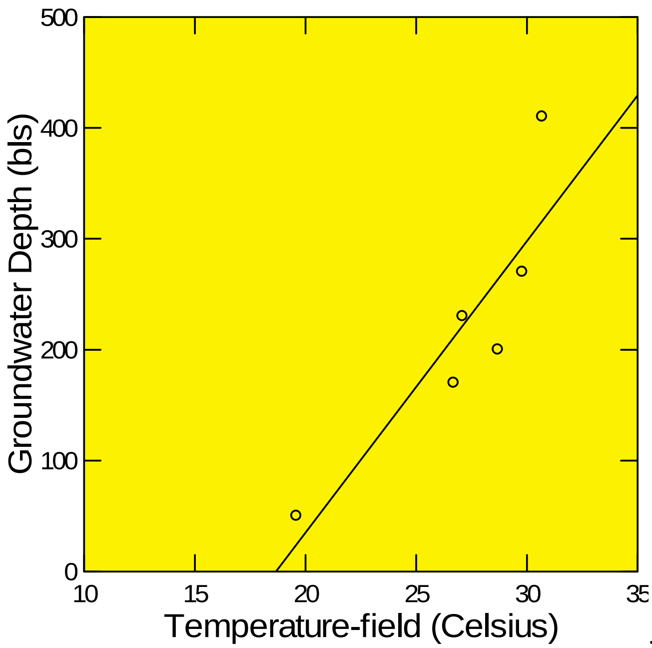


Diagram 1 – The graph illustrates a strong positive correlation; as groundwater depth increases water temperature as measured in the field also increases. The regression equation for this relationship is $y = 26.3x - 491$, $n = 6$, $r = 0.88$. Groundwater temperature should increase with depth, approximately 3 degrees Celsius with every 100 meters or 328 feet. [13]

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.[26]

- 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 except for arsenic which is at 0.05 mg/L compared with the Primary MCL of 0.01 mg/L. [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.[26]

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.[26] Exceedances of specific constituents for each groundwater site is found in Appendix B.

Overall Results - Of the 9 sites sampled in the Butler Valley basin, 2 (22 percent) met all SDW Primary and Secondary MCLs, 2 (22 percent) exceeded Primary MCLs, and 7 (78 percent) exceeded Secondary MCLs.

Inorganic Constituent Results - Health-based Primary MCL water quality standards and State aquifer water quality standards were exceeded at 2 of 9 sites (22 percent; Map 3; Table 2). Constituents exceeding Primary MCLs include fluoride (1 site) and uranium (1 site).[26] Potential health effects of these chronic Primary MCL exceedances are provided in Table 2.

Aesthetics-based Secondary MCL water quality guidelines were exceeded at 7 of 9 sites (78 percent; Map 3; Table 3). Constituents above Secondary MCLs include TDS (5 sites), chloride (3 sites), sulfate (3 sites), fluoride (2 sites), and manganese (1 site). Potential impacts of these Secondary MCL exceedances are provided in Table 3.

Radiochemical Results - Of the 3 sites sampled for radionuclides in the Butler Valley basin, 1 exceeded SDW Primary MCLs.[26]

Radon Results - Of the 6 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. Two (2) sites exceeded the proposed 300 pCi/L standard that would apply if Arizona doesn't develop a multimedia program. [26]

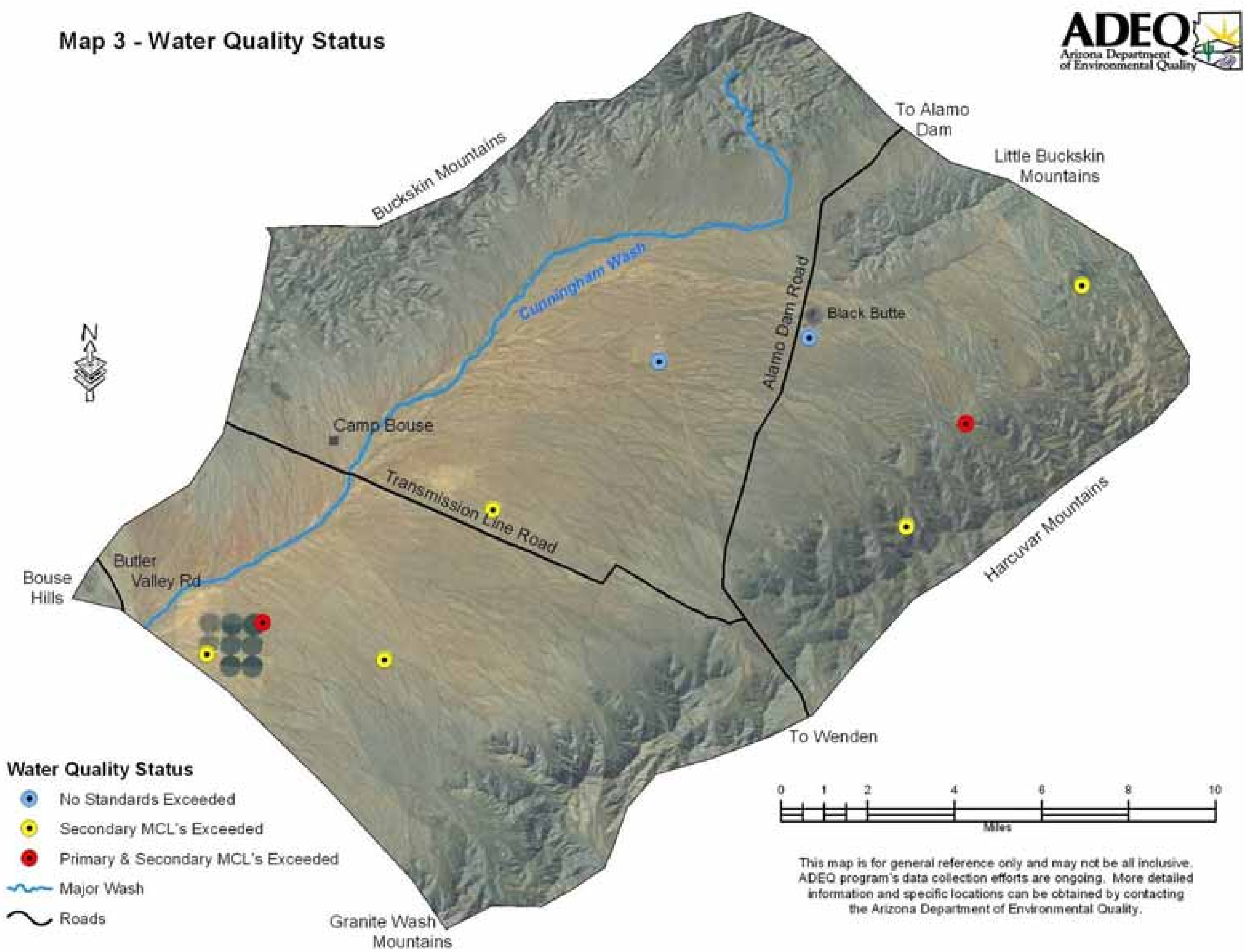
Suitability for Irrigation

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. Irrigation water may be classified using SC and the Sodium Adsorption Ratio (SAR) in conjunction with one another. [27] Groundwater sites in the Butler Valley basin display a wide range of irrigation water classifications. The alkalinity and salinity hazard categories that the nine sample sites fall within are provided in Table 4.

Analytical Results

Analytical inorganic and radiochemistry results of the Butler Valley basin sample sites are summarized (Table 5) 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.[29] Specific constituent information for each sampled groundwater site is in Appendix B.

Map 3 - Water Quality Status



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.

Table 2. Sampled Sites Exceeding Health-based Water Quality Standards or Primary MCLs

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	0	-	-
Trace Elements				
Antimony (Sb)	0.006	0	-	-
Arsenic (As)	0.01	0	-	-
Arsenic (As)	0.05	0	-	-
Barium (Ba)	2.0	0	-	-
Beryllium (Be)	0.004	0	-	-
Cadmium (Cd)	0.005	0	-	-
Chromium (Cr)	0.1	0	-	-
Copper (Cu)	1.3	0	-	-
Fluoride (F)	4.0	**1**	5.0	skeletal damage
Lead (Pb)	0.015	0	-	-
Mercury (Hg)	0.002	0	-	-
Nickel (Ni)	0.1	0	-	-
Selenium (Se)	0.05	0	-	-
Thallium (Tl)	0.002	0	-	-
Radiochemistry Constituents				
Gross Alpha	15	0	-	-
Ra-226+Ra-228	5	0	-	-
Radon **	300	**2**	718	cancer
Radon **	4,000	0	-	-
Uranium	30	**1**	59.1	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.[26]
** Proposed EPA Safe Drinking Water Act standards for radon in drinking water. [26]

Table 3. Sampled Sites Exceeding Aesthetics-based Water Quality Guidelines or Secondary MCLs

Constituents	Secondary MCL	Number of Sites Exceeding Secondary MCLs	Concentration Range of Exceedances	Aesthetic Effects of MCL Exceedances
Physical Parameters				
pH - field	< 6.5	0	-	-
pH - field	> 8.5	0	-	-
General Mineral Characteristics				
TDS	500	**5**	2,100	hardness; deposits; colored water; staining; salty taste
Major Ions				
Chloride (Cl)	250	**3**	800	salty taste
Sulfate (SO_4)	250	**3**	670	salty taste
Trace Elements				
Fluoride (F)	2.0	**2**	5.0	tooth discoloration
Iron (Fe)	0.3	0	-	-
Manganese (Mn)	0.05	**1**	0.10	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: [26]

Table 4. Alkalinity and Salinity Hazards for Sampled Sites

Hazard	Total Sites	Low	Medium	High	Very High
Alkalinity Hazard					
Sodium Adsorption Ratio (SAR)		0 - 10	10- 18	18 - 26	> 26
Sample Sites	9	6	3	0	0
Salinity Hazard					
Specific Conductivity (uS/cm)		100–250	250 – 750	750-2250	>2250
Sample Sites	9	0	4	3	2

Table 5. Summary Statistics for 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	9 / 9	27.1	20.9	25.6	30.4
pH-field (su)	0.01	9 / 9	7.73	7.44	7.73	7.99
pH-lab (su)	0.01	9 / 9	8.10	7.67	7.92	8.18
Turbidity (ntu)	0.01 / 0.20	9 / 6	1.2	0.0	5.9	11.9
General Mineral Characteristics						
T. Alkalinity	2.0 / 6.0	9 / 9	170	84	185	285
Phenol. Alk.	2.0 / 6.0	9 / 0	> 50% of data below MRL			
SC-field (uS/cm)	N/A	9 / 9	808	540	1369	2197
SC-lab (uS/cm)	N/A / 2.0	9 / 9	830	507	1318	2129
Hardness-lab	10 / 6	9 / 9	180	84	308	531
TDS	10 / 20	9 / 9	520	325	842	1360
Major Ions						
Calcium	5 / 2	9 / 9	60	31	86	140
Magnesium	1.0 / 0.25	9 / 9	7.9	0	23	46
Sodium	5 / 2	9 / 9	110	47	159	271
Potassium	0.5 / 2.0	9 / 9	4.3	3.0	4.6	6.3
Bicarbonate	2.0 / 6.0	9 / 9	210	104	226	349
Carbonate	2.0 / 6.0	9 / 0	> 50% of data below MRL			
Chloride	1 / 20	9 / 9	110	39	229	419
Sulfate	10 / 20	9 / 9	96	27	198	369
Nutrients						
Nitrate (as N)	0.02 / 0.20	9 / 8	2.3	1.0	2.0	2.9
Nitrite (as N)	0.02 / 0.20	9 / 0	> 50% of data below MRL			
TKN	0.05 / 1.0	9 / 2	> 50% of data below MRL			
Ammonia	0.02 / 0.05	9 / 1	> 50% of data below MRL			
T. Phosphorus	0.02 / 0.10	9 / 3	> 50% of data below MRL			

