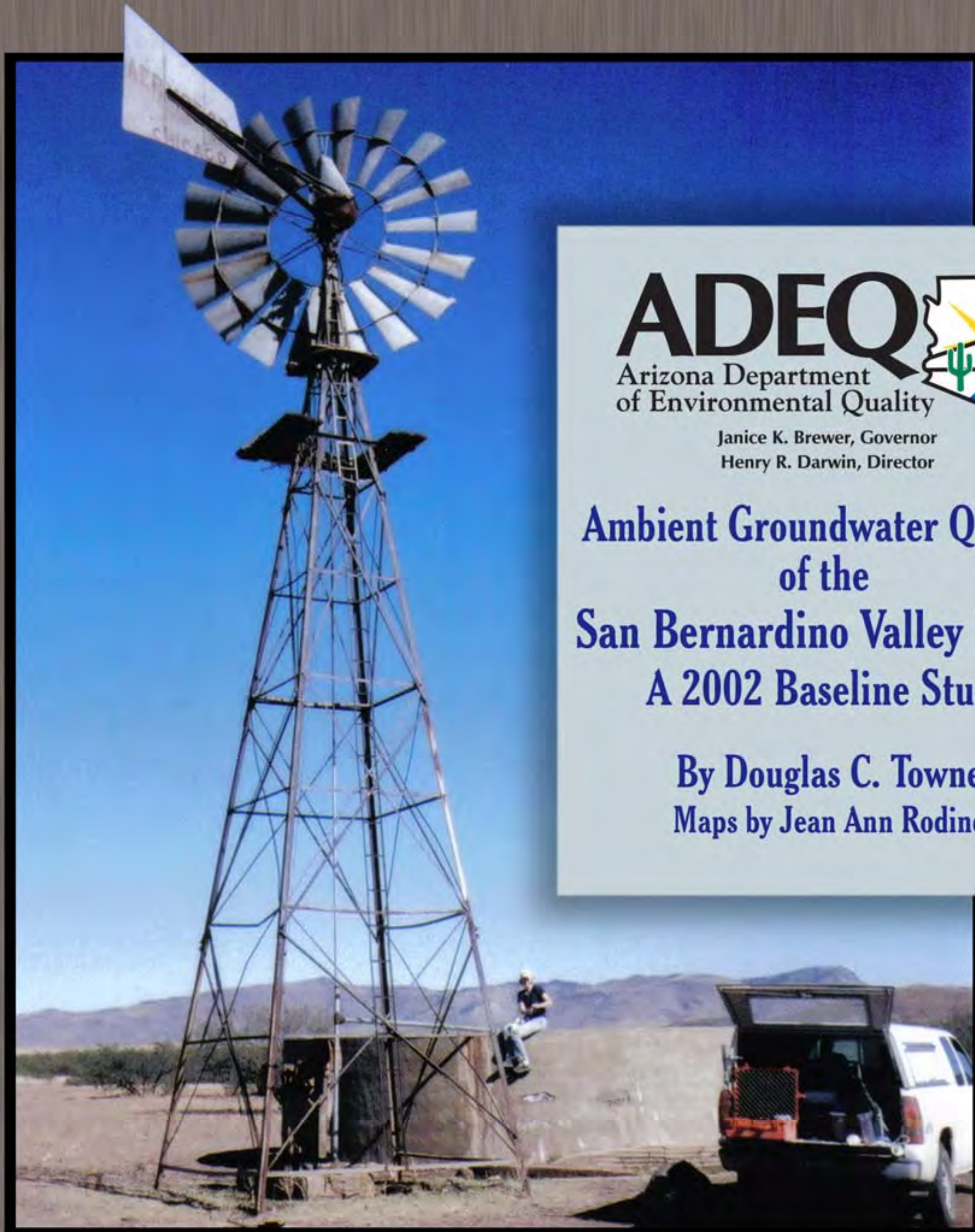


ADEQ
Arizona Department of Environmental Quality

Janice K. Brewer, Governor
Henry R. Darwin, Director

Ambient Groundwater Quality of the San Bernardino Valley Basin: A 2002 Baseline Study

By Douglas C. Towne
Maps by Jean Ann Rodine

Arizona Department of Environmental Quality
ADEQ Water Quality Division
Surface Water Section
Monitoring Unit
1110 West Washington St.
Phoenix, Arizona 85007-2935
Open File Report 2010 - OFR 10-03

Ambient Groundwater Quality of the San Bernardino Valley Basin: A 2002 Baseline Study

By Douglas C. Towne
Maps by Jean Ann Rodine

Arizona Department of Environmental Quality
Open File Report 10-03

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

Thanks:

Field Assistance:	Elizabeth Boettcher and Angela Lucci. Special recognition is extended to the well owners who were kind enough to give permission to collect groundwater data on their property.
Report Cover:	ADEQ's Elizabeth Boettcher collects a sample (SBV-14) from a windmill pumping water into a tank that supplies a series of drinking troughs for livestock and wildlife. The windmill is located north of Wildcat Hill about a half mile east of Black Draw in the San Bernardino Valley basin.

Other Publications of the ADEQ Ambient Groundwater Monitoring Program

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

Dripping Springs Wash Basin	OFR 10-02, August 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 U.S. Geological Survey)
Prescott Active Management Area	OFR 00-01, May 2000, 77 p.
Upper San Pedro Basin	OFR 99-12, July 1999, 50 p. (With the U.S. Geological Survey)
Douglas Basin	OFR 99-11, June 1999, 155 p.
Virgin River Basin	OFR 99-04, March 1999, 98 p.
Yuma Basin	OFR 98-07, September, 1997, 121 p.

ADEQ Ambient Groundwater Quality Fact sheets (FS):

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 U.S. Geological Survey)

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

ADEQ Ambient Groundwater Monitoring Program Studies

July 2010

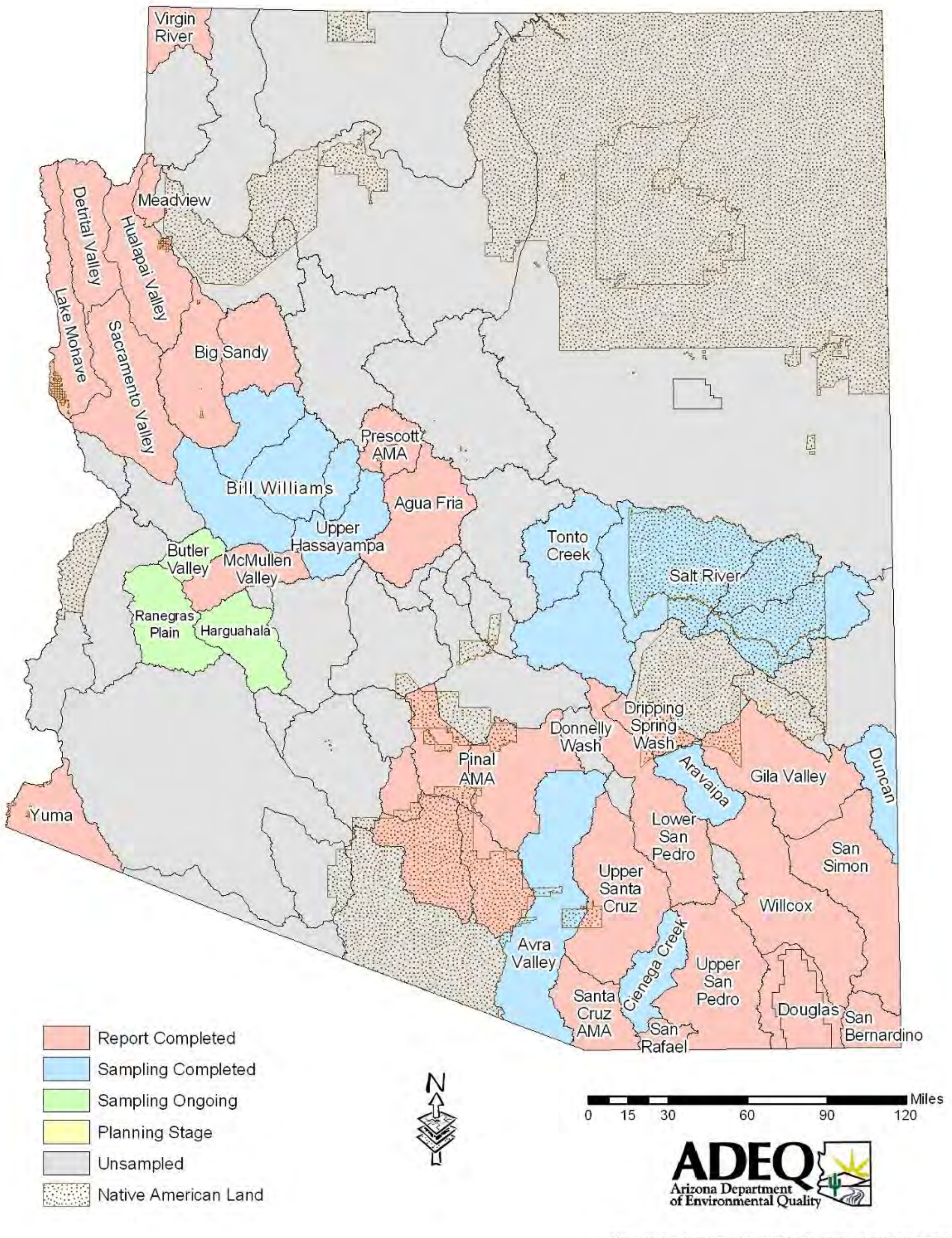


Table of Contents

Maps

Tables

Figures

Diagrams

Abbreviations

amsl	above mean sea level
ac-ft	acre-feet
ac-ft/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
^{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
SBV	San Bernardino Valley basin
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 San Bernardino Valley Basin: A 2002 Baseline Study

Abstract - In 2002, the Arizona Department of Environmental Quality (ADEQ) conducted a baseline groundwater quality study of the San Bernardino Valley basin located within Cochise County in the southeastern corner of Arizona. The basin is, north-to-south, 21 miles long and is a gently sloping valley between low elevation mountain ranges. [21] The basin covers 387 square miles in Arizona and is bounded by the Pedregosa and Perilla Mountains on the west, the Peloncillo Mountains on the east, and the International border with Mexico to the south. The northern border with the San Simon sub-basin is a gentle, poorly defined boundary that is adjacent to the high elevation Chiricahua Mountains. [17] The basin has both interstate and international aquifer components, encompassing 35 square miles to the east in New Mexico, and about 400 square miles to the south in Sonora, Mexico. [17]

Besides sharing an aquifer with an adjacent state and country, the basin's groundwater resources are also important to local ranchers and other residents located in scattered locations. Although there are no incorporated communities in the basin, groundwater is the primary source for domestic and stock use. [15, 17] Black Draw is the major drainage in the basin and is ephemeral except near the international border where springs and artesian wells supply ponds that provide habitat for endangered native fish at the San Bernardino National Wildlife Refuge.[17]

Volcanic flows and cinder cones cover much of the valley floor. Most groundwater in the basin is obtained from thin units of sand and gravel inter-bedded with basalt flows or from shallow alluvium. [17] Thick deposits of alluvium are generally not present in the basin. Groundwater flow is generally from the mountains toward the central part of the valley and then south towards Mexico. [15] Most of the 100 acre-feet of groundwater annually pumped is used for domestic and stock purposes. [21]

To characterize regional groundwater quality, samples were collected from 14 sites consisting of domestic and stock wells located throughout the basin. Inorganic constituents and oxygen and deuterium isotopes were collected at 14 sites; at 13 sites radon samples were also collected. The data indicate that groundwater in the San Bernardino Valley basin meets drinking water quality standards and is suitable for domestic, municipal, stock and irrigation purposes.[23]

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 not exceeded at any of the 14 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 7 of the 14 sites. Of the 13 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. Six sites exceeded the proposed 300 pCi/L standard that would apply if Arizona doesn't develop a multimedia program. [23]

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] Most samples consisted of calcium, mixed or sodium-bicarbonate chemistry. Nutrient concentrations were low. Fluoride and zinc were the only trace elements commonly detected.