Table 5. Summary Statistics for 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	0.5 / 0.2	7 / 0	> 50% of data below MRL			
Antimony	0.005 / 0.003	9 / 0	> 50% of data below MRL			
Arsenic	0.01 / 0.001	9 / 6	0.002	0.001	0.003	0.005
Barium	0.1 / 0.001	9 / 9	0.059	0.043	0.062	0.082
Beryllium	0.0005 / 0.001	9 / 0	> 50% of data below MRL			
Boron	0.1 / 0.2	9 / 4	> 50% of data below MRL			
Cadmium	0.001	9 / 0	> 50% of data below MRL			
Chromium	0.01 / 0.001	9 / 3	> 50% of data below MRL			
Copper	0.01 / 0.001	9 / 7	0.003	0.003	0.004	0.005
Fluoride	0.2 / 0.4	9 / 7	4.0	3.3	4.0	4.7
Iron	0.1 / 0.05	9 / 0	> 50% of data below MRL			
Lead	0.005 / 0.001	9 / 0	> 50% of data below MRL			
Manganese	0.05 / 0.01	9 / 3	> 50% of data below MRL			
Mercury	0.0005 / 0.0002	9 / 0	> 50% of data below MRL			
Nickel	0.1 / 0.01	9 / 0	> 50% of data below MRL			
Selenium	0.005 / 0.002	9 / 4	>50% of data below MRL			
Silver	0.001	9 / 0	> 50% of data below MRL			
Thallium	0.002 / 0.001	9 / 0	> 50% of data below MRL			
Strontium	0.10	7 / 7	1.5	0.2	1.9	3.6
Zinc	0.05	9 / 4	> 50% of data below MRL			
Radiochemical						
Gross Alpha **	Varies	3 / 2	1.0	0.5	1.7	2.8
Gross Beta **	Varies	3 / 0	> 50% of data below MRL			
Radon **	Varies	6 / 5	442	369	480	590
Isotopes						
Oxygen-18 ***	Varies	9 / 9	- 8.8	- 8.7	- 8.5	- 8.3
Deuterium ***	Varies	9 / 9	- 67.0	- 65.8	- 63.7	- 61.7

* = ADHS MRL / Test America MRL   All units mg/L except where noted or ** = pCi/L and *** = 0/00

GROUNDWATER COMPOSITION

General Summary

The water chemistry at the 9 sample sites in the Butler Valley basin (in decreasing frequency) includes sodium-chloride (3 sites), sodium-mixed (2 sites), mixed-bicarbonate (2 sites), and calcium-bicarbonate and mixed-mixed (1 site each) (Diagram 2 – middle diagram; Map 4).

Of the 9 sample sites in the Butler Valley basin, the dominant cation was sodium at 5 sites and calcium at 1 site; at 3 sites, the composition was mixed as there was no dominant cation (Diagram 2 – left diagram).

The dominant anion was chloride at 3 sites and bicarbonate at 3 sites; at 3 sites the composition was mixed as there was no dominant anion (Diagram 2 – right diagram).

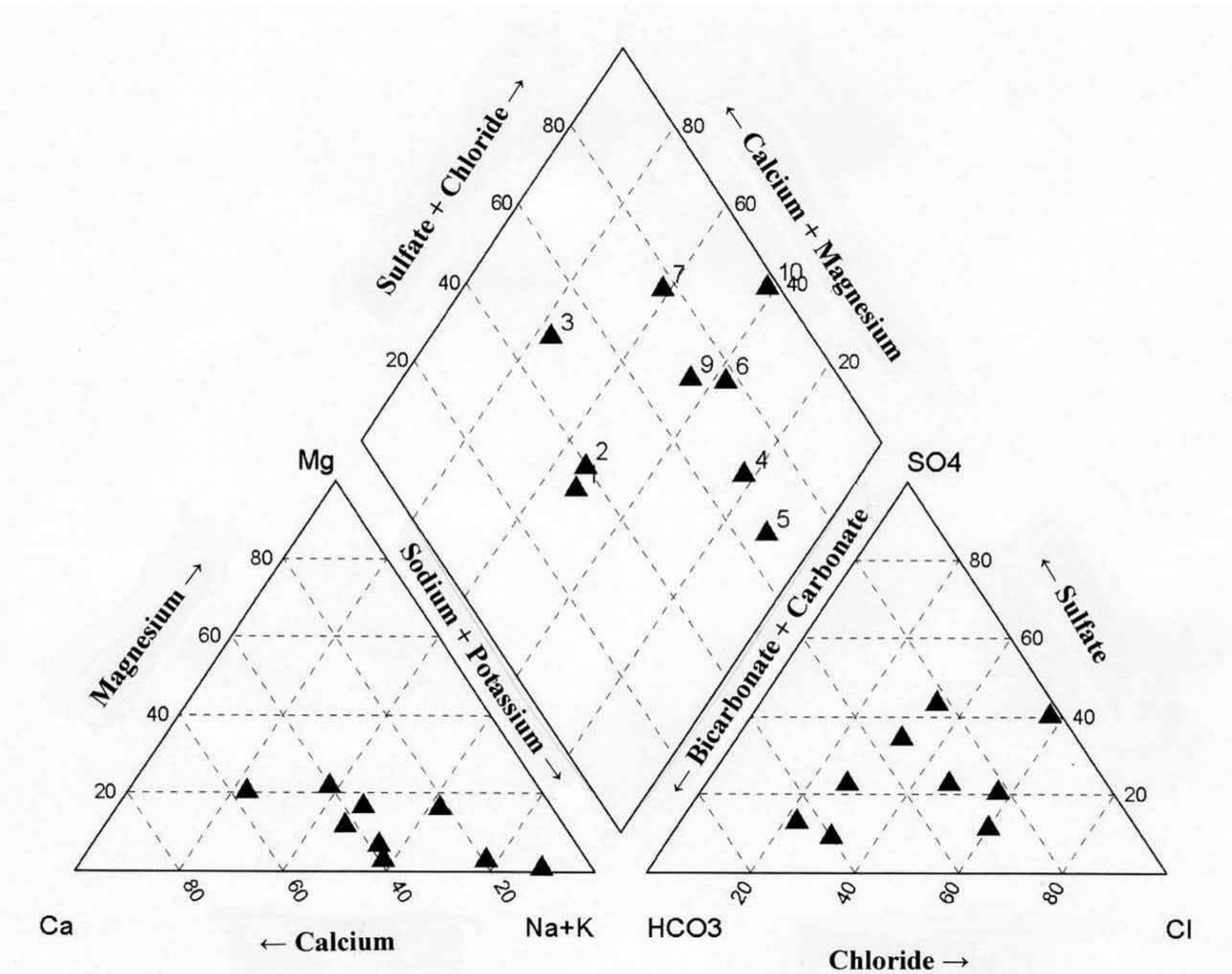
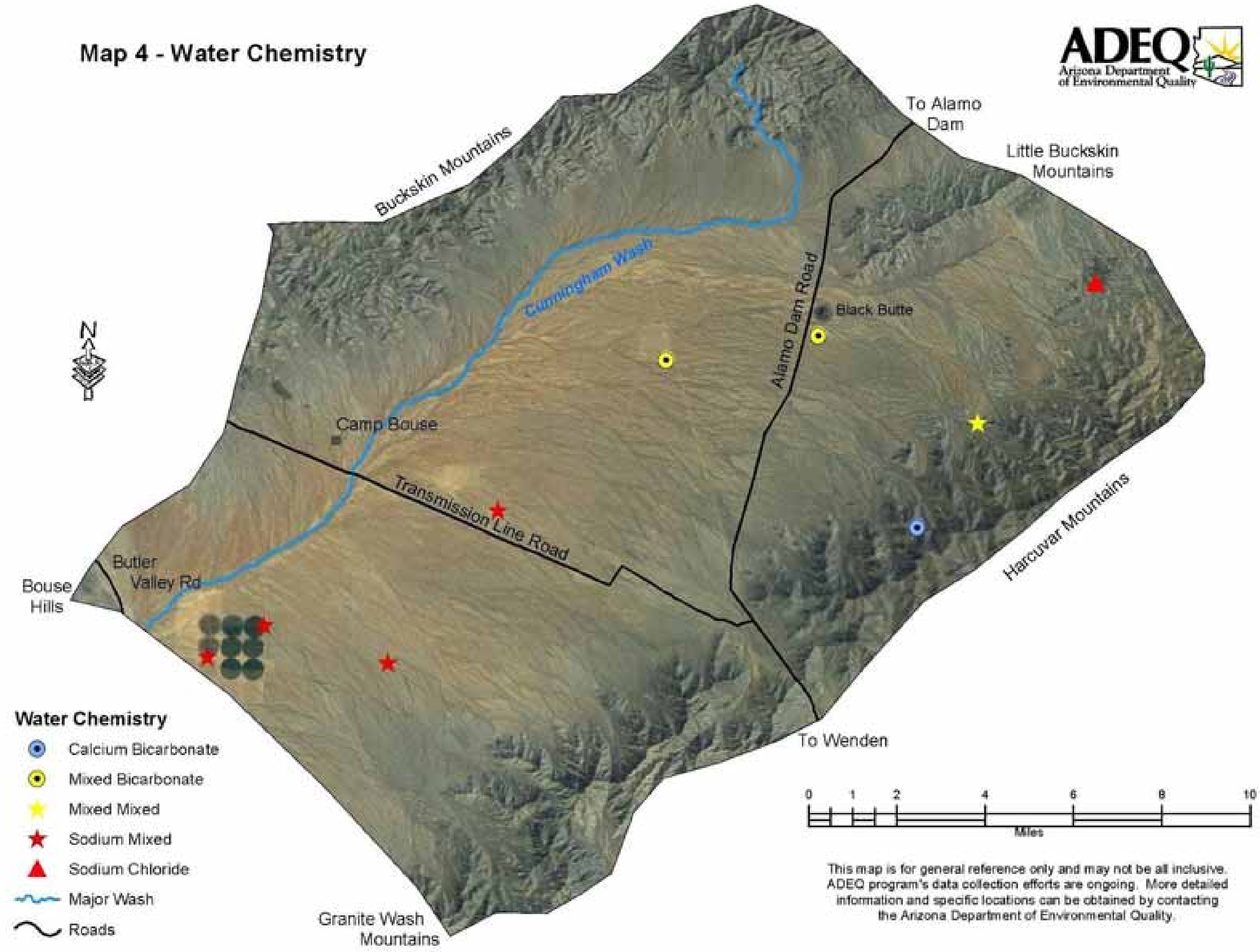


Diagram 2 – Groundwater in the Butler Valley basin evolves as it moves through the basin based on water chemistry and oxygen and hydrogen isotope values. Recent recharge occurring from precipitation in the higher elevation mountains along the boundaries of the basin and (or "recent" groundwater) starts as a calcium-bicarbonate or mixed-bicarbonate/mixed chemistry and evolves into "older" groundwater that has a sodium-chloride/mixed chemistry as it approaches the Narrows where sub-flow enters the Ranegras Plain basin.

Map 4 - Water Chemistry



At all 9 sites, levels of pH-field were all *slightly alkaline* (above 7 su) and 2 sites were above 8 su.[12]

TDS concentrations were considered *fresh* (below 999 mg/L) at 6 sites and *slightly saline* (1,000 to 3,000 mg/L) at 3 sites (Map 5).[12]

Hardness concentrations were *soft* (below 75 mg/L) at 2 sites, *moderately hard* (75 – 150 mg/L) at 2 sites, *hard* (150 – 300 mg/L) at 1 site, *very hard* (300 - 600 mg/L) at 2 sites, *extremely hard* (> 600 mg/L) at 2 sites (Diagram 3 and Map 6).[8]

Nitrate (as nitrogen) concentrations at most sites may have been influenced by human activities (Map 8). Nitrate concentrations were divided into natural background (1 site at < 0.2 mg/L), may or may not indicate human influence (5 sites at 0.2 – 3.0 mg/L), may result from human activities (3 sites at 3.0 – 10 mg/L), and probably result from human activities (0 sites > 10 mg/L).[15] Nitrogen isotope analysis on a subset of six sample sites further indicates nitrate concentrations are likely the result of either natural soil organic matter or fertilizer applications.[24]

Most trace elements such as aluminum, antimony, beryllium, cadmium, iron, lead, mercury, nickel, silver, and thallium were rarely – if ever - detected. Only arsenic, barium, boron, chromium, copper, fluoride, manganese, selenium, strontium, and zinc were detected at more than 25 percent of the sites.

Diagram 3. Hardness Concentrations of Butler Valley Basin Samples

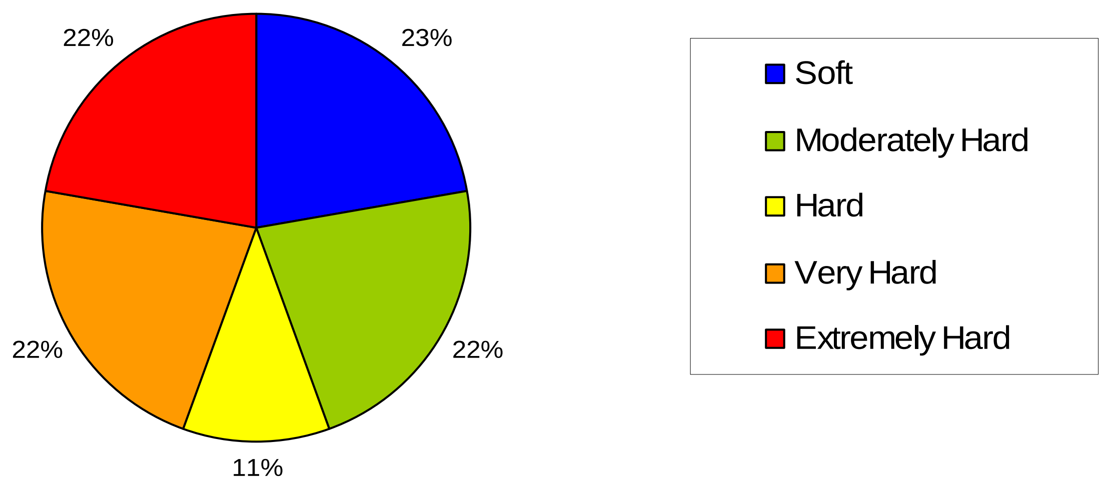
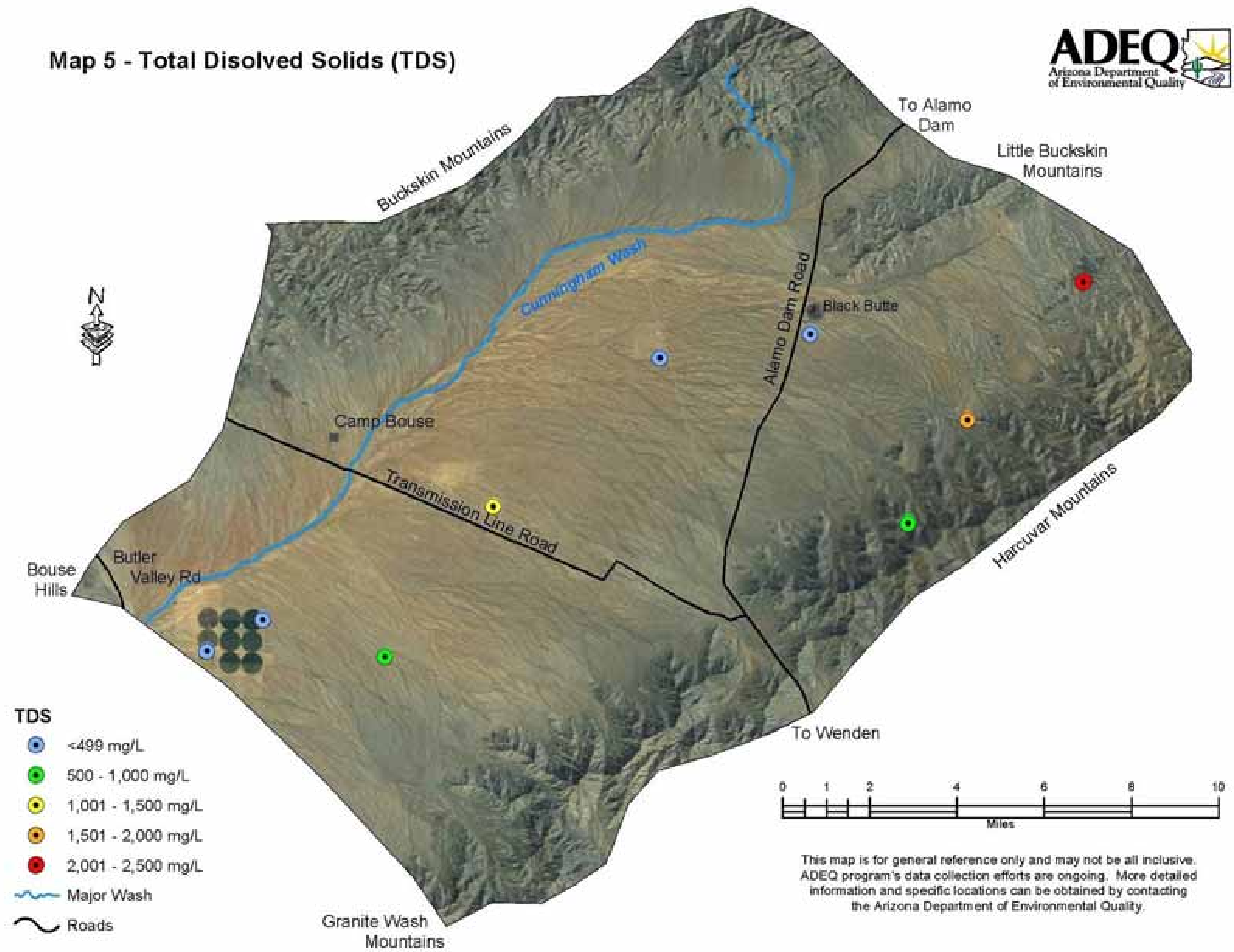
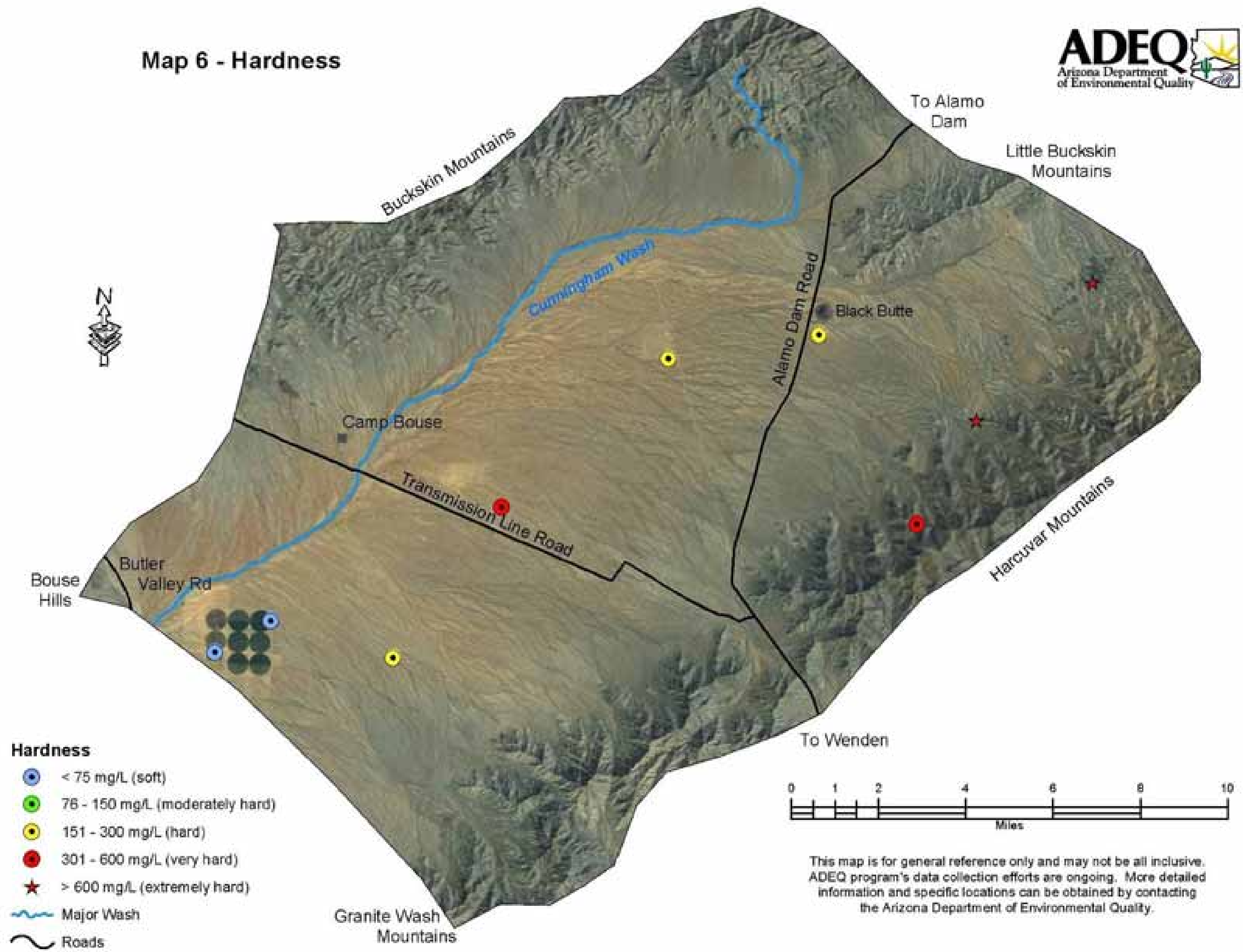


Diagram 3 – In the Butler Valley basin hardness concentrations vary widely ranging from 27 to 890 mg/L. The highest hardness concentrations occurred in samples collected from wells and a spring in or or near the Harcuvar Mountains. From these upgradient locations, groundwater generally softened moving downgradient through the basin. Soft water samples were collected from irrigation wells used by Butler Valley Farm located in the southwestern portion of the basin near the boundary with the Ranegras Plain basin.