Isotope values of samples were lighter and more depleted than would be expected from recharge originating at the basin's low elevations. Most samples appear to consist of recharge originating high in the cool Chiricahua Mountains which indicates that the northern boundary of the basin is likely more of a surface water divide than a groundwater demarcation. [10, 22] Some shallow wells have slightly enriched isotope values that indicate a limited amount of recharge occurs locally from low elevation mountains or alluvial channels in the San Bernardino Valley.[10] Samples from some deep wells have isotope values so depleted that they likely consist of paleowater predominantly recharged 8,000-12,000 years ago when the basin was cooler and subject to much less evaporation. [10, 27]

Generally, wells pumping paleowater and Chiricahua Mountain recharge were significantly deeper than wells pumping water that included low elevation recharge. With most constituents however, concentrations are highest in the paleowater and lowest in the Chiricahua Mountain recharge, but only total dissolved solids, specific conductivity, sodium and fluoride concentrations were significantly different (Kruskal-Wallis with Tukey test, $p \leq 0.05$). These four constituents are often elevated in groundwater having a long aquifer residence time. [20]

INTRODUCTION

Purpose and Scope

The San Bernardino Valley groundwater basin encompasses approximately 387 square miles within Cochise County in the extreme southeast corner of Arizona (Map 1). [21] The basin also includes about 35 square miles in New Mexico and about 400 square miles in Mexico. [17, 21] The basin is lightly populated and there are no incorporated towns located within its boundaries. Arizona Highway 80 runs through the basin providing access to scattered ranches and domestic residences.

Groundwater is the primary source for domestic and stock water supply within the basin. [4] In addition, groundwater discharge through springs and artesian wells provides habitat for several species of threatened and endangered fish, including the Yaqui shiner, Yaqui chub, Yaqui catfish, and Yaqui topminnow in the 2,309-acre San Bernardino National Wildlife Refuge. [17]

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 San Bernardino Valley basin identifying areas with impaired conditions and water quality variations between groundwater of different origins.

- A process for evaluating potential groundwater quality impacts arising from a variety of sources including mineralization, mining, 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

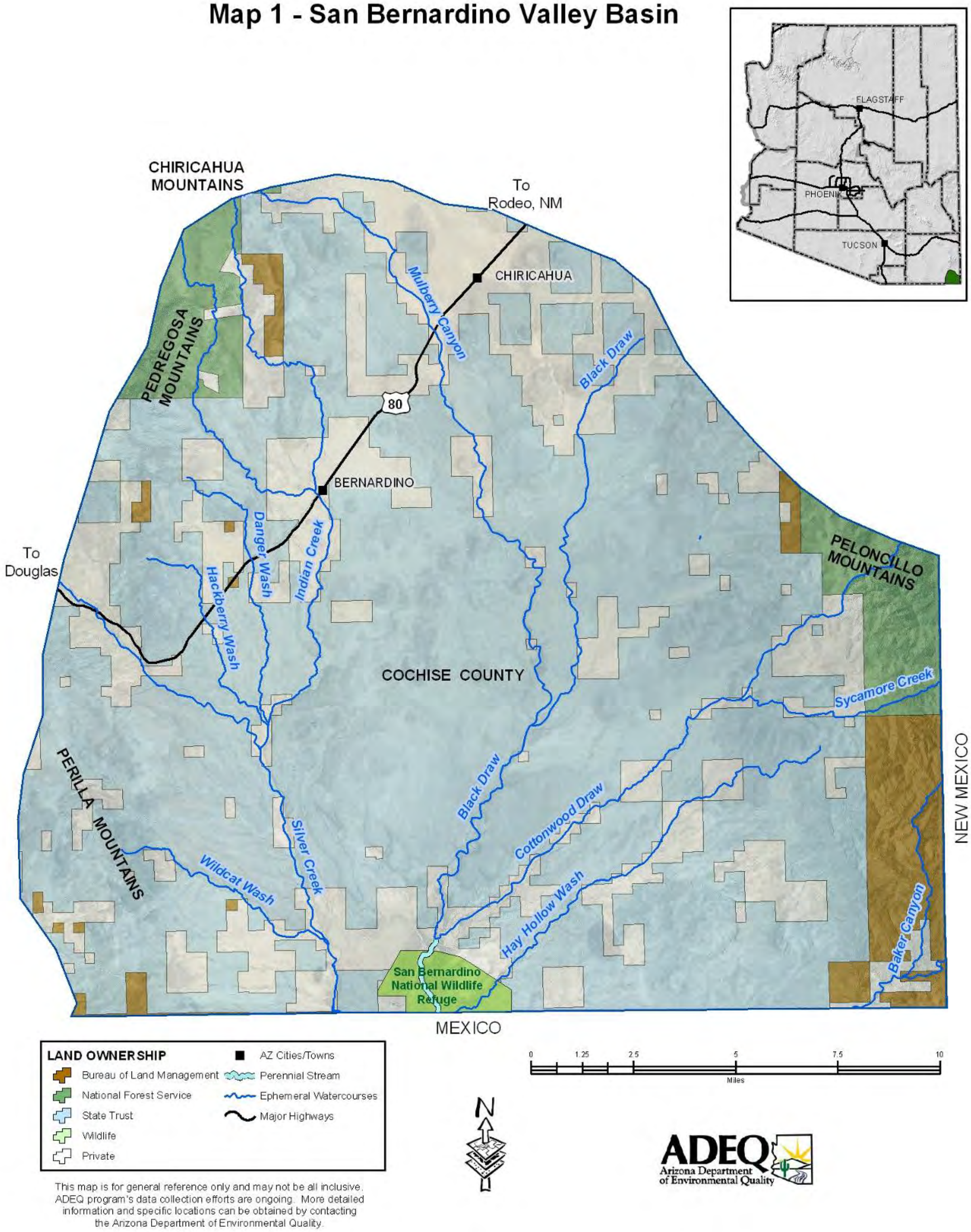
Geography – The San Bernardino Valley basin is an elongated structural basin in the Basin and Range physiographic province and is bordered by north-south trending, low elevation mountain ranges. The basin is approximately 21 miles long from the north to south in Arizona and 18 miles wide at the international border and extends south into Mexico. [21]

The basin is bounded on the south by the international border with Mexico, on the east by the southern Peloncillo Mountains (sometimes referred to as the Guadalupe Mountains), and on the west by the Perilla and Pedregosa Mountains.[21] The northern portion of the basin is not bounded by a mountain range, but by a poorly defined flow divide at the south edge of the San Simon Valley sub-basin. (Figure 1). [17] The exact delineation of the boundary between the San Bernardino and San Simon valleys is a matter of great subjectivity, as hydrologic reports are not consistent in its location. [10] Beyond the basin boundary to the northwest are the high elevation Chiricahua Mountains. Elevations range from 6,410 feet above mean sea level (amsl) in the Pedregosa Mountains to 3,715 feet amsl at Black Draw at the International Boundary.[21] In comparison, the Chiricahua Peak has an elevation of 9,751 feet amsl.

The San Bernardino Valley basin predominantly consists of State Trust lands; interspersed are scattered parcels of private land. Areas managed by the U.S. Forest Service and Bureau of Land Management are found in the highest elevations of the Peloncillo Mountains to the east and the Pedregosa Mountains to the northwest. [3]

Established in 1982, the San Bernardino National Wildlife Refuge is located in the center of the valley along the international border and has long been a historic source of water for travelers. Once a part of the 73,240 acre San Bernardino Land Grant created in 1822 by the Mexican government, approximately a quarter of it was annexed to the U.S. under the Gadsden Purchase. John Slaughter, Cochise County sheriff and rancher, purchased the land grant in 1884 and his San Bernardino ranch is now a museum located just west of the refuge. [21]

Map 1 - San Bernardino Valley Basin



The primary vegetation type in the San Bernardino Valley is Chihuahuan desert scrub, consisting primarily of white-thorn acacia, creosote bush, and tarbush. At higher elevations grow oak, juniper, and pinyon trees. [17] On the San Bernardino National Wildlife Refuge, a mesquite bosque is present, with mesquite, hackberry, and catclaw as the predominant species. Along Black Draw within the refuge, there is a riparian/aquatic assemblage, with cattails along with cottonwood and black willow trees. [15]

Climate – The semi-arid climate of the San Bernardino Valley basin is characterized by hot summers and mild winters. 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. Annual precipitation amounts increase with elevation, ranging from 8 to 16 cm precipitation per year. In the nearby Chiricahua Mountains, annual precipitation averages 36 cm. [10]

Geology – The mountain ranges surrounding the San Bernardino Valley basin are composed primarily of Cretaceous and Tertiary intermediate and silicic volcanics. Outcrops of Cretaceous and Paleozoic sedimentary rocks occur in the Perilla Chiricahua and Pedregosa Mountains and in the southeastern corner of the valley floor. [18, 21]

The major geomorphic feature in the San Bernardino Valley basin is the extensive Geronimo volcanic field, which is dominated by young basalt flows and vent complexes. In many areas of the basin, the basalts are also present in the subsurface. Well logs reveal layering of at least four basalt flows separated by basin-fill sediments. [10] The thickness of the basalt flow decreases to the south. A thin layer of alluvium covers the basalt flows around the southern and western margins of the basin. [21]

HYDROLOGY

Surface Water - The San Bernardino Valley basin is drained by Black Draw which crosses the border with Mexico to become a tributary to the Rio San Bernardino. Ephemeral over the majority of its length, Black Draw is perennial at a small cienega fed by springs and artesian wells in the San Bernardino National Wildlife Refuge. [17]

Black Draw has two major tributaries, Cottonwood Draw and Hay Hollow Wash, both of which head in the Peloncillo Mountains at the east edge of the basin. Silver Creek, which heads in the Pedregosa and Perilla Mountains drains the western part of the basin and joins the Black Draw-Rio San Bernardino system about one mile south of the International Boundary.

Groundwater - The San Bernardino Valley is an open, drained basin in which both surface water and groundwater flow out of the basin.

Heterogeneous basin-fill deposits form the only important aquifer in the basin. [10, 17] Basalt flows inter-bedded within the basin fill have the potential of creating confined aquifers (Diagram 1). However, it is likely that the basin-fill is interconnected to some degree creating a single aquifer system. [21] The basin-fill aquifer is unconfined over most of its extent. The only artesian conditions known to occur are where a lacustrine clay layer produces confined conditions within the San Bernardino National Wildlife Refuge. A shallow, unconfined aquifer is present above the confining layer at the refuge. [10]

Minor amounts of groundwater also occur in the surrounding mountains within zones of fractured or weathered volcanics and in thin layers of valley-fill alluvium overlying the bedrock. [21]

Depth to groundwater generally increases south to north in the basin. From depths to water less than 200 feet near the international border, groundwater depths increase to more than 600 feet along the northern boundary with the San Simon sub-basin. [26]

Around 300 wells have been drilled in the basin although probably much fewer remain in production. In 1985, 57 wells were found outside the refuge with 46 wells primarily used for stock supply, eight wells used for domestic supply, three wells were unused and no wells were used for irrigation. [15] Depth of these wells varies greatly but a few are oil exploration wells drilled in the early 1970s to almost 6,000 feet in depth. [4]

In addition, there are numerous springs in the mountain ranges surrounding the valley. Generally, these upland springs discharge minor amounts of flow from fractured bedrock in the mountains or represent underflow in alluvial channels that is forced to the surface by shallow bedrock. [10] In contrast, on the valley floor, all known springs and seeps are located on the San Bernardino National Wildlife Refuge that discharge flow from the basin-fill aquifer. Springs at the refuge act as drains to the basin-fill aquifer. [21]

Recharge, Movement and Discharge – Only a small percentage of precipitation and the associated surface runoff contribute to groundwater recharge in the basin. [17] Most piedmont slopes and basalt-capped valley floor surfaces are not considered to be important recharge areas because of a partially indurated surface and deep depths to groundwater. Recharge has been estimated to be approximately 6,500 acre-feet annually and consists of both mountain-front recharge and tributary-recharge from runoff percolating through thinner parts of the vadose zone beneath the basin's ephemeral waterways. [21]