Map 5 - Total Disolved Solids (TDS)




Map 6 - Hardness
ADEQ
Arizona Department of Environmental Quality
N
Buckskin Mountains
Cunningham Wash
To Alamo Dam
Little Buckskin Mountains
Alamo Dam Road
Black Butte
Camp Bouse
Transmission Line Road
Harcuvar Mountains
Bouse Hills
Butler Valley Rd
To Wenden
Granite Wash Mountains
Hardness
< 75 mg/L (soft)
76 - 150 mg/L (moderately hard)
151 - 300 mg/L (hard)
301 - 600 mg/L (very hard)
> 600 mg/L (extremely hard)
Major Wash
Roads
0 1 2 4 6 8 10
Miles
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.

Constituent Co-Variation

The correlations between different chemical parameters were analyzed to determine the relationship between the constituents that were sampled. The strength of association between the chemical constituents allows for the identification of broad water quality patterns within a basin.

The results of each combination of constituents were examined for statistically-significant positive or negative correlations though such relationships were challenging to attain with only nine samples. A ***positive correlation*** occurs when, as the level of a constituent increases or decreases, the concentration of another constituent also correspondingly increases or decreases. A ***negative correlation*** occurs when, as the concentration of a constituent increases, the concentration of another constituent decreases, and vice-versa. A positive correlation indicates a direct relationship between constituent concentrations; a negative correlation indicates an inverse relationship.[29]

Several significant correlations occurred among the 9 sample sites (Table 6, Pearson Correlation Coefficient test, $p \leq 0.05$). Four groups of correlations were identified:

- pH-field was negatively correlated with TDS, hardness (Diagram 4), calcium, magnesium, bicarbonate, and sulfate.

- Arsenic and fluoride were positively correlated with each other. Fluoride was also positively correlated with pH-field and negatively correlated with oxygen and deuterium.

- Positive correlations occurred among TDS, calcium, magnesium, sodium, bicarbonate, chloride, and sulfate.

- Nitrate was negatively correlated with TDS, hardness, calcium, sodium, potassium chloride and sulfate.

TDS concentrations are best predicted among major ions by chloride concentrations (standard coefficient = 0.79), among cations by sodium concentrations (standard coefficient = 0.64) and among anions, by chloride concentrations (standard coefficient = 0.55) (multiple regression analysis, $p \leq 0.01$).

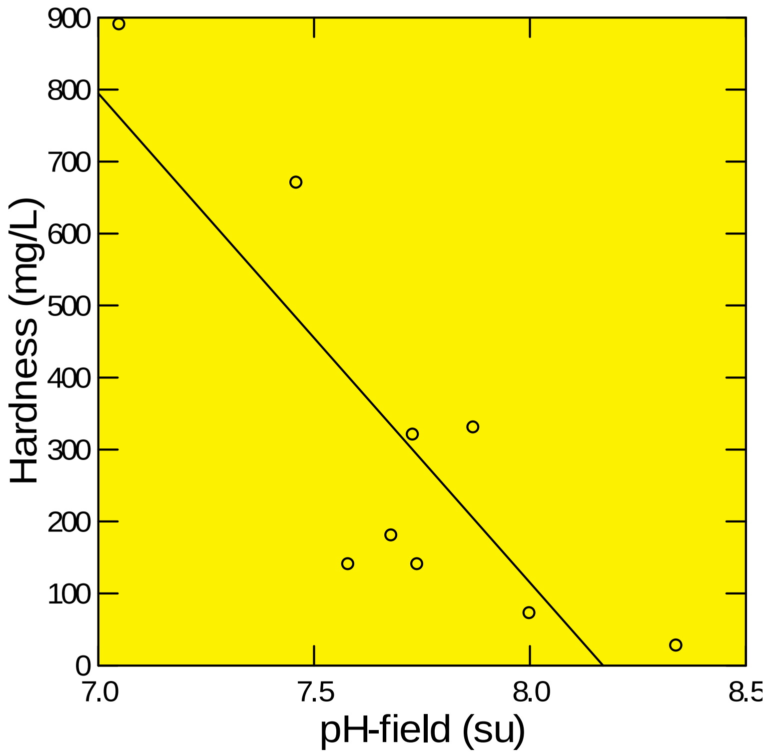


Diagram 4 – The graph illustrates a strong negative correlation between two constituents; as pH-field values increase, hardness concentrations decrease. This relationship is described by the regression equation: $y = -680x + 5553$ ($r = 0.84$). The pH-hardness relationship has been found in other Arizona groundwater basins and is likely related to precipitation of calcite in response to increases in pH.[19]

Table 6. Correlation Among Groundwater Quality Constituent Concentrations

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

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

Oxygen and Hydrogen Isotopes

The data for the Butler Valley basin roughly conforms to what would be expected in an arid environment, having a slope of 6.4, with the Local Meteoric Water Line (LMWL) described by the linear equation:

$$\delta D = 6.4 \delta {}^{18}O - 7.38$$

The LMWL for the Butler Valley basin (6.4) is higher than other basins in Arizona including Dripping Springs Wash (4.4), Detrital Valley (5.2), Agua Fria (5.3), Bill Williams (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), Lake Mohave (7.8), and Ranegras Plain (8.3). [22, 23]

The most depleted isotope samples were found in downgradient areas; the two Butler Valley Farm wells (BUT-4 and BUT-5), three stock wells (BUT-2, BUT-9, and BUT-10), and Dripping Spring (BUT-3) (Diagram 5). The light signatures of these samples are more depleted than would be expected from precipitation occurring either in Butler Valley or the bordering low elevation mountains. This suggests that these "old recharge" samples may consist of paleowater that was recharged during cooler climate conditions roughly 8,000 – 12,000 years ago.[9]

In contrast, three isotope samples (BUT-1, BUT-7, and BUT-6) collected in the upgradient southeast portions of the basin are more enriched (Map 7). These isotope values suggest that much of the groundwater at these wells and springs consists of "recent recharge" stemming from precipitation originating in the Harcuvar Mountains. While BUT-1 and BUT-7 plot lower on the LWML and appear to contain some older water resulting in a "mixed recharge," BUT-6 does not. This "well" is actually a covered mine shaft in which a solar-powered submersible pump produces water for stock. The mine shaft's cover however, would allow surface flow to enter which may account for the enriched sample.

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:

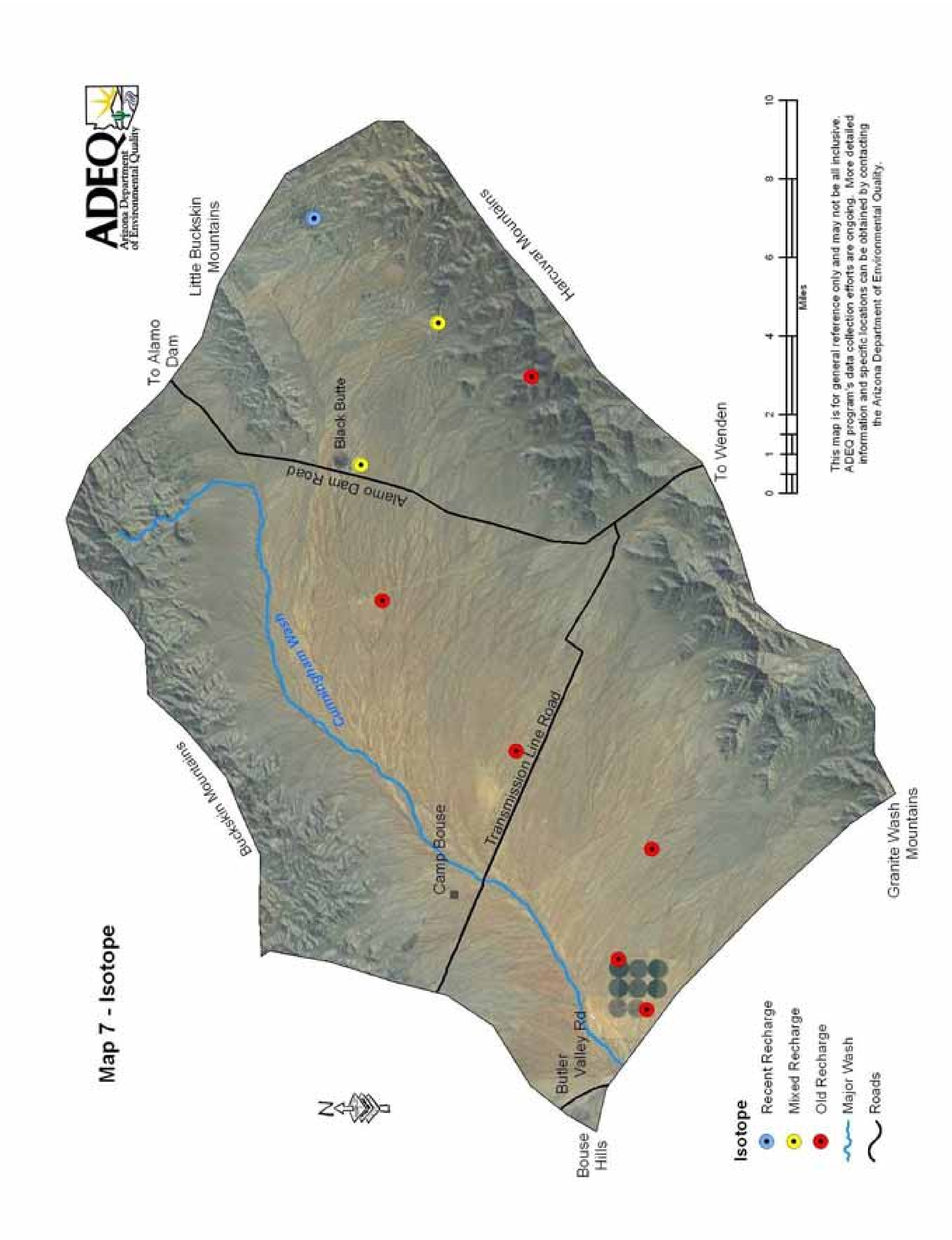
$$\delta D = 8 \delta {}^{18}O + 10$$

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.[8] The LMWL created by $\delta {}^{18}O$ and δD values for samples collected at sites in the Butler Valley 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]



Map 7 - Isotope
N
ADEQ
Arizona Department of Environmental Quality
Buckskin Mountains
Little Buckskin Mountains
To Alamo Dam
Black Butte
Alamo Dam Road
Harcuvar Mountains
To Wenden
Cunningham Wash
Transmission Line Road
Camp Bouse
Granite Wash Mountains
Butler Valley Rd
Bouse Hills
Isotope
Recent Recharge
Mixed Recharge
Old Recharge
Major Wash
Roads
0 1 2 4 6 8 10
Miles
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.

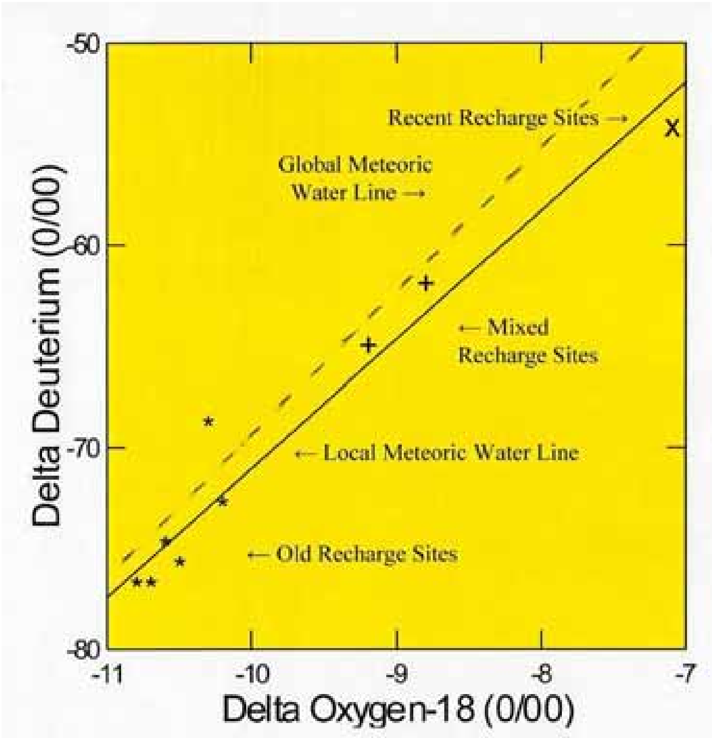


Diagram 5 – The nine isotope samples are plotted according to their oxygen-18 and deuterium values. Along the Local Meteoric Water Line starting from highest on the precipitation trajectory (upper right of the graph), the following ages of samples plot: recharge from recent precipitation, mixed recharge sites consisting of both recent and old recharge, and old recharge consisting of paleowater from precipitation that occurred roughly 10,000 years ago when the basin's climate was much cooler.[9]

Nitrogen Isotopes

Sources of nitrate in groundwater may be distinguished by measuring two stable isotopes of nitrogen, nitrogen-14 and nitrogen-15, often represented by $\delta^{15}N$. Although the percentage of the two isotopes is nearly constant in the atmosphere, certain chemical and physical processes preferentially utilize one isotope, causing a relative enrichment of the other isotope in the remaining reactants. Because of these isotopic fractionation processes, nitrate from different nitrogen sources has been shown to have different N isotope ratios. The $\delta^{15}N$ values have been cited as ranging from +2 to +9 per mil for natural soil organic matter sources, -3 to +3 for fertilizer sources, +10 to +20 per mil for animal waste. [20]

Groundwater samples for $\delta^{15}N$ analysis were collected at 6 sites in the Butler Valley basin (Map 8). The $\delta^{15}N$ values ranged from -0.3 to +3.0 0/00 while nitrate values ranged from non-detect to 3.5 mg/L (Diagram 6). Based on these results, it appears that the nitrogen source is either from fertilizer sources or natural soil organic matter. [20, 24]

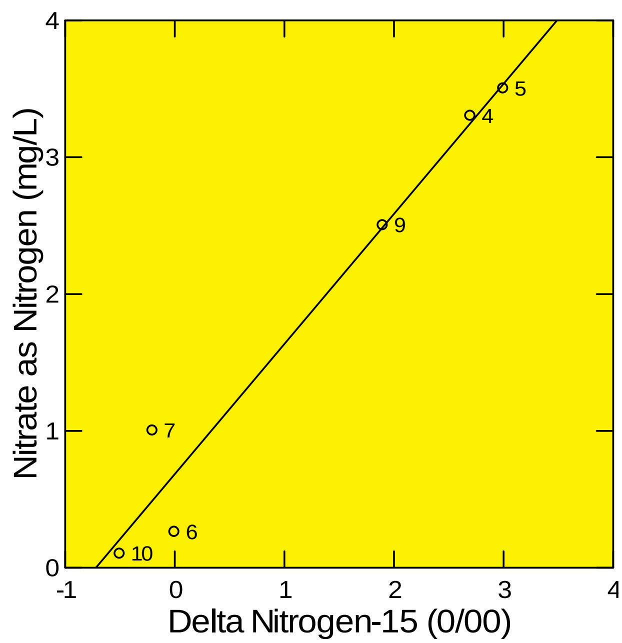
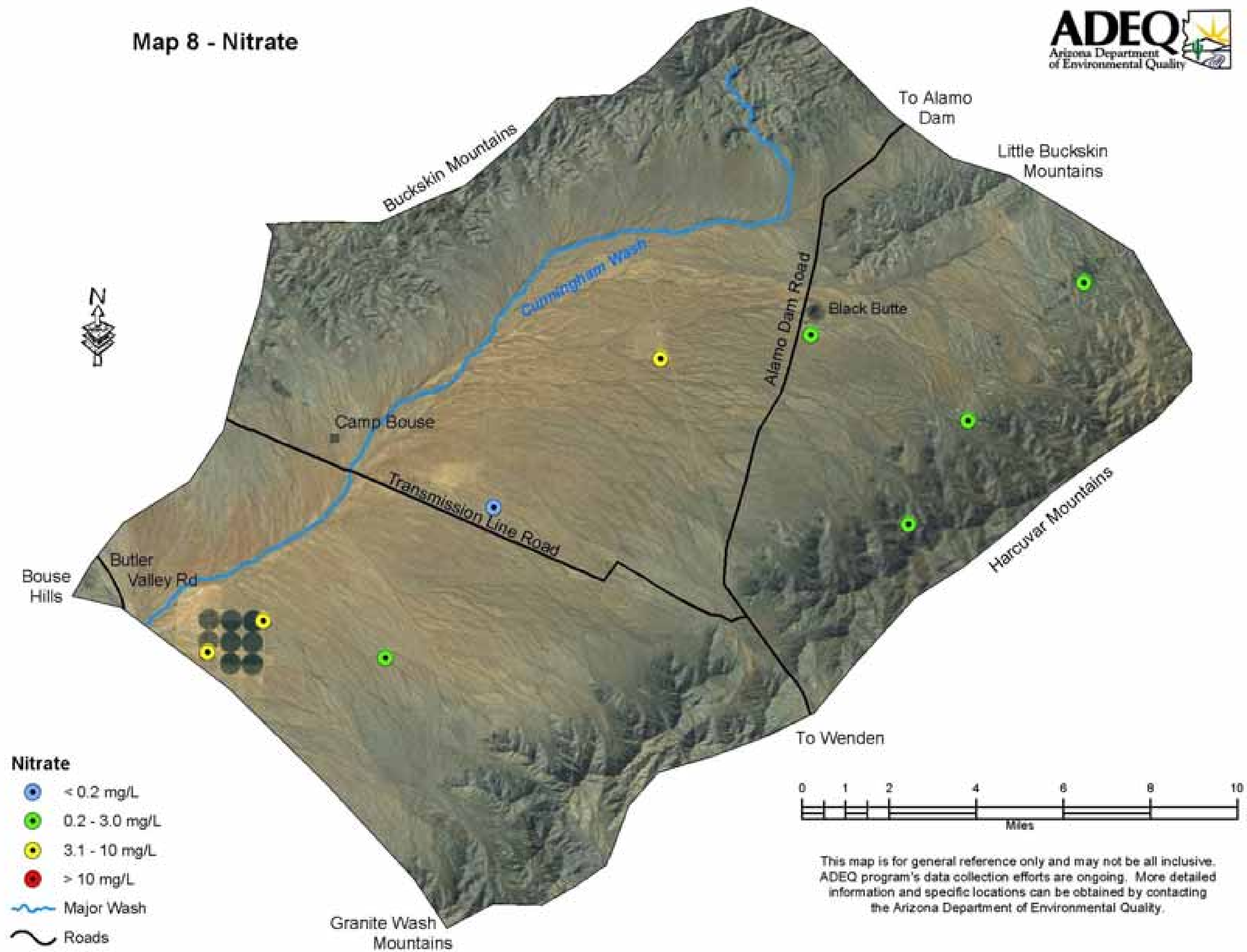


Diagram 6 – The graph illustrates that natural organic soil or fertilizer is likely the major source of nitrogen in the six samples at which nitrogen isotope samples were collected. Their relationship is described by the linear equation: $NO_3\text{-}N = 0.95\delta^{15}N + 0.68$ ($r = 0.98$).

Map 8 - Nitrate



Groundwater Quality Variation

Between Two Recharge Ages – Twenty-five (25) groundwater quality constituents were compared between two recharge types: old (6 sites) and recent/mixed (3 sites).

Significant concentration differences were found with five constituents: bicarbonate (Diagram 7), magnesium (Diagram 8), copper, oxygen-18 and deuterium (Kruskal-Wallis test, $p \leq 0.05$).

Complete statistical results are in Table 7 and 95 percent confidence intervals for significantly different groups based on isotope recharge ages are in Table 8.

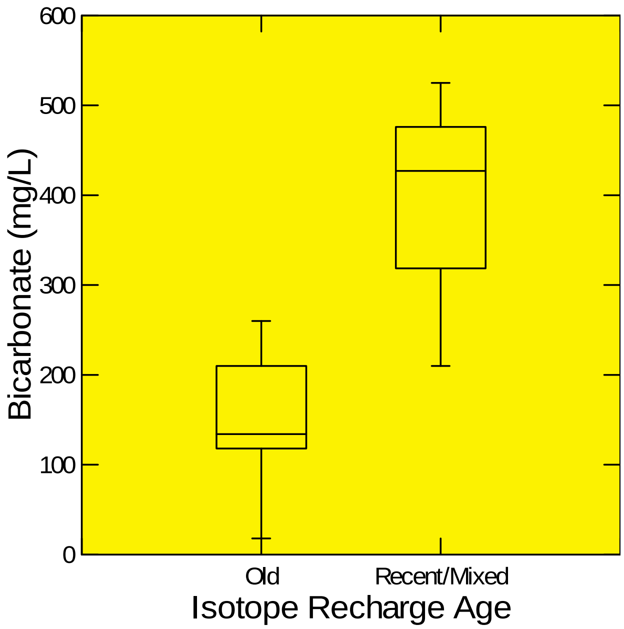


Diagram 7 – Sample sites with recent and/or mixed recharge have significantly higher bicarbonate concentrations than sample sites derived from "old recharge" group. (Kruskal-Wallis, $p \leq 0.05$). Elevated bicarbonate concentrations are often associated with recharge areas. [19] This is another indication that this groundwater is of a more recent origin than other downgradient sampled wells in the Butler Valley basin.