Groundwater generally moves toward the basin center from the bordering mountain ranges, then south to the regional sink formed by the Rio San Bernardino in Mexico. The annual trans-boundary discharge is estimated at 5,545 acre-feet.[21] Groundwater movement and discharge have remained essentially at a pre-development state since there have been few attempts to significantly develop groundwater resources in the basin because of its small population and limited economic development. However, limited well data suggests that substantial supplies of economically recoverable groundwater are not present in the basin. [17]

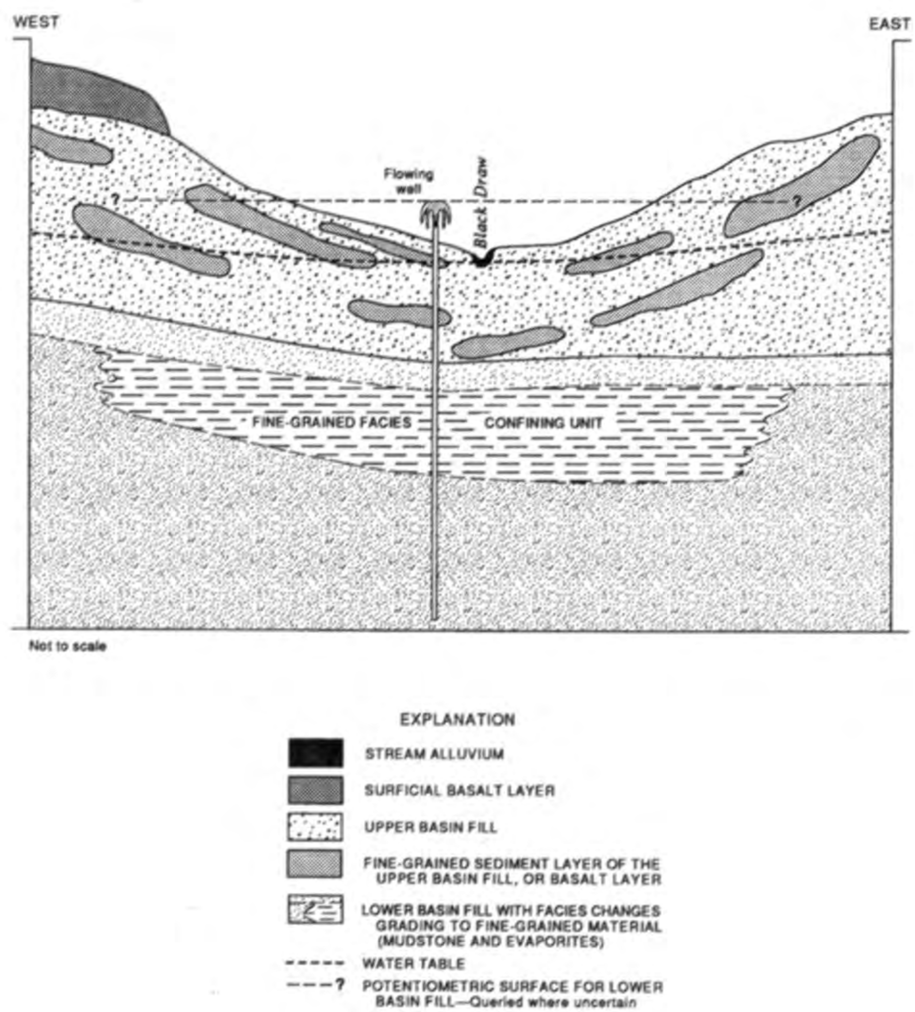


Diagram 1. The diagram illustrates a generalized lithologic cross-section of the San Bernardino Valley basin along the international border. Artesian groundwater conditions occur in the San Bernardino National Wildlife Refuge because the lower basin fill is partly confined by low permeability clays of the lower basin fill or overlying dense basalt. [15]

Figure 1 – The San Bernardino National Wildlife Refuge is located where Black Draw intersects the border with Mexico. Springs and artesian wells within the refuge supply water to ponds that hold several species of threatened and endangered fish, including the Yaqui shiner, Yaqui chub, Yaqui catfish, and Yaqui topminnow.

Figure 2 – The majority of land is used for livestock grazing; there are no incorporated towns within the basin. Scattered ranches are about the only structures within the San Bernardino Valley basin.

Figure 3 – Since much of the land within the San Bernardino Valley is far from electrical power lines, windmills are used in many locations to pump groundwater such as at this ranch home in the Pedregosa Mountains.

Figure 4 – Pump jacks were once commonly used in the basin to pump groundwater at remote locations; these have generally been replaced with windmills and, most recently, by submersible pumps powered by solar cells.

Figure 5 – The northern part of the San Bernardino Valley is characterized by basalt flows. The vegetation in this area consists predominantly of grass. The boundary between the San Bernardino Valley basin and the San Simon sub-basin to the north is poorly defined.

Figure 6 – This windmill located in proximity to U.S. Highway 80 near the former community of Bernardino was sampled (SBV-9) as part of the study. The sample from the well consisted of soft, sodium-bicarbonate water with a low TDS concentration of 240 mg/L.

Figure 7 – The Choate Well is located along the border east of the San Bernardino National Wildlife Refugee. Formerly a windmill was used to pump water; now a submersible pump powered by solar cells brings groundwater to the surface. The sample (SBV-1/1D) from this well revealed very hard water with the highest TDS, fluoride and zinc concentrations in the study.

Figure 8 – In the southern part of the basin, the vegetation transitions into a Chihuahuan desert scrub, consisting primarily of creosote bush, white-thorn acacia, creosote bush, and tarbush. The Pelloncillo Mountains are seen in the background.

Figure 9 – Artesian flow from the stand pipe for Oasis Well discharges into a pond located within the San Bernardino National Wildlife Refuge. A lacustrine clay layer produces confined conditions which result in the flowing wells; a shallow, unconfined aquifer is also present at the refuge (Photo courtesy of Chris Lohrengel, U.S. Fish and Wildlife Service).

Figure 10 – Ponds located within the San Bernardino National Wildlife Refuge contain several rare, endangered fish species. These ponds are supplied by a combination of natural springs and flow from artesian wells such as from the standpipe from the Twin Ponds well (Photo courtesy of Chris Lohrengel, U.S. Fish and Wildlife Service).

Figure 11 – ADEQ's Elizabeth Boettcher samples an artesian well (SBV-4) located at the Slaughter Ranch adjacent to the San Bernardino National Wildlife Refuge. A lacustrine clay layer produces confined conditions which result in the flowing wells; a shallow, unconfined aquifer is also present.

Figure 12 – The San Bernardino Valley basin has remained essentially at a pre-development hydrologic state since there has never been any significant attempt to extract groundwater resources in the area. Wells drilled for domestic and livestock uses in the basin suggest however, that there are not substantial supplies of economically recoverable groundwater. [17] The groundwater in the basin appears suitable for domestic uses as all 14 samples met all health-based, drinking water quality standards.

INVESTIGATION METHODS

ADEQ collected samples from 14 groundwater sites, to characterize regional groundwater quality in the San Bernardino Valley (Map 2). Samples for this study were collected during two field trips conducted in November 2002. Specifically, the following types of samples were collected:

- oxygen and deuterium isotopes at 14 sites
- inorganic suites at 14 sites
- radon at 13 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 domestic and stock purposes were sampled for this study. A well was considered suitable for sampling if the owner gave permission to sample, if a sampling point existed near the wellhead, and if the 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 14 wells, seven windmills, six wells served by submersible pumps, and one well had artesian flow. Additional information on groundwater sample sites is compiled from the ADWR well registry in Appendix A. [4]

Sample Collection

The sample collection methods for this study conformed to the *Quality Assurance Project Plan* (www.azdeq.gov/function/programs/lab/index.html) 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.

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.

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 such as with windmills during intermittent winds, it was not possible to purge three bore hole volumes. In these cases, at least one bore hole volume was evacuated and the physical parameters had stabilized within 10 percent.

Sample bottles were filled in the following order:

1. Radon
2. Inorganic
3. Isotope

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]

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

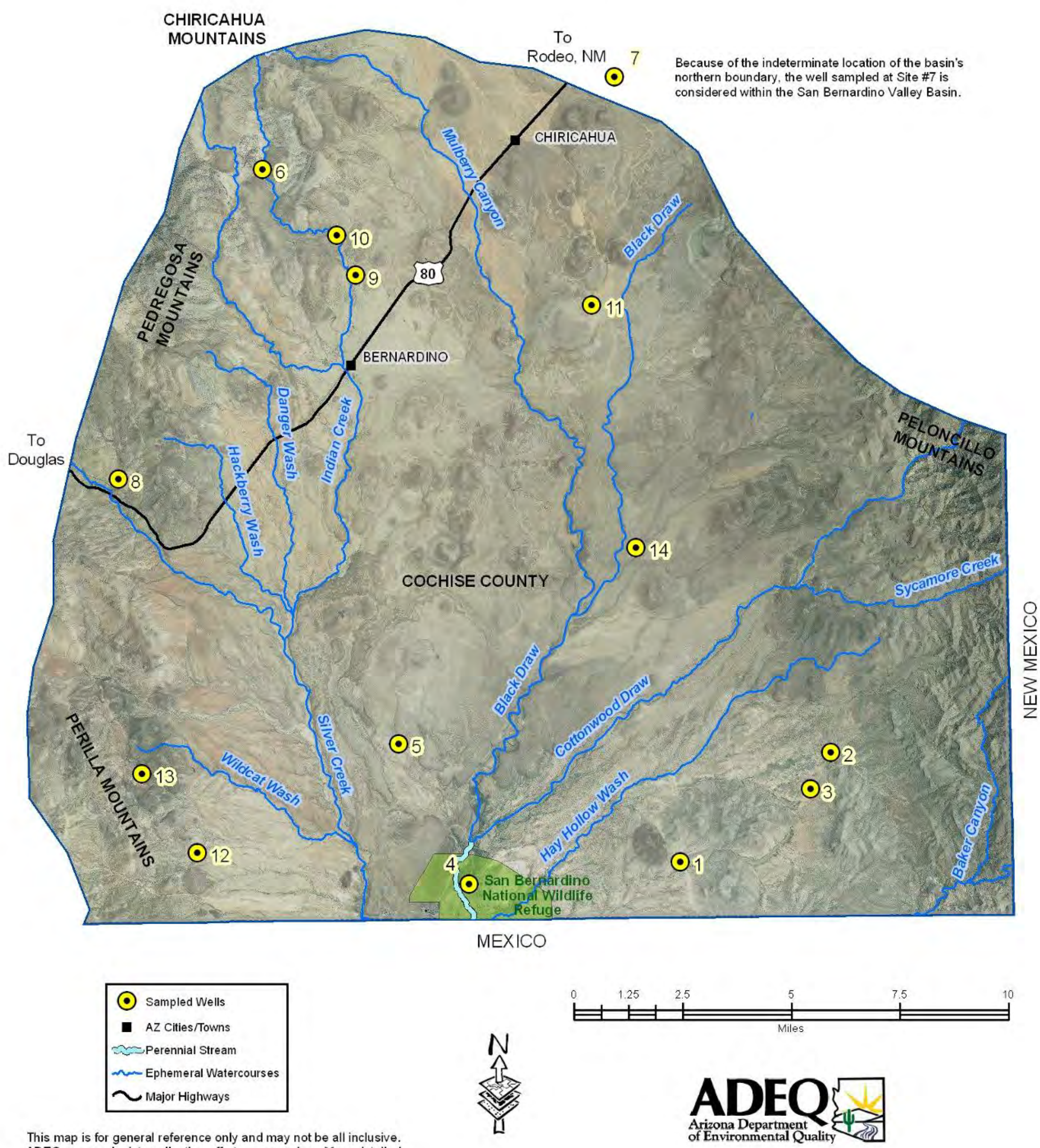
Laboratory Methods

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 Del Mar Laboratory in Phoenix, Arizona. A complete listing of inorganic parameters, including laboratory method, EPA water method and Minimum Reporting Level (MRL) for each laboratory is provided in Table 1.