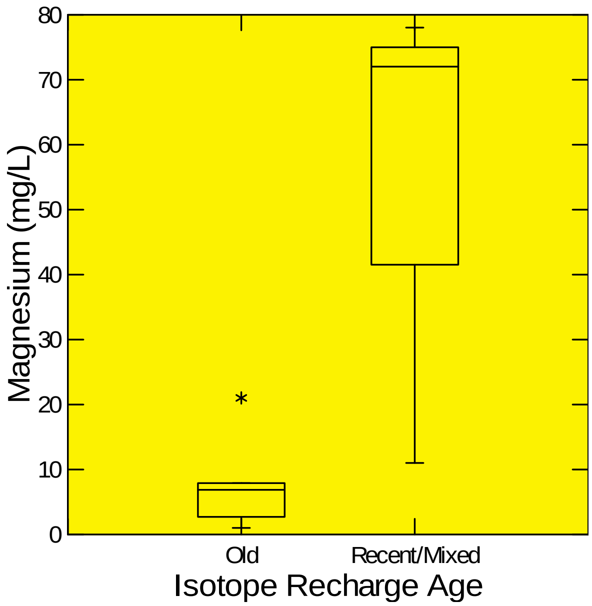


Diagram 8 – Sample sites with recent and/or mixed recharge have significantly higher magnesium concentrations than sample sites derived from "old recharge" group. (Kruskal-Wallis, $p \leq 0.05$). Elevated magnesium concentrations are often associated with recharge areas. [19]

Table 7. Variation in Constituent Concentrations between Two Recharge Groups Using Kruskal Wallis Test

Constituent	Significance	Significant Differences Among Recharge Sources
Well Depth	ns	-
GW Depth	ns	-
Temperature - field	ns	-
pH – field	ns	-
pH – lab	ns	-
SC - field	ns	-
SC - lab	ns	-
TDS	ns	-
Turbidity	ns	-
Hardness	ns	-
Calcium	ns	-
Magnesium	*	Recent / Mixed > Old
Sodium	ns	-
Potassium	ns	-
Bicarbonate	*	Recent / Mixed > Old
Chloride	ns	-
Sulfate	ns	-
Nitrate (as N)	ns	-
Arsenic	ns	-
Barium	ns	-
Copper	*	Recent / Mixed > Old
Fluoride	ns	-
Strontium	ns	-
Oxygen	*	Recent / Mixed > Old
Deuterium	*	Recent / Mixed > Old

ns = not significant
* = significant at $p \leq 0.05$ or 95% confidence level
** = significant at $p \leq 0.01$ or 99% confidence level

Table 8. Summary Statistics for Two Recharge Groups with Significant Constituent Differences Using Kruskal-Wallis Test and 95 Percent Confidence Intervals

Constituent	Significance	Recent / Mixed	Old
Well Depth	ns	-	-
GW Depth	ns	-	-
Temperature - field	ns	-	-
pH – field	ns	-	-
pH – lab	ns	-	-
SC - field	ns	-	-
SC - lab	ns	-	-
TDS	ns	-	-
Turbidity	ns	-	-
Hardness	ns	-	-
Calcium	ns	-	-
Magnesium	*	-38 to 146	0 to 15
Sodium	ns	-	-
Potassium	ns	-	-
Bicarbonate	*	-13 to 787	58 to 233
Chloride	ns	-	-
Sulfate	ns	-	-
Nitrate (as N)	ns	-	-
Arsenic	ns	-	-
Barium	ns	-	-
Copper	*	-0.011 to 0.025	0.002 to 0.003
Fluoride	ns	-	-
Strontium	ns	-	-
Oxygen	*	-5.6 to -11.1	-10.3 to -10.8
Deuterium	*	-46.2 to -74.6	-71.3 to -77.7

ns = not significant
* = significant at $p \leq 0.05$ or 95% confidence level
** = significant at $p \leq 0.01$ or 99% confidence level
All units are in mg/L except temperature (degrees Celsius) and SC (uS/cm).

Between Two Geologic Types - Twenty-five (25) groundwater quality constituents were compared between two geologic types: hard rock (3 sites) and alluvium (6 sites). [28]

Significant concentration differences were found with five constituents: temperature (Diagram 9), hardness (Diagram 10), calcium, magnesium, and bicarbonate (Kruskal-Wallis test, $p \leq 0.05$).

Complete statistical results are in Table 9 and 95 percent confidence intervals for significantly different groups based on isotope recharge ages are in Table 10.

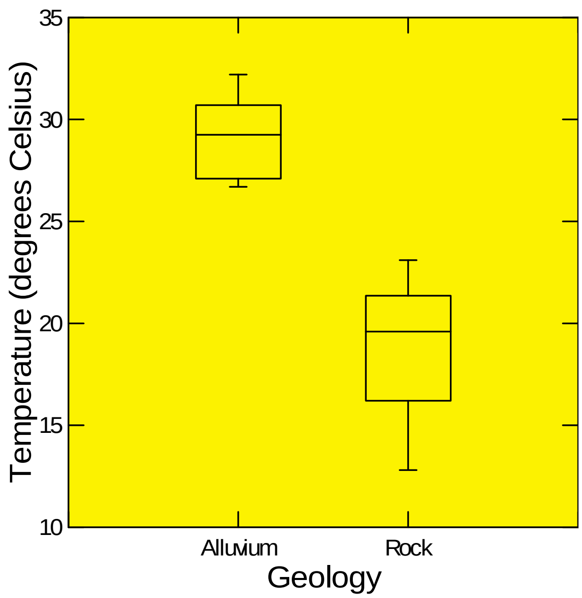


Diagram 9 – Samples collected from wells in valley alluvium have significantly higher temperatures than samples collected from wells drilled in hard rock (Kruskal-Wallis test, $p \leq 0.05$). Wells drilled in the alluvium of Butler Valley extend up to over 1,000 feet in depth while those drilled in the hard rock of the surrounding mountains are generally much shallower.[4] Groundwater temperature increases with depth, approximately 3 degrees Celsius with every 100 meters or 328 feet. [12] Thus, it is not unexpected that there are significantly higher temperatures of samples collected from the valley alluvium.

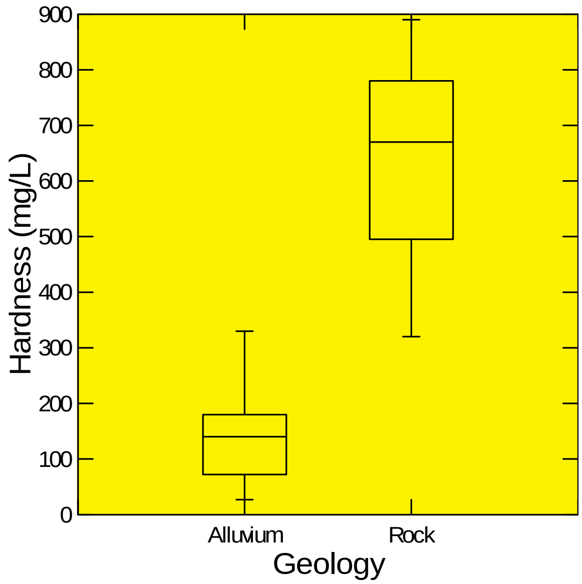


Diagram 10 – Samples collected from wells located in hard rock locations have significantly higher hardness concentrations than wells located in valley alluvium (Kruskal-Wallis, $p \leq 0.05$). Elevated hardness concentrations are often associated with recharge areas and the hard rock sample sites are located in upgradient portions of the Butler Valley basin. [19] In downgradient areas, sodium becomes the dominant cation as the groundwater softens.

Table 9. Variation in Groundwater Quality Constituent Concentrations Between Two Geologic Types Using Kruskal Wallis Test

Constituent	Significance	Significant Differences Between Geologic Types
Well Depth	ns	-
GW Depth	ns	-
Temperature - field	*	Alluvium > Rock
pH – field	ns	-
pH – lab	ns	-
SC - field	ns	-
SC - lab	ns	-
TDS	ns	-
Turbidity	ns	-
Hardness	*	Rock > Alluvium
Calcium	*	Rock > Alluvium
Magnesium	*	Rock > Alluvium
Sodium	ns	-
Potassium	ns	-
Bicarbonate	*	Rock > Alluvium
Chloride	ns	-
Sulfate	ns	-
Nitrate (as N)	ns	-
Arsenic	ns	-
Barium	ns	-
Copper	ns	-
Fluoride	ns	-
Strontium	ns	-
Oxygen	ns	-
Deuterium	ns	-

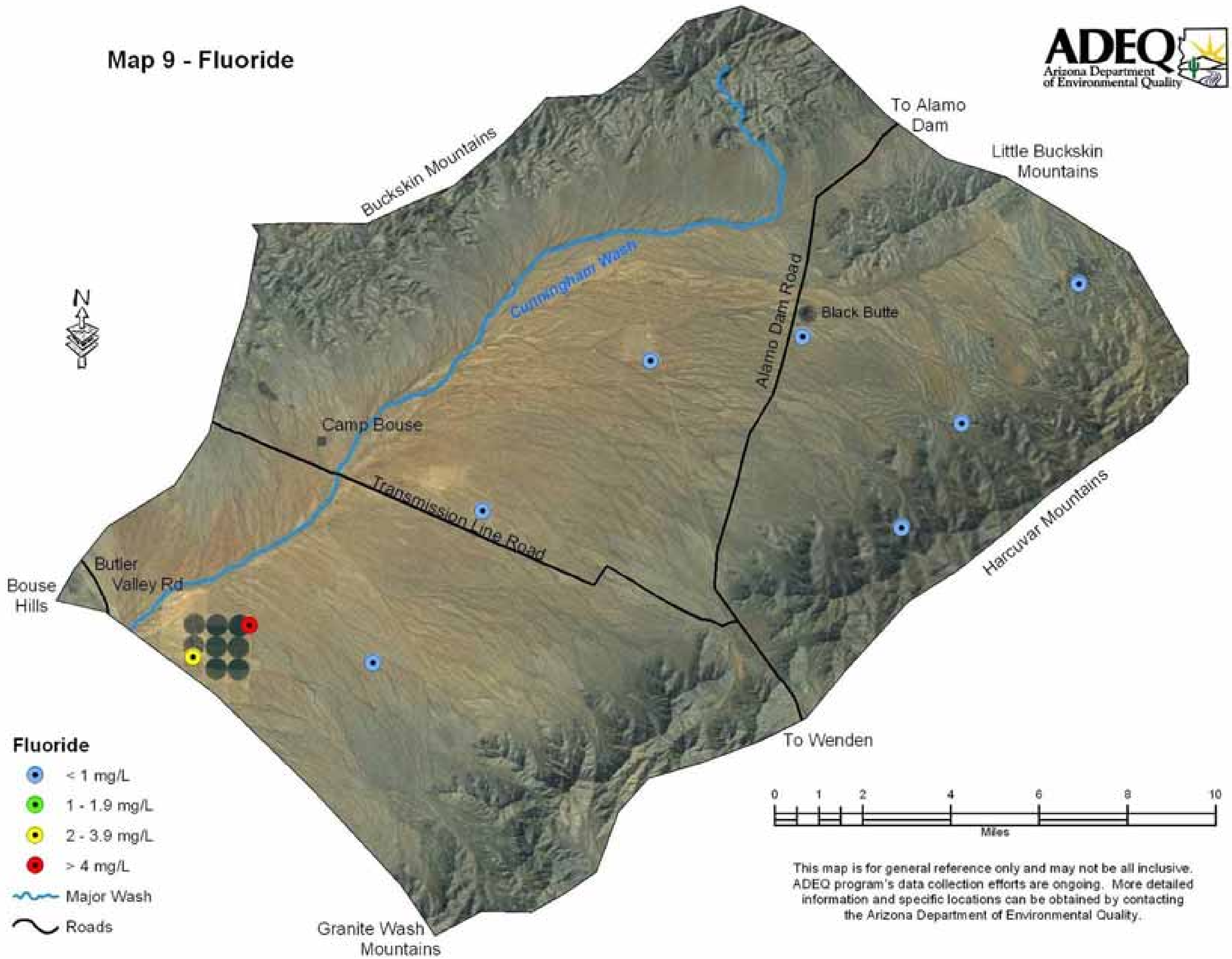
ns = not significant
* = significant at $p \leq 0.05$ or 95% confidence level
** = significant at $p \leq 0.01$ or 99% confidence level

Table 10. Summary Statistics for Two Geologic Types with Significant Constituent Differences Using Kruskal-Wallis Test and 95 Percent Confidence Intervals

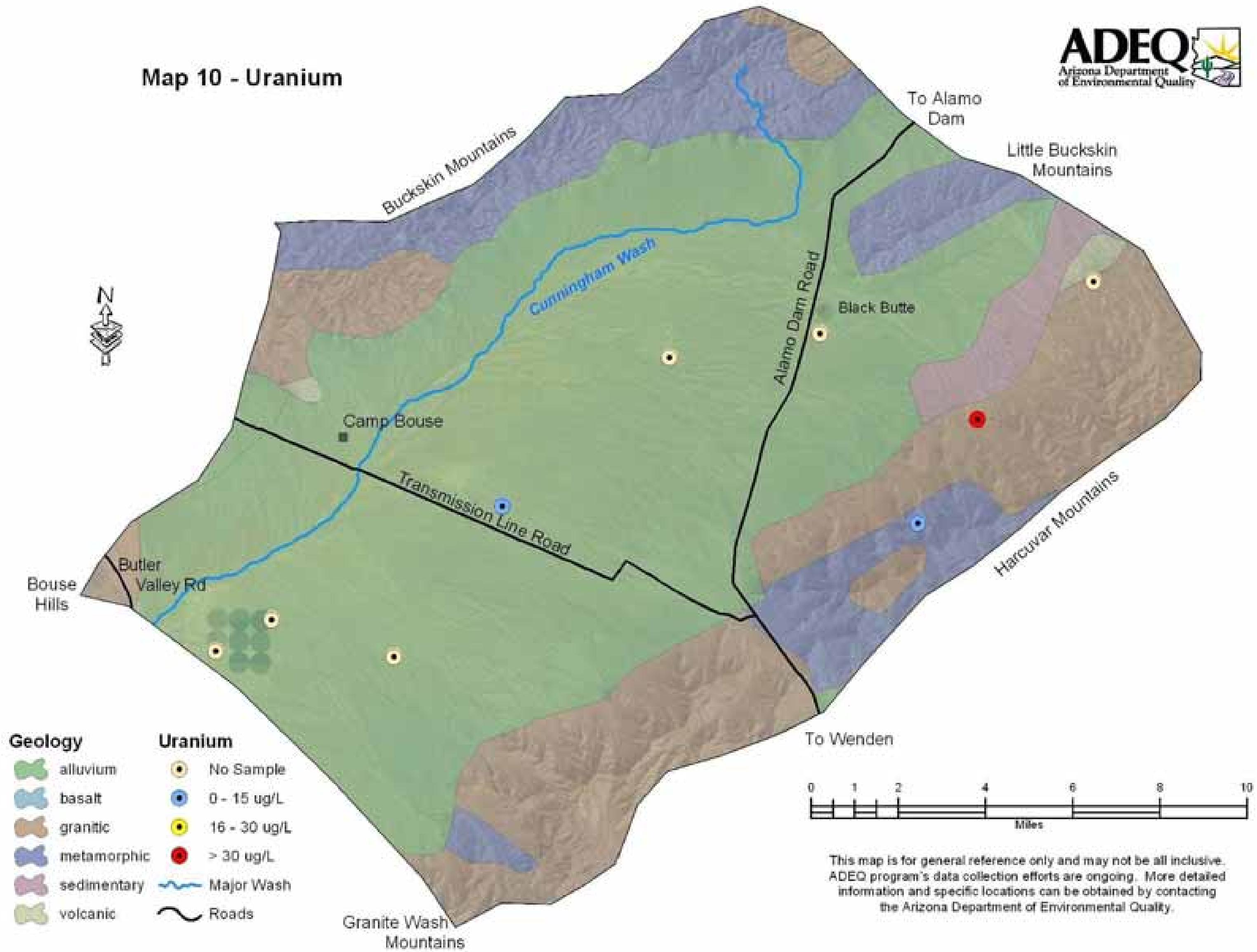
Constituent	Significance	Recent / Mixed	Old
Well Depth	ns	-	-
GW Depth	ns	-	-
Temperature - field	*	5.5 to 31.5	27.0 to 31.4
pH – field	ns	-	-
pH – lab	ns	-	-
SC - field	ns	-	-
SC - lab	ns	-	-
TDS	ns	-	-
Turbidity	ns	-	-
Hardness	*	-87 to 1341	38 to 258
Calcium	*	-13 to 329	9 to 90
Magnesium	*	-21 to 135	2 to 10
Sodium	ns	-	-
Potassium	ns	-	-
Bicarbonate	*	71 to 737	62 to 212
Chloride	ns	-	-
Sulfate	ns	-	-
Nitrate (as N)	ns	-	-
Arsenic	ns	-	-
Barium	ns	-	-
Copper	ns	-	-
Fluoride	ns	-	-
Strontium	ns	-	-
Oxygen	ns	-	-
Deuterium	ns	-	-

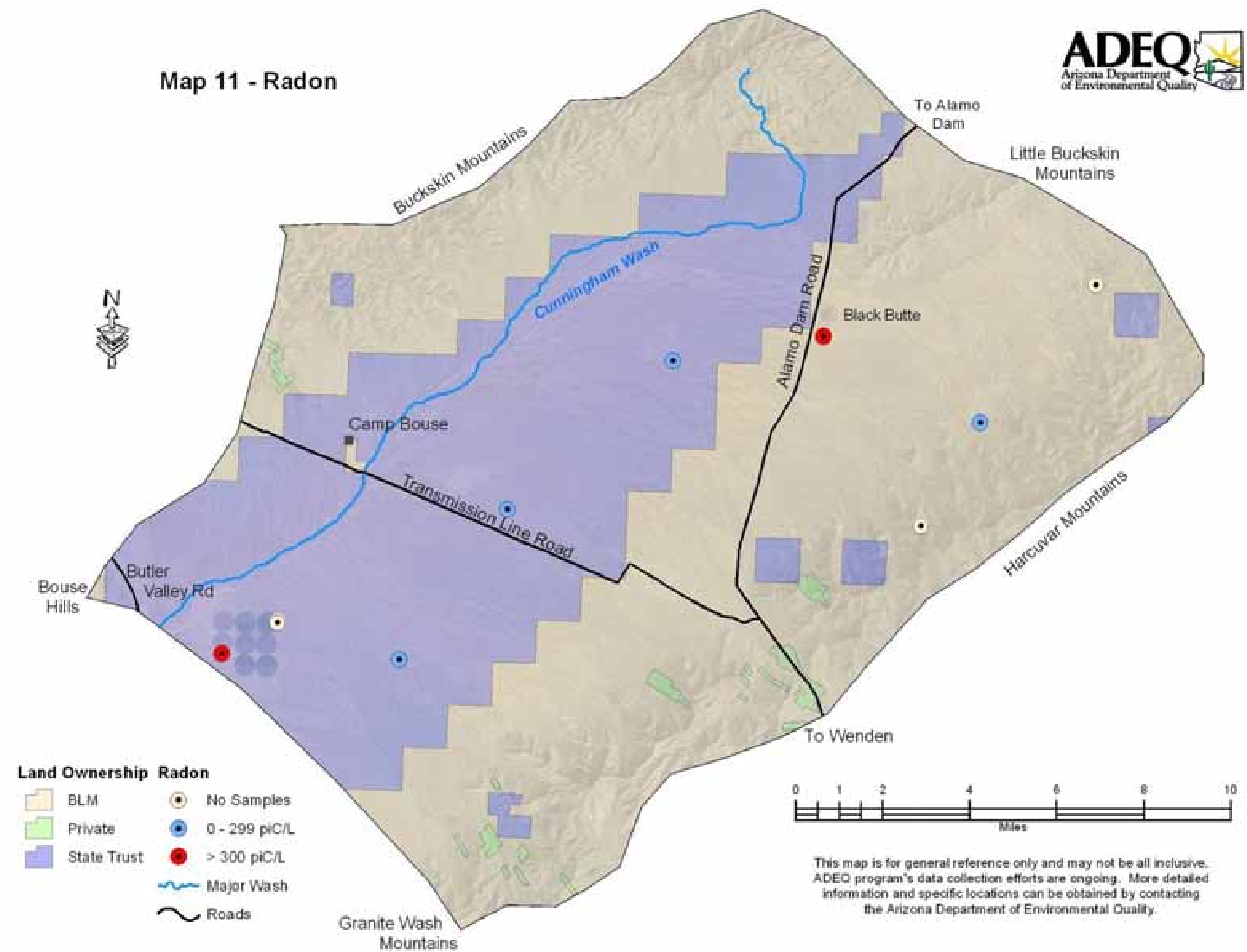
ns = not significant
* = significant at $p \leq 0.05$ or 95% confidence level
** = significant at $p \leq 0.01$ or 99% confidence level
All units are in mg/L except temperature (degrees Celsius) and SC (uS/cm).