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

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

Map 2 - Sampled Wells



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 numbers identify wells sampled for the study. Information about each well is located in the report appendices.

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

Constituent	Instrumentation	ADHS / Del Mar Water Method	ADHS / Del Mar Minimum Reporting Level
Physical Parameters and General Mineral Characteristics			
Alkalinity	Electrometric Titration	SM232OB / M2320 B	2 / 6
SC (uS/cm)	Electrometric	EPA 120.1/ M2510 B	-- / 2
Hardness	Titrimetric, EDTA	SM 2340 C / SM2340B	10 / 1
Hardness	Calculation	SM 2340 B	--
pH (su)	Electrometric	SM 4500 H-B	0.1 / 0.1
TDS	Gravimetric	SM2540C	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 / / M2320 B	2 / 2
Carbonate	Calculation	Calculation / / M2320 B	2 / 2
Chloride	Potentiometric Titration	SM 4500 CL D / E300	5 / 2
Fluoride	Ion Selective Electrode	SM 4500 F-C	0.1 / 0.4
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 / M4500-NH3	0.05 / 1.3
Total Phosphorus	Colorimetric	EPA 365.4 / M4500-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 Metals	
Aluminum	ICP-AES	EPA 200.7	0.5 / 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 / 0.5

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

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 San Bernardino 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] Types and numbers of QC samples collected for this study are as follows:

- Inorganic: (two duplicates, two partial duplicates and two splits).
- Radon: (no QA/QC samples)
- Isotope: (no QA/QC 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.[5] No equipment blank samples were collected for this study.

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.[5] Duplicate samples were collected from sampling sites that were believed to have elevated constituent concentrations as judged by specific conductivity (SC) field values. Two duplicate samples and two partial duplicate samples were collected in this study.

Analytical results indicate that of the 40 constituents examined, 21 had concentrations above the Minimum Reporting Levels (MRL). The maximum variation between duplicates was less than 10 percent (Table 2). The only exceptions were TKN (26 percent), turbidity (24 percent), and beryllium and zinc (13 percent). However, the constituents with a high percentage variation of concentrations show a small difference in actual concentrations (Table 2).

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.[5] Two 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 19 had concentrations above MRLs for both ADHS and Del Mar laboratories (Table 3). The maximum variation between splits was 10 percent. The only exceptions were TKN (83 percent), nitrate (35 percent), and fluoride (20 percent). Split samples were also evaluated using the non-parametric Sign test to determine if there were any significant differences between ADHS laboratory and Del Mar laboratory analytical results.[13, 25] There were no significant differences in constituent concentrations between the labs (Sign test, $p \leq 0.05$).

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. There were however, two exceptions.

One site, SRB-3/3D had a nitrite concentration of 10 mg/L, which is 10 times the health-based water quality standard. In over 1,450 sites sampled by the ADEQ ambient monitoring program, there have been no nitrite water quality exceedances, let alone one of this magnitude. The partial duplicate also collected at the well did not include nutrients. There was no documentation of rechecking this highly unusual result with the ADHS laboratory back in 2003 when the water quality report was received. In 2010, the ADHS laboratory was not able to investigate potential errors to the sample because records are only kept for five years. The well from which the high nitrite sample was collected could not be resampled in 2010 because it was no longer used. Based on previous nitrite concentrations found in groundwater in Arizona, the nitrite exceedance was deleted from the study.

Radon sampling was also problematic as there were two non-detects and two very low concentrations of the 13 collected samples. Such low radon concentrations in groundwater in Arizona are often indicative of incorrect sampling techniques that have allowed off-gassing.[9] Thus, radon concentrations collected in this study should be used with caution.

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.

Table 2. Summary Results of San Bernardino Valley 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	2	1 %	1 %	-	2	30	-
SC (uS/cm)	2	0 %	0 %	-	0	0	-
Hardness	2	0 %	0 %	-	0	0	-
pH (su)	2	1 %	1 %	-	0.1	0.2	-
TDS	2	0 %	3 %	-	0	10	-
Turb. (ntu)	2	18 %	24 %	-	0.7	1.3	-
Major Ions							
Bicarbonate	2	0 %	1 %	-	1	30	-
Calcium	5	0 %	4 %	1 %	0	10	0.7
Magnesium	5	1 %	3 %	2 %	0.2	3	1
Sodium	5	0 %	7 %	0 %	0	20	0
Potassium	5	0 %	3 %	0 %	0	1	0
Chloride	2	3 %	8 %	-	1	1.1	-
Sulfate	2	0 %	1 %	-	0	0.1	-
Nutrients							
Nitrate (as N)	2	4 %	8 %	-	0.004	0.09	-
TKN	2	0 %	26 %	-	0	0.053	
Trace Elements							
Barium	5	0 %	4 %	0 %	0	0.1	0
Beryllium	5	0 %	13 %	3 %	0	0.0001	0.00022
Boron	5	0 %	3 %	0 %	0	0.1	0
Copper	4	0 %	8 %	-	0	0.002	-
Fluoride	2	2 %	4 %	-	0.1	0.1	-
Zinc	5	0 %	13 %	7 %	0	0.9	0.3

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

Table 3. Summary Results of San Bernardino Valley Basin Split Samples from the ADHS/Del Mar Labs

Constituents	Number	Difference in Percent		Difference in Levels		Significance
		Minimum	Maximum	Minimum	Maximum	
Physical Parameters and General Mineral Characteristics						
Alkalinity, total	2	2 %	4 %	12	60	ns
SC (uS/cm)	2	1 %	3 %	10	100	ns
Hardness	2	1 %	3 %	10	20	ns
pH (su)	2	2 %	5 %	0.21	0.84	ns
TDS	2	0 %	2 %	0	30	ns
Turbidity (ntu)	1	3 %	3 %	1	1	ns
Major Ions						
Calcium	2	0 %	0 %	0	0	ns
Magnesium	2	2 %	5 %	1	4	ns
Sodium	2	3 %	3 %	4	10	ns
Potassium	2	4 %	7 %	0.4	2	ns
Chloride	2	3 %	9 %	0.1	1	ns
Sulfate	2	4 %	5 %	4	20	ns
Nutrients						
Nitrate as N	2	0 %	35 %	0	1.4	ns
TKN	1	83 %	83%	1.27	1.27	ns
Trace Elements						
Barium	2	0 %	4 %	0	0.01	ns
Beryllium	1	4 %	4 %	.00007	.00007	ns
Fluoride	2	5 %	20 %	0.14	0.3	ns
Iron	1	0 %	0 %	0	0	ns
Zinc	1	5 %	5 %	0.03	0.03	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

Cation/Anion Balances - Overall, cation/anion meq/L balances of the San Bernardino Valley basin samples were significantly correlated (regression analysis, $p \leq 0.01$). Of the 14 samples collected, all were within +/- 5 percent.

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]

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]

pH - The pH value is closely related to the environment of the water and is likely to be altered by sampling and storage.[14] However, the pH values measured in the field using a YSI meter at the time of sampling were still significantly correlated with laboratory pH values (regression analysis, $r = 0.94$, $p \leq 0.01$).

Temperature / Well Depth – Groundwater temperature measured in the field was compared to well depth. Groundwater temperature should increase with depth, approximately 3 degrees Celsius with every 100 meters or 328 feet.[14] Groundwater depth was not compared because of the few wells with water level measurements. Well depth was not significantly correlated with temperature (regression analysis, $r = 0.26$, $p \leq 0.05$).

Statistical Considerations

Various methods were used to complete the statistical analyses for the groundwater quality data of the study. All statistical tests were conducted on a personal computer using SYSTAT software.[25] Data associated with 21 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 none of the 21 constituents 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 recharge sources were the same. The Kruskal-Wallis test uses the differences, but also incorporates information about the magnitude of each difference.[40] 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.[21] 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.[20]

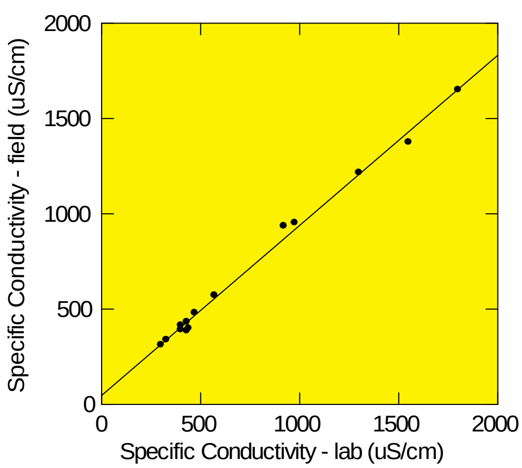


Diagram 2. The graph illustrates a strong positive correlation between two constituents; as specific conductivity concentrations collected in the field increase so do specific conductivity concentrations measured in the laboratory. The regression equation for this relationship is $y = 1.1x - 49$, $n = 14$, $r = 0.99$ (regression, $p \leq 0.01$).

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]

Inorganic Constituent Results - Of the 14 sites sampled for the full suite of inorganic constituents in the San Bernardino Valley study, 7 (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 not exceeded at any of the 14 sites.

Aesthetics-based Secondary MCL water quality guidelines were exceeded at 7 of 14 sites (29 percent; Map 3; Table 4). Constituents above Secondary MCLs include fluoride (2 sites), iron (2 sites), pH (3 sites), and TDS (4 sites). Potential impacts of these Secondary MCL exceedances are provided in Table 4.[23]

Radon Results - Of the 13 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. Six (6) sites exceeded the proposed 300 pCi/L standard that would apply if Arizona doesn't develop a multimedia program. [23]

Suitability for Irrigation

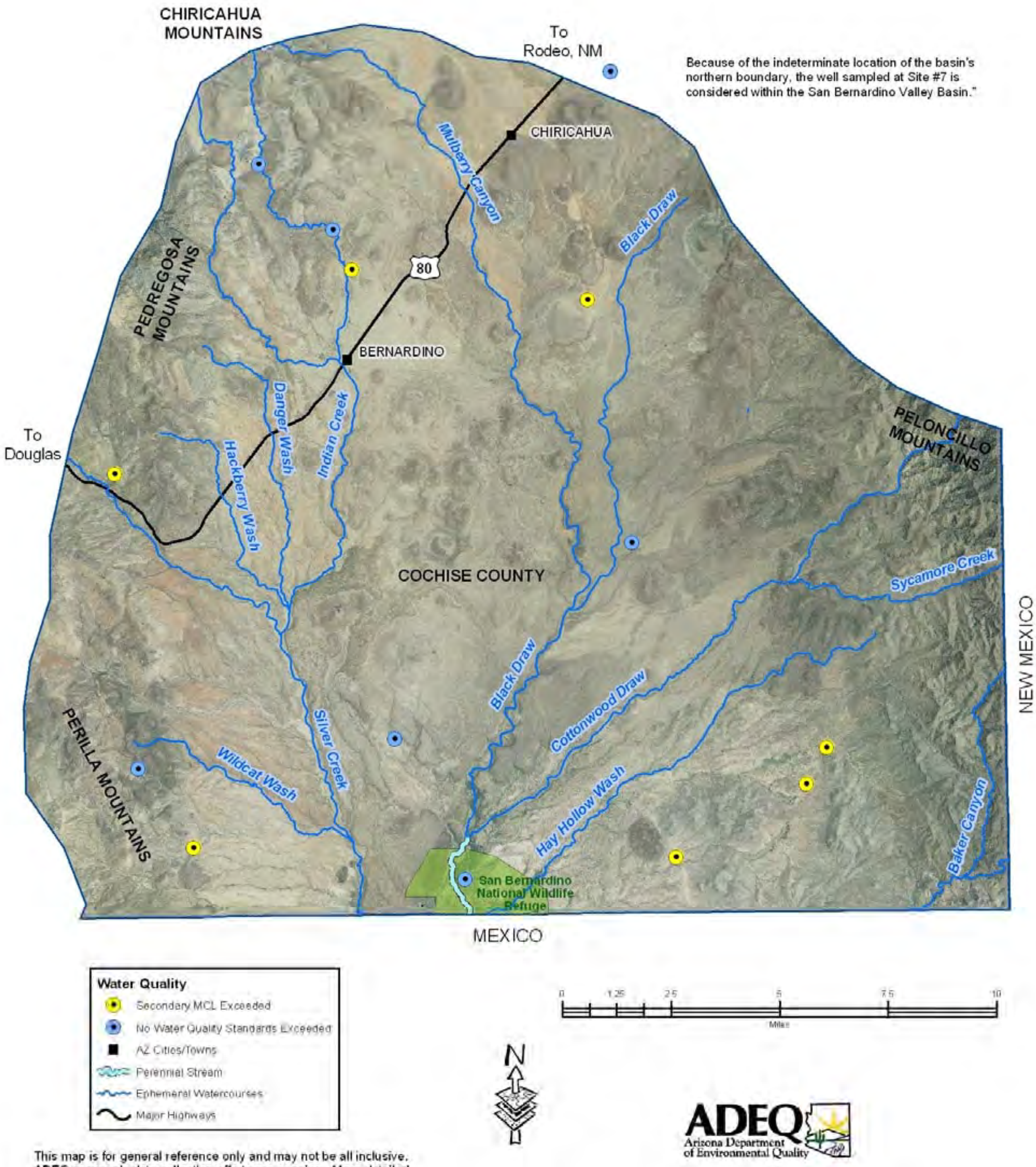
The groundwater at each sample site was assessed as to its suitability for irrigation use based on salinity and sodium hazards. Excessive levels of sodium are known to cause physical deterioration of the soil and vegetation. [24] Irrigation water may be classified using specific conductivity (SC) and the Sodium Adsorption Ratio (SAR) in conjunction with one another. [24]