Map 9 - Fluoride



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 10 - Uranium
ADEQ
Arizona Department of Environmental Quality
To Alamo Dam
Little Buckskin Mountains
Buckskin Mountains
Cunningham Wash
Alamo Dam Road
Black Butte
Camp Bouse
Transmission Line Road
Harcuvar Mountains
Butler Valley Rd
Bouse Hills
To Wenden
Granite Wash Mountains
N
Geology
alluvium
basalt
granitic
metamorphic
sedimentary
volcanic
Uranium
No Sample
0 - 15 ug/L
16 - 30 ug/L
> 30 ug/L
Major Wash
Roads
0
1
2
4
6
8
10
Miles
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 11 - Radon
ADEQ
Arizona Department of Environmental Quality
Buckskin Mountains
To Alamo Dam
Little Buckskin Mountains
Cunningham Wash
Alamo Dam Road
Black Butte
Camp Bouse
Transmission Line Road
Harcuvar Mountains
Bouse Hills
Butler Valley Rd
To Wenden
Granite Wash Mountains
Land Ownership
BLM
Private
State Trust
Radon
No Samples
0 - 299 piC/L
> 300 piC/L
Major Wash
Roads
0 1 2 4 6 8 10
Miles
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

Butler Valley is a small, remote groundwater basin located in western Arizona. The basin consists almost entirely of BLM and State Trust land; less than one percent is in private ownership (Map 11). [3] Only approximately a dozen people reside in Butler Valley. [4] Most of the basin is used for low-intensity livestock grazing except for irrigated agriculture which occurs at Butler Valley Farm near the basin's southwest boundary where subflow enters the Ranegras Plain basin.

Except at Butler Valley Farm, groundwater development has been minimal in the basin. Two of the farm's approximately ten irrigation wells were sampled. In other areas of the basin, all operational wells and flowing springs were sampled yet this consisted of just six wells and one spring.

Six groundwater samples were collected from wells located in the alluvium of Butler Valley; three other samples were collected from sources in the Harcuvar Mountains. No samples were able to be collected from the large portions of the basin in or near the Buckskin Mountains to the north. Despite collecting few samples, the study was still able to make some limited characterizations concerning groundwater quality in the basin. However, these conclusions are of a limited nature as large portions of the basin went unsampled.

Six sites, particularly wells located in the valley alluvium, consist of "old" paleowater predominantly recharged 8,000 – 12,000 years ago when the basin's climate was much cooler and subject to less evaporation. [9] Samples from these sites generally exhibit sodium chemistry and meet most water quality standards. However, constituents such as TDS, chloride, sulfate, and fluoride occasionally exceeded aesthetics standards at these sites. The elevated constituent concentrations appear to be predominantly naturally occurring. Long aquifer residence time of groundwater is likely a major factor in elevating these constituents over water quality standards. [19]

Fluoride was the only constituent that exceeded a health-based standard at these sites. In one sample, the fluoride concentration of 5.0 mg/L exceeded the 4.0 mg/L Primary MCL (Map 9). This elevated fluoride concentration is 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. [19]

The remaining three sample sites in the basin were higher on the precipitation trajectory and appear to consist of recent recharge and/or a mixture of recent and old recharge. These sites are located in or near to the Harcuvar Mountains. These sites generally do not have a dominant chemistry and frequently exceed water quality standards for TDS, chloride, and sulfate. In addition, one radionuclide sample collected from a well located drilled in the granitic rock of the Harcuvar Mountains exceeded the health based water quality standard for uranium (Map 10). Radionuclide concentrations are often elevated in groundwater residing in granitic geology. [30]

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Appendix A. Data for Sample Sites, Butler Valley Basin, 2008 - 2012

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Geology / Recharge Age
1st Field Trip, August 19-20, 2008 – Towne (Equipment Blank - MMU-115)									
BUT-1	B(8-12)6bda submersible	34°04'06.69" 113°33'01.41"	633306	19366	HQ Well	Inorganic, Radiochem Radon, Isotopes	830'	-	Alluvium Mixed
BUT-2	B(8-13)4ddd submersible	34°03'33.45" 113°36'37.03"	614575	19369	Upper State Well	Inorganic Radon, Isotopes	1200'	410'	Alluvium Old
2nd Field Trip, February 28, 2011 – Towne									
BUT-3	B(8-12)28dac spring	34°00'22.548" 113°30'33.959"	-	76801	Dripping Springs	Inorganic Radiochem, Isotopes	-	-	Metamorphic Old
3rd Field Trip, January 18, 2012 – Towne & Determann									
BUT-4	B(7-15)11ddd turbine	33°57'28.013" 113°47'16.601"	614540	19112	BV Farm Shop Well	Inorganic Radon, Isotopes	500'	170'	Alluvium Old
BUT-5	B(7-15)12aad turbine	33°58'06.685" 113°45'58.174"	614541	19115	BV Farm Well #1	Inorganic Isotopes	500'	200'	Alluvium Old
BUT-6	B(9-11)30ab submersible	34°05'16.582" 113°26'30.911"	633309	19522	Burnt Well	Inorganic Isotopes	65'	50'	Granitic Recent
BUT-7	B(8-12)14bcb submersible	34°02'27.609" 113°29'12.900"	801558	77701	Hangman's Well	Inorganic, Radiochem Radon, Isotopes	-	-	Granitic Mixed
4th Field Trip, January 23, 2012 – Towne & Boettcher									
BUT-9	B(7-14)16aaa submersible	33°57'25.798" 113°43'00.568"	614534	19105	Jug Head Well	Inorganic Radon, Isotopes	280'	230'	Alluvium Old
BUT-10	B(8-14)25bdc submersible	34°00'30.520" 113°40'30.889"	614583	19381	HQ Well	Inorganic, Radiochem Radon, Isotopes	320'	270'	Alluvium Old

Appendix B. Groundwater Quality Data, Butler Valley Basin, 2008 - 2012

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)
BUT-1		32.2	7.74	*8.1*	573	540	350	140	140	*1.2*
BUT-2		30.7	7.58	8.1	633	600	370	160	140	0.18
BUT-3	TDS	12.8	7.73	*8.26*	808	830	**520**	-	320	3.3
BUT-4	F	26.7	8.00	*8.10*	747	720	410	-	72	ND
BUT-5	**F**	28.7	8.34	8.36	647	620	370	-	27	ND
BUT-6	TDS, Cl, SO_4, Mn	19.6	7.46	*7.74*	3562	3500	**2100**	-	670	ND
BUT-7	TDS, Cl, SO_4 U	23.1	7.05	***7.37***	2700	2600	**1800**	-	890	18
BUT-9	TDS,	27.1	7.68	7.67	927	850	**560**	-	180	17
BUT-10	TDS, Cl, SO_4	29.8	7.87	*7.62*	1721	1600	**1100**	-	330	13

italics = constituent exceeded holding time

bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Butler Valley Basin, 2008 - 2012---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)
BUT-1	38	11	56	2.3	170	210	ND	42	35
BUT-2	45	7.9	55	3.1	170	210	ND	63	27
BUT-3	93	21	41	3.8	210	260	ND	82	96
BUT-4	24	2.7	110	4.4	100	122	ND	110	75
BUT-5	11	ND	120	2.9	97	118	ND	65	98
BUT-6	150	72	500	7.0	430	525	ND	**800**	**400**
BUT-7	230	78	250	4.3	350	427	ND	**380**	**670**
BUT-9	60	7.1	98	4.8	120	146	ND	180	49
BUT-10	120	6.6	200	9.1	15	18	ND	**340**	**330**

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

Appendix B. Groundwater Quality Data, Butler Valley Basin, 2008 - 2012---Continued

Site #	Nitrate-N (mg/L)	δ^{15}N ($^0/_{00}$)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	T. Phos (mg/L)	SAR (value)	Irrigation Quality	Aluminum (mg/L)	Strontium (mg/L)
BUT-1	1.5	-	ND	0.39	ND	0.064	2.1	C2-S1	-	-
BUT-2	3.1	-	ND	0.23	ND	0.044	2.0	C2-S1	-	-
BUT-3	2.3	-	ND	ND	0.11	ND	1.0	C3-S1	ND	0.58
BUT-4	3.3	2.7	ND	ND	ND	ND	5.7	C2-S1	ND	1.2
BUT-5	3.5	3.0	ND	ND	ND	ND	9.3	C2-S2	ND	0.66
BUT-6	0.26	0.0	ND	ND	ND	0.14	8.4	C4-S2	ND	1.9
BUT-7	1.0	-0.2	ND	ND	ND	ND	3.6	C4-S2	ND	1.5
BUT-9	2.5	1.9	ND	ND	ND	ND	3.2	C3-S1	ND	1.5
BUT-10	ND	-0.5	ND	ND	ND	ND	4.8	C3-S1	ND	6.0

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

Appendix B. Groundwater Quality Data, Butler Valley Basin, 2008 - 2012---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)
BUT-1	ND	0.0058	0.090	ND	0.14	ND	ND	ND	0.63
BUT-2	ND	ND	0.10	ND	ND	ND	ND	ND	0.14
BUT-3	ND	0.0015	0.059	ND	ND	ND	0.0014	0.0026	ND
BUT-4	ND	0.0036	0.080	ND	ND	ND	0.026	0.0022	**2.1**
BUT-5	ND	0.0076	0.052	ND	0.23	ND	0.043	0.0022	**5.0**
BUT-6	ND	0.0028	0.057	ND	0.90	ND	ND	0.0085	0.86
BUT-7	ND	0.0016	0.022	ND	0.46	ND	ND	0.0057	0.93
BUT-9	ND	ND	0.068	ND	ND	ND	ND	0.0020	ND
BUT-10	ND	ND	0.032	ND	ND	ND	ND	0.0031	0.53

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

Appendix B. Groundwater Quality Data, Butler Valley Basin, 2008 - 2012---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)
BUT-1	ND	ND	ND	ND	ND	ND	ND	ND	0.17
BUT-2	ND	ND	ND	ND	ND	ND	ND	ND	0.12
BUT-3	ND	ND	ND	ND	ND	0.0060	ND	ND	ND
BUT-4	ND	ND	ND	ND	ND	ND	ND	ND	ND
BUT-5	ND	ND	ND	ND	ND	ND	ND	ND	ND
BUT-6	ND	ND	**0.10**	ND	ND	0.0069	ND	ND	ND
BUT-7	ND	ND	ND	ND	ND	0.022	ND	ND	0.22
BUT-9	ND	ND	0.012	ND	ND	0.0029	ND	ND	0.24
BUT-10	ND	ND	0.025	ND	ND	ND	ND	ND	ND

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

Appendix B. Groundwater Quality Data, Butler Valley Basin, 2008 - 2012---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
BUT-1	518	-	-	-	-	- 8.8	- 62	mixed-bicarbonate
BUT-2	110	-	-	-	-	- 10.5	- 76	mixed-bicarbonate
BUT-3	-	ND	-	ND	5.3	-10.3	-69	calcium-bicarbonate
BUT-4	718	-	-	-	-	-10.6	-75	sodium-mixed
BUT-5	-	-	-	-	-	-10.7	-77	sodium-mixed
BUT-6	-	-	-	-	-	-7.1	-54	sodium-chloride
BUT-7	181	3.9	ND	ND	**59.1**	-9.2	-65	mixed-mixed
BUT-9	262	-	-	-	-	-10.2	-73	sodium-chloride
BUT-10	ND	2.2	ND	ND	ND	-10.8	-77	sodium-chloride

LLD = Lower Limit of Detection
italics = constituent exceeded holding time
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level