Groundwater sites in the San Bernardino Valley basin display a narrow range of irrigation water classifications. The 14 sample sites are divided into the following salinity hazards: low or C1 (0), medium or C2 (8), high or C3 (6), and very high or C4 (0). The 14 sample sites are divided into the following sodium or alkali hazards: low or S1 (13), medium or S2 (1), high or S3 (0), and very high or S4 (0).

Analytical Results

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

Map 3 - Water Quality Standards



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 4. San Bernardino Valley Basin Sites Exceeding Aesthetics-Based (Secondary MCL) Water Quality Standards

Constituents	Secondary MCL	Number of Sites Exceeding Secondary MCLs	Maximum Exceedance	Aesthetic Effects of MCL Exceedances
		Physical Parameters		
pH - field	<6.5 ; >8.5	**3**	6.41; 8.79	*low pH:* bitter metallic taste; corrosion *high pH:* slippery feel; soda taste; deposits
		General Mineral Characteristics		
TDS	500	**4**	1,100	hardness; deposits; colored water; staining; salty taste
		Major Ions		
Chloride (Cl)	250	0	-	-
Sulfate (SO_4)	250	0	-	-
		Trace Elements		
Fluoride (F)	2.0	**2**	3.05	tooth discoloration
Iron (Fe)	0.3	**2**	0.76	rusty color; sediment; metallic taste; reddish or orange staining
Manganese (Mn)	0.05	0	-	
Silver (Ag)	0.1	0	-	-
Zinc (Zn)	5.0	0	-	-

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

Table 5. Summary Statistics for San Bernardino Valley 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	14 / 14	22.0	21.0	23.8	26.6
pH-field (su)	0.01	14 / 14	7.93	7.51	7.90	8.30
pH-lab (su)	0.01	14 / 14	7.85	7.58	7.80	8.02
Turbidity (ntu)	0.01	14 / 14	0.52	-1.59	4.46	10.50
General Mineral Characteristics						
T. Alkalinity	2.0	14 / 14	199	160	302	445
Phenol. Alk.	2.0	14 / 0	> 50% of data below MRL			
SC-field (uS/cm)	N/A	14 / 14	457	450	704	959
SC-lab (uS/cm)	N/A	14 / 14	455	452	737	1021
Hardness-lab	10.0	14 / 14	145	112	211	311
TDS	10.0	14 / 14	290	270	445	620
Major Ions						
Calcium	5.0	14 / 14	42	26	54	82
Magnesium	1.0	14 / 14	13	12	19	26
Sodium	5.0	14 / 14	56	42	80	119
Potassium	0.5	14 / 14	1.5	5.2	8.0	13.4
Bicarbonate	2.0	14 / 14	242	194	365	535
Carbonate	2.0	14 / 0	> 50% of data below MRL			
Chloride	1.0	14 / 14	7.6	3.5	17	31
Sulfate	10.0	14 / 14	20	13	57	100
Nutrients						
Nitrate (as N)	0.02	12 / 12	0.8	0.6	1.4	2.3
Nitrite (as N)	0.02	12 / 0	> 50% of data below MRL			
TKN	0.05	12 / 6	> 50% of data below MRL			
T. Phosphorus	0.02	12 / 3	> 50% of data below MRL			

Table 5. Summary Statistics for San Bernardino Valley 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			
Antimony	0.005	14 / 0	> 50% of data below MRL			
Arsenic	0.01	14 / 0	> 50% of data below MRL			
Barium	0.1	14 / 4	> 50% of data below MRL			
Beryllium	0.0005	14 / 2	> 50% of data below MRL			
Boron	0.1	14 / 3	> 50% of data below MRL			
Cadmium	0.001	14 / 0	> 50% of data below MRL			
Chromium	0.01	14 / 1	> 50% of data below MRL			
Copper	0.01	14 / 3	> 50% of data below MRL			
Fluoride	0.20	14/ 14	0.49	0.33	0.86	1.39
Iron	0.1	14 / 3	> 50% of data below MRL			
Lead	0.005	14/ 0	> 50% of data below MRL			
Manganese	0.05	14 / 0	> 50% of data below MRL			
Mercury	0.0005	14 / 0	> 50% of data below MRL			
Nickel	0.1	14 / 0	> 50% of data below MRL			
Selenium	0.005	14 / 0	>50% of data below MRL			
Silver	0.001	14 / 0	> 50% of data below MRL			
Thallium	0.002	14 / 0	> 50% of data below MRL			
Zinc	0.05	14 / 10	0.09	-0.11	0.40	0.92
			Radiochemical			
Radon *	Varies	13 / 13	298	150	291	432
			Isotopes			
Oxygen-18 **	Varies	14 / 14	- 8.8	- 9.5	- 8.9	- 8.2
Deuterium **	Varies	14 / 14	- 63.5	- 69.7	- 65.2	- 60.8

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

GROUNDWATER COMPOSITION

General Summary

Groundwater in the San Bernardino Valley basin was predominantly of calcium, mixed or sodium-bicarbonate chemistry (Map 4) (Diagram 3). The water chemistry at the 14 sample sites, in decreasing frequency, includes mixed-bicarbonate (six sites), calcium-bicarbonate (four sites), sodium-bicarbonate (three sites) and sodium-mixed (one site) (Diagram 3 – middle diagram).

Of the 14 sample sites, the dominant cation was calcium at five sites and sodium at three sites; at six sites the composition was mixed as there was no dominant cation (Diagram 3 – left diagram).

The dominant anion was bicarbonate at 13 sites; at one site the composition was mixed as there was no dominant anion (Diagram 3 – right diagram).

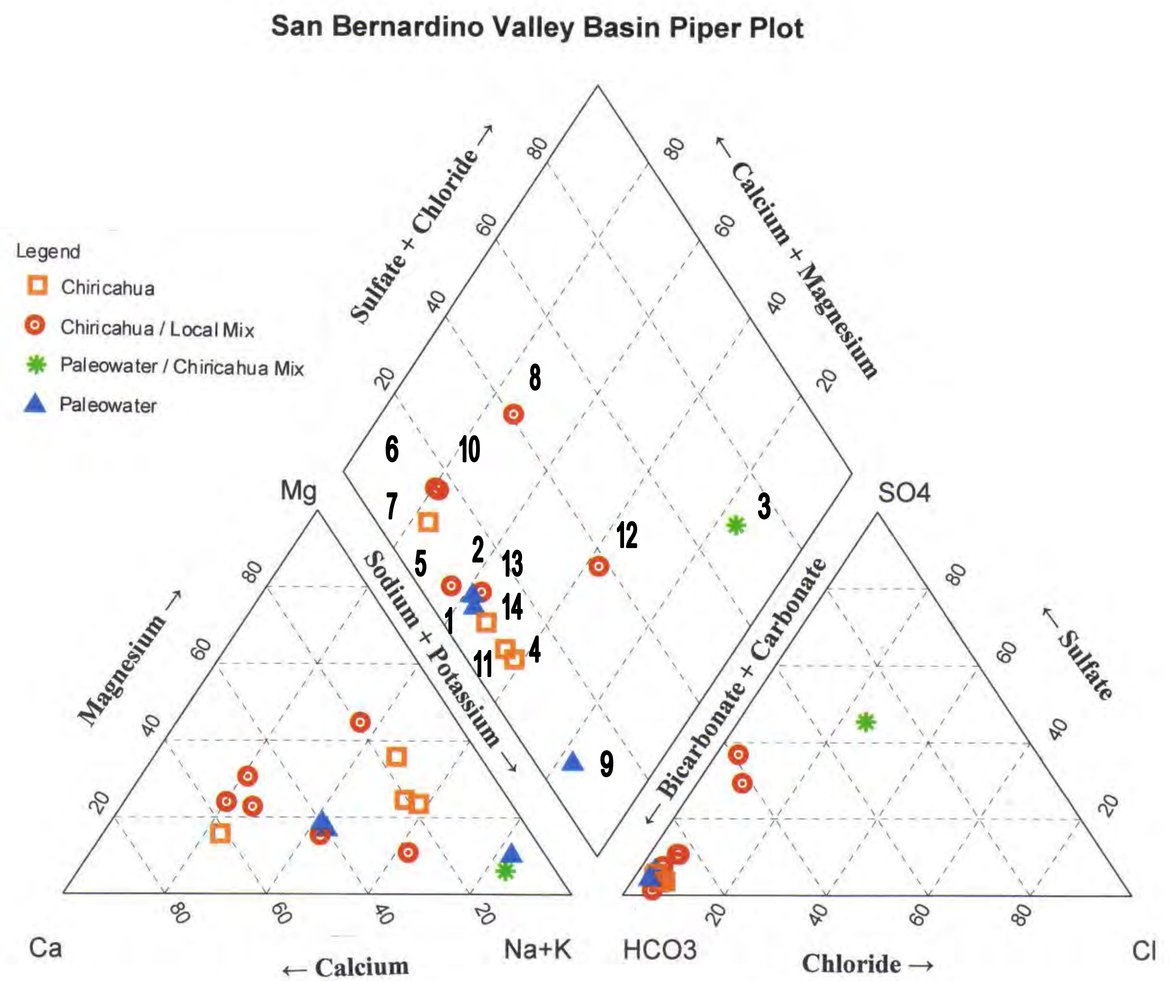
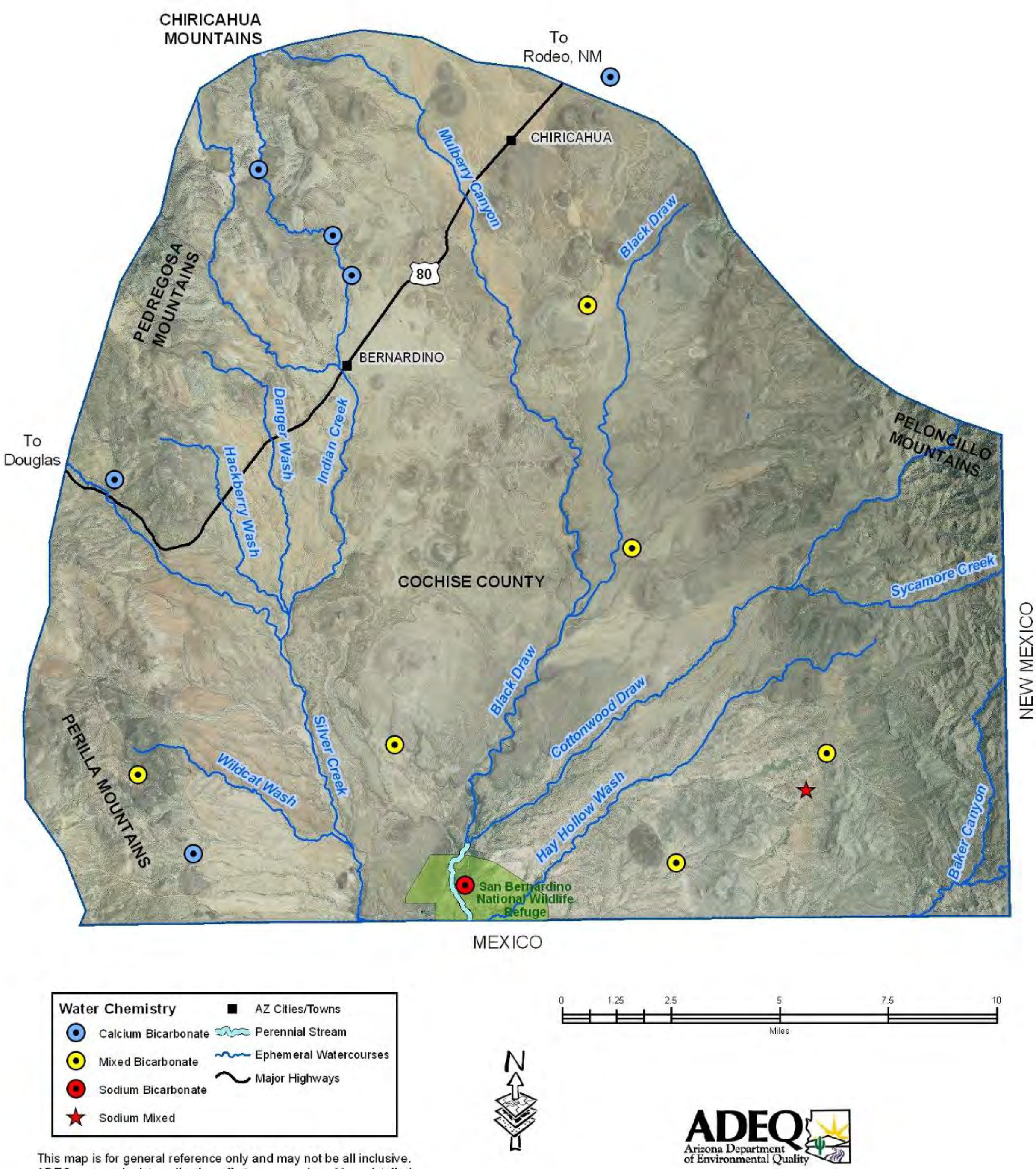


Diagram 3 – The Piper trilinear diagram shows the water chemistry of wells sampled for the study. The numbers correspond to those provided on Map #2 and in the appendices. Samples in the basin are predominantly of mixed-calcium-sodium-bicarbonate chemistry with the exception of SRB-3, which has a sodium-mixed chemistry. Samples sites are designated by recharge source which will be discussed in the isotope comparison section.

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.

ADEQ Arizona Department of Environmental Quality

Levels of pH-field were *slightly alkaline* (above 7 su) at 12 sites and *slightly acidic* (below 7 su) at 2 sites.[12] Of the 12 sites above 7 su, 6 sites had pH-field levels over 8 su.

TDS concentrations were considered *fresh* (below 1,000 mg/L) at 13 sites and slightly saline (1,000 to 3,000 mg/L) at 1 site (Map 5).[12]

Hardness concentrations were *soft* (below 75 mg/L) at 2 sites, *moderately hard* (75 – 150 mg/L) at 6 sites, *hard* (150 – 300 mg/L) at 3 sites, and *very hard* (above 300 mg/L) at 3 sites (Map 6).[8]

Nitrate (as nitrogen) concentrations at most sites may have been influenced by human activities. Nitrate concentrations were divided into natural background (1 site at <0.2 mg/L), may or may not indicate human influence (10 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 >10mg/L).[16]

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

Constituent Co-Variation - TDS concentrations are best predicted among major ions by calcium (Diagram 4) or sodium concentrations (standard coefficient = 0.40), among cations by sodium concentrations (standard coefficient = 0.62) and among anions, bicarbonate (standard coefficient = 0.81) (multiple regression analysis, $p \leq 0.01$).

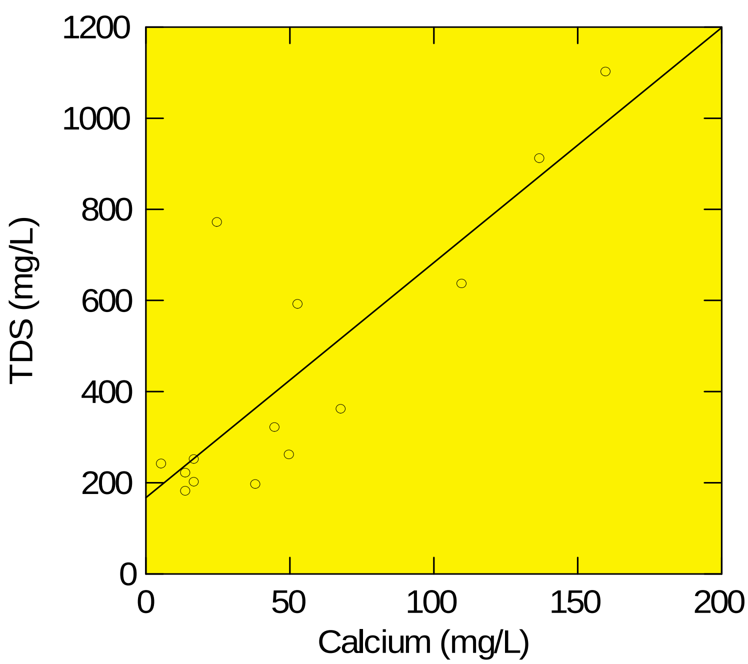
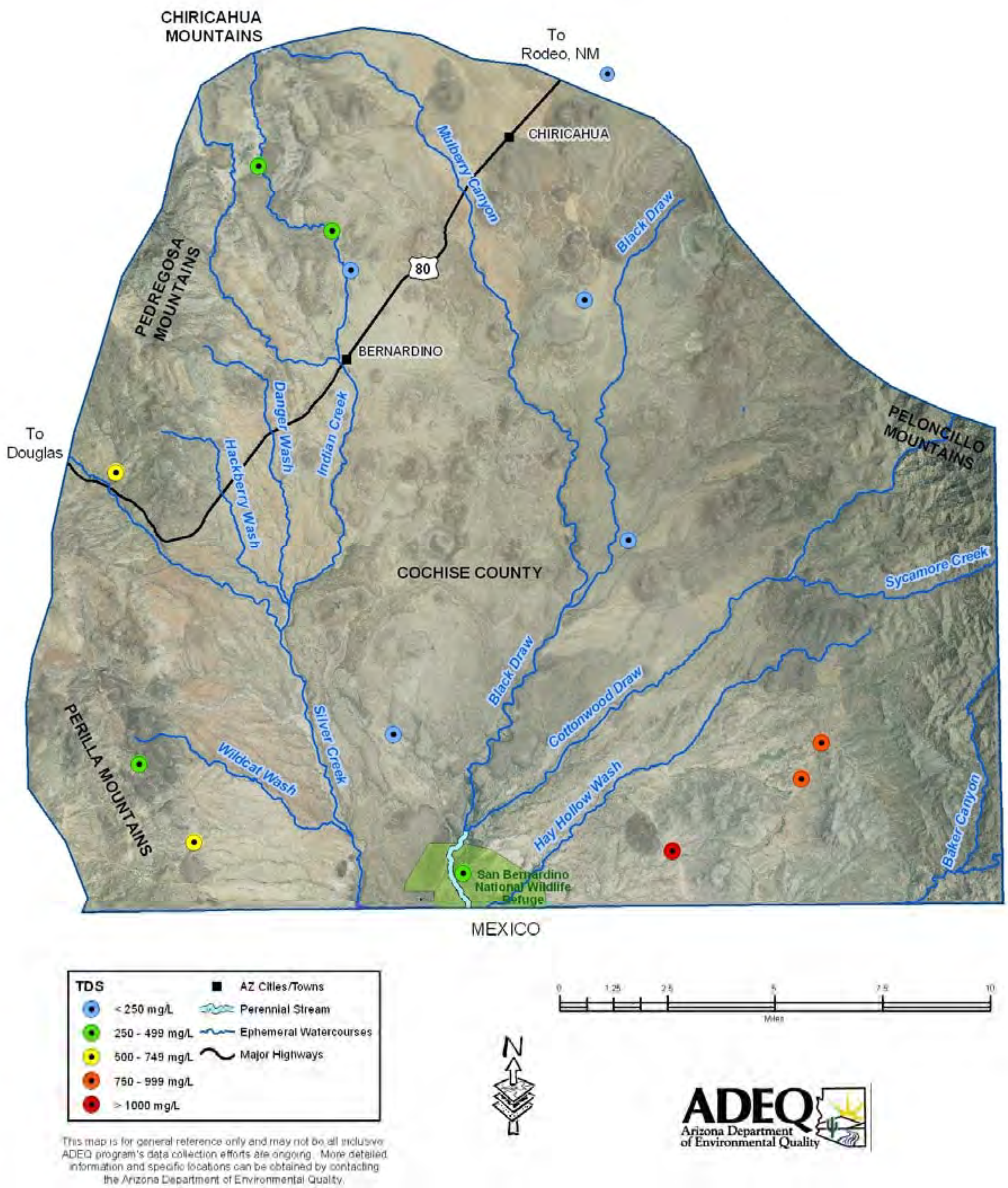
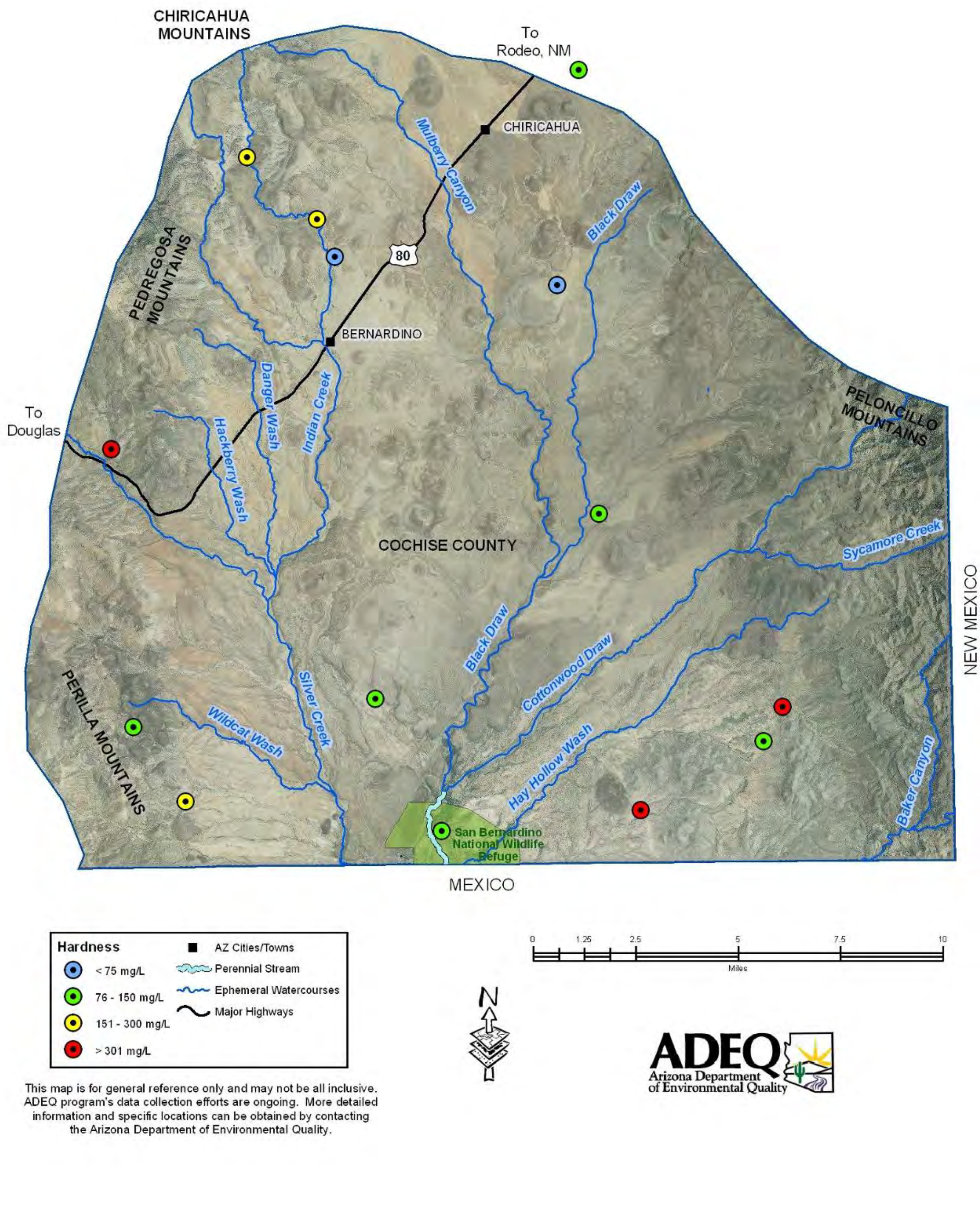


Diagram 4 – Although TDS concentrations are best predicted by calcium concentrations in samples collected in the San Bernardino Valley basin, the relationship is comparatively weak as illustrated in this diagram. The regression for this relationship is y = 5.2x = 167, r = 0.83, n = 14.

Map 5 - Total Dissolved Solids (TDS)



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.

Isotope Comparison

The data for the San Bernardino Valley basin roughly conforms to what would be expected in an arid environment, having a slope of 6.8, with the LMWL described by the linear equation:

$$\delta D = 6.8\,\delta^{18}O - 5.0$$

The LMWL for the San Bernardino Valley basin (6.8) is higher than many 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), McMullen Valley (7.4) and Lake Mohave (7.8).[22]

The four most depleted isotope samples consisted of three sites were located in the southeast portion of the basin (SBV-1, SBV-2 and SBV-3) and the most depleted site (SBV-9) was located near the north center of the basin (Map 2 and Diagram 5). The light signatures of these samples were more depleted than would be expected from either valley or low elevation mountain recharge within the basin. Three samples were even lighter than spring samples collected at high elevations in Chiricahua Mountains for the San Simon sub-basin study. [22]

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. [10, 27] Sample, SBV-3, is likely producing a combination of paleowater combined with more recent recharge occurring in the Chiricahua Mountains.

The remaining 10 samples collected in the San Bernardino Valley basin are more enriched and plot slightly heavier than high elevation springs in the Chiricahua Mountains. [10, 22] The values suggest that much of the groundwater from these wells originated outside the basin in the Chiricahua Mountains.

Within the 10 samples that were more enriched, there appear to be two sub-groups. Four samples (SBV-4, SBV-7, SBV-11 and SBV-14) are less enriched than the other six samples. This suggests that waters sampled from these wells consist of recharge almost entirely from the Chiricahua Mountains. All four samples were collected from wells at least 475 feet in depth. The six most enriched samples, which were all collected from wells less than 312 feet in depth (most much shallower), may have various amounts of low-elevation precipitation within the basin contributing to their recharge. Local sources of low elevation precipitation include mountain front recharge from the Peloncillo/Guadalupe Mountains to the east and the Pedregoasa Mountains to the northwest as well as water percolating beneath ephemeral stream channels of the basin's major drainages. [17]

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:

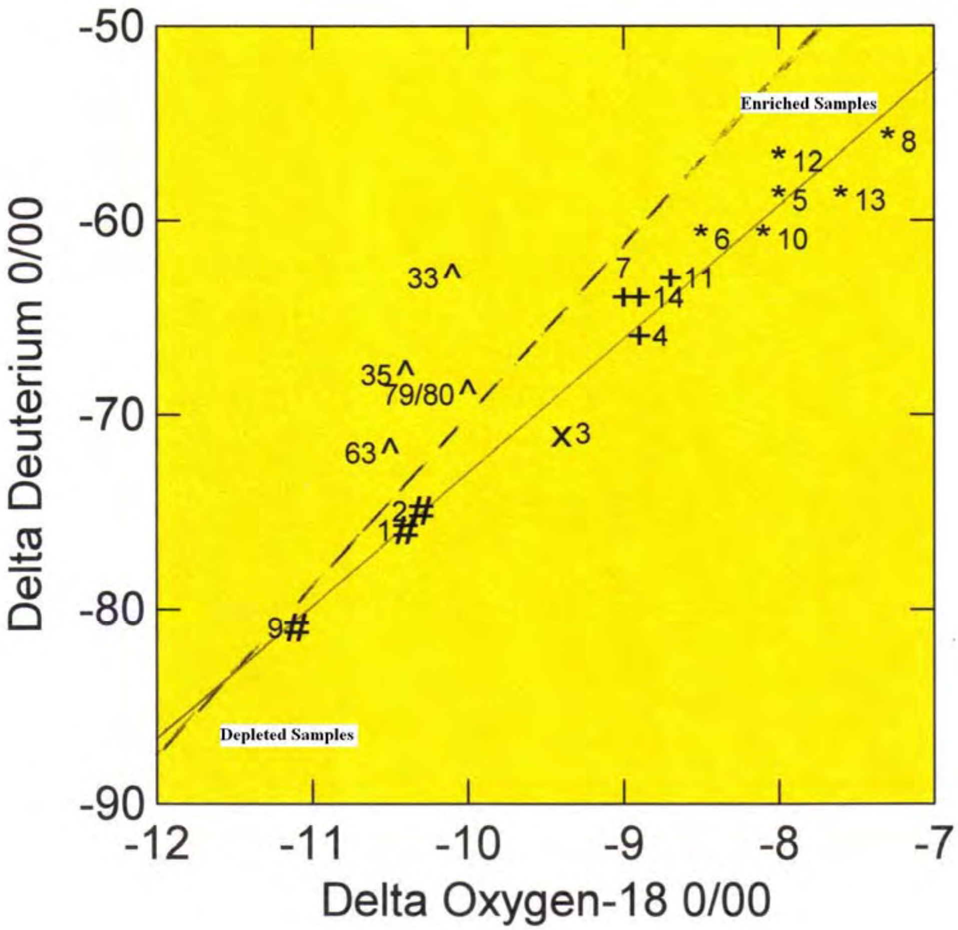
$$\delta D = 8\,\delta^{18}O + 10$$

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 San Bernardino 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 heavier. [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]

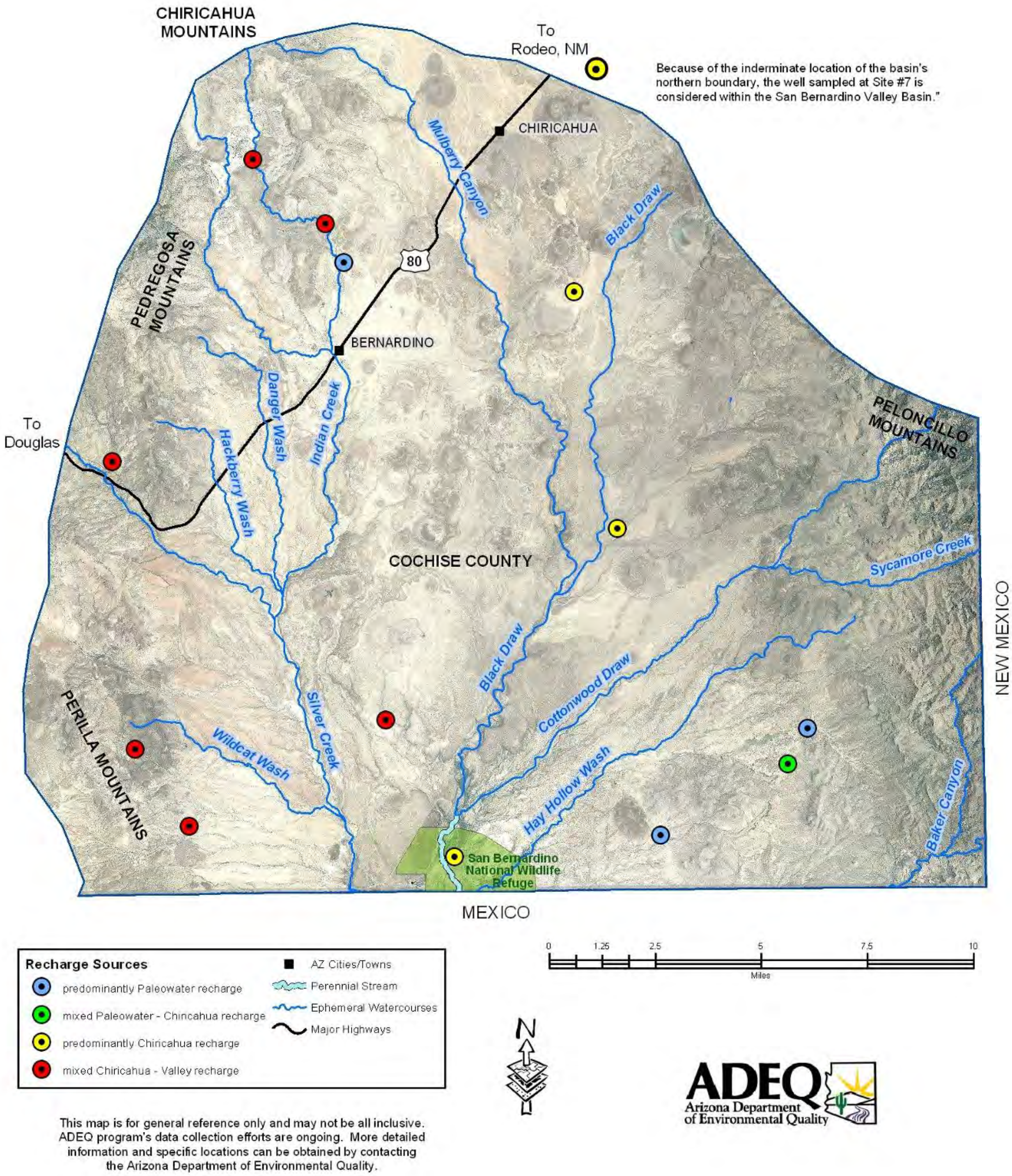


Isotope Diagram Legend

- # = Predominantly Paleowater recharge sample site
- x = Mixed Paleowater/Chiricahua recharge sample site
- + = Predominantly Chiricahua recharge sample site
- * = Mixed Chiricahua/Valley recharge sample site
- ^ = San Simon sub-basin sample from the Chiricahua Mountains
- - - - = Global Meteoric Water Line
- ____ = Local Meteoric Water Line for the SBV basin samples only

Diagram 5 – Water samples from wells in the San Bernardino Valley basin are plotted according to their oxygen and hydrogen isotope values. The lowest points along the Local Meteoric Water Line (LMWL) have the lightest signatures and have undergone the least evaporation prior to sampling. These samples are more depleted than would be possible from high elevation precipitation in the Chiricahua Mountains making it likely they consist of paleowater recharged long ago during cooler climatic conditions. The remaining samples appear to consist of recharge from the Chiricahua Mountains. The highest points along the LMWL have the heavest signatures and have undergone the most evaporation prior to sampling. These enriched samples likely consist of varying amounts of local, valley recharge suplimenting the recharge from the Chiricahua Mountains.

Map 7 - Recharge Sources



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.

Groundwater Quality Variation

Among Recharge Sources – Twenty-one (21) groundwater quality constituent concentrations were compared between samples collected from four wells pumping ancient paleowater, four wells pumping water recharged from the Chiricahua Mountains, and six wells pumping water recharged from the Chiricahua Mountains along with varying amounts of recharge from lower elevation mountains and valley areas in the San Bernardino Valley basin.

Most constituents followed a general pattern in which concentrations in the paleowater samples were greater than the Chiricahua-Valley recharge which was greater than the Chiricahua recharge. However, only TDS (Diagram 6), SC-field, SC-lab, sodium, fluoride (Diagram 7), oxygen (Diagram 8), hydrogen and well depth (Diagram 9) had significant differences among the recharge groups (Kruskal-Wallis with Tukey test, $p \leq 0.05$).

Complete results are found in Table 5. Summary statistics in the form of 95% confidence intervals are provided for those constituents with significant concentration differences between recharge sources in Table 6.

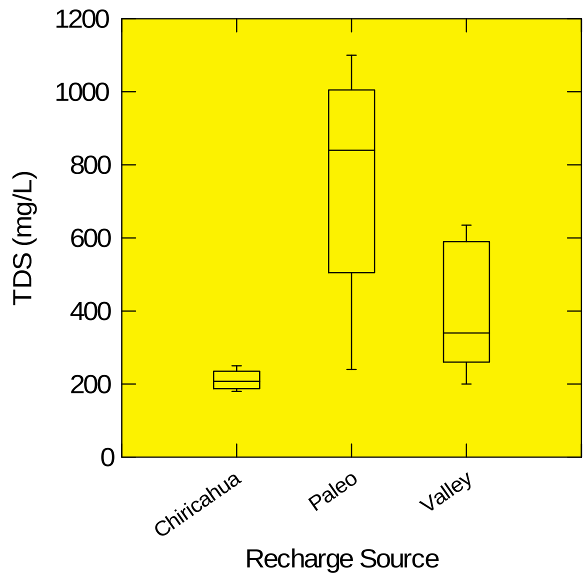


Diagram 6. TDS concentrations of samples collected from wells pumping recharge from the Chiricahua Mountains were significantly lower than samples from wells pumping ancient paleowater. Wells pumping water thought to be a combination of recharge from the Chiricahua Mountains and local Valley recharge had TDS concentrations that were not significantly different from the other two groups (Kruskal-Wallis with Tukey test, $p \leq 0.05$). TDS is often elevated in groundwater having a long aquifer residence time.[20] The sites having the highest TDS concentrations in the ADEQ study corresponded to those in a previous study and were located in the southern portion of the basin near outcrops of Paleozoic sedimentary rocks, predominantly limestone.[21]

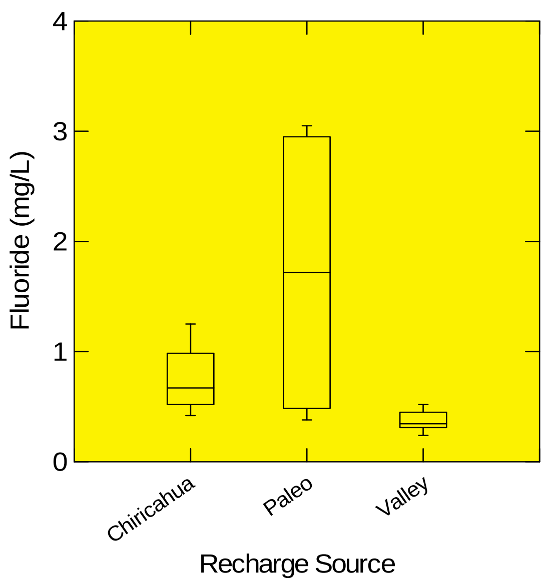


Diagram 7. Fluoride concentrations of samples collected from wells pumping a combination of recharge from the Chiricahua Mountains and local Valley recharge were significantly lower than samples from wells pumping ancient paleowater. Wells pumping recharge from the Chiricahua Mountains had fluoride concentrations that were not significantly different from the other two groups (Kruskal-Wallis with Tukey test, $p \leq 0.05$). Fluoride is often elevated in groundwater having a long aquifer residence time.[20] The ADEQ study had remarkably similar results to previous research conducted in 1991 that found fluoride concentrations ranged from 0.1 to 3.0 mg/L.[21]

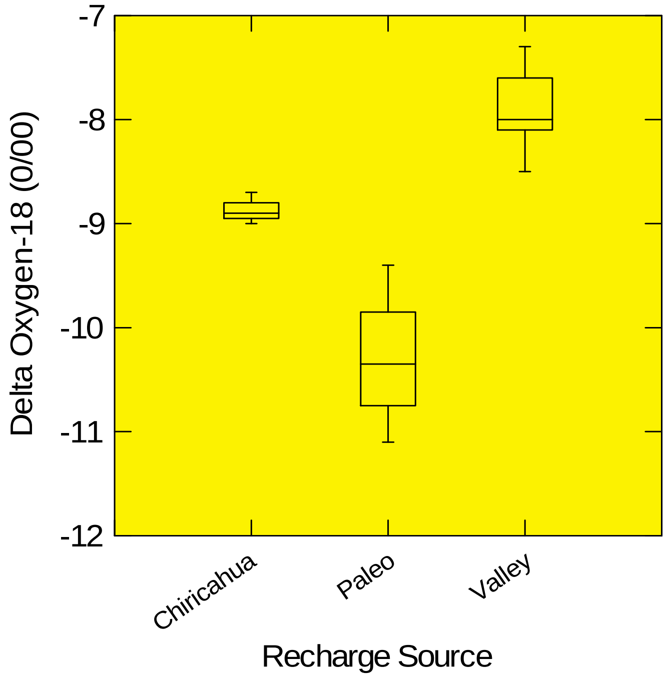


Diagram 8. Oxygen-18 isotope values of samples collected from the three recharge groups of wells were all significantly different from each other (Kruskal-Wallis with Tukey test, $p \leq 0.05$). Many well samples have isotope values that correspond to samples collected in the Chiricahua Mountains.[10, 22] Samples labeled as “Valley” are isotopically heavy compared to other wells which suggest that they contain a combination of Chiricahua recharge and low-elevation recharge originating in the basin.[10] Samples labeled as “Paleo” are distinctly depleted compared to other wells and are lighter than even Chiricahua recharge. The extreme depletion, along with often deep well depths, suggests this is ancient paleowater recharged long ago during cooler climate conditions in the basin.[10]

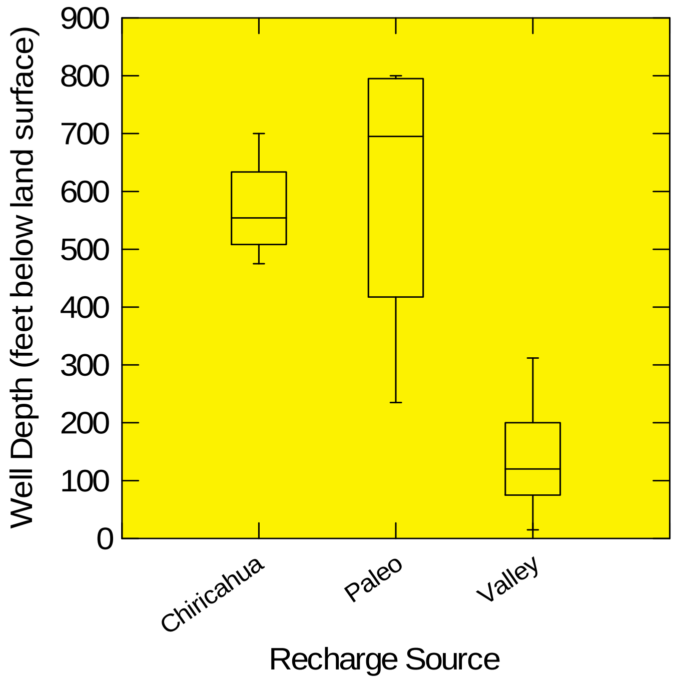


Diagram 9. Well depths of the three recharge groups were all significantly different from each other (Kruskal-Wallis with Tukey test, $p \leq 0.05$). “Valley” wells are the shallowest which makes it more likely that they are receiving local, low-elevation recharge from within the San Bernardino Valley basin.[10]

Table 5. Variation in Groundwater Quality Constituent Concentrations Among Recharge Sources Using Kruskal-Wallis with Tukey Test

Constituent	Significance	Significant Differences Among Recharge Sources
Well Depth	*	Paleo > Chiricahua & Valley
Temperature - field	ns	-
pH – field	ns	-
pH – lab	ns	-
SC - field	*	Paleo > Chiricahua
SC - lab	*	Paleo > Chiricahua
TDS	*	Paleo > Chiricahua
Turbidity	ns	-
Hardness	ns	-
Calcium	ns	-
Magnesium	ns	-
Sodium	*	Paleo > Chiricahua & Valley
Potassium	ns	-
Bicarbonate	ns	-.
Chloride	ns	-
Sulfate	ns	-
Nitrate (as N)	ns	-
Fluoride	*	Paleo > Valley
Oxygen	ns	Paleo > Chiricahua > Valley
Deuterium	ns	Paleo > Chiricahua > Valley
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

Table 6. Summary Statistics (95% Confidence Intervals) for Groundwater Quality Constituents With Significant Concentration Differences Among Recharge Sources

Constituent	Significant Differences	Paleowater	Chiricahua	Valley
Well Depth	ns	186 to 1026	420 to 721	1 to 288
Temperature - field	ns	-	-	-
pH – field	*	-	-	-
pH – lab	ns	-	-	-
SC - field	ns	320 to 2009	294 to 427	360 to 893
SC - lab	ns	292 to 2233	264 to 470	370 to 895
TDS	ns	168 to 1342	163 to 260	207 to 581
Turbidity	ns	-	-	-
Hardness	ns	-	-	-
Calcium	ns	-	-	-
Magnesium	ns	-	-	-
Sodium	ns	60 to 260	8 to 67	10 to 102
Potassium	*	-	-	-
Bicarbonate	*	-	-	-
Chloride	ns	-	-	-
Sulfate	ns	-	-	-
Nitrate (as N)	ns	-	-	-
Fluoride	**	-0.6 to 4.0	-	0.3 to 0.5
Oxygen	ns	-11.4 to -9.2	-9.1 to -8.7	-8.4 to -7.5
Deuterium	ns	-82.3 to -69.2	-66.3 to -62.3	-61.0 to -56.7
Radon	ns	-	-	-

All units in milligrams per liter (mg/L) unless otherwise noted
ns = not significant
* = significant at $p \leq 0.05$ or 95% confidence level
** = significant at $p \leq 0.01$ or 99% confidence level

SUMMARY AND CONCLUSIONS

The San Bernardino Valley groundwater basin is a sparsely populated, remote area in the extreme southeastern corner of Arizona. Limited groundwater development has occurred in the basin for domestic and stock use. Based on the results of blanks, duplicates and the split sample collected for this study, the groundwater data collected for this study was generally acceptable. However, there were two exceptions where sampling results appear to be in error involving nitrite and radon.

Water Quality Standards - Interpretation of the analytical results from 14 samples collected by ADEQ indicates that groundwater in the basin meets drinking water standards and is suitable for domestic, stock, municipal, and irrigation purposes. Each sample met all health based water quality standards. This result corresponds to earlier studies that also showed no health based water quality standard exceedances in samples collected from 18 wells and two springs between 1956 and 1987. [15] Seven of the 14 sites had constituents that exceeded aesthetic based water quality standards. TDS was elevated at four sites, pH at three sites, and fluoride and iron were elevated in two sites apiece.

Groundwater Characteristics - Groundwater is *slightly-alkaline*, *fresh*, and *hard* to *very hard*, based upon pH levels and concentrations of TDS and hardness.[8, 12] These report findings correspond to previous data collected in the San Bernardino Valley basin did not reveal any samples exceeding TDS concentrations of 1,000 mg/L. [17]

Most sampled sites consisted of water with calcium/mixed/sodium-bicarbonate chemistry. While bicarbonate is the dominant anion, the dominant cation appears to shift from calcium to a mixed composition and even to sodium as groundwater flows from the basin's peripheries to its center and south toward the international border. The heterogeneity of the aquifer however, makes this transition an irregular pattern. The water chemistry progression from calcium-dominated waters that are common in recharge areas towards sodium-dominated waters suggests that cation exchange is an important process in the southern portion of the basin. [17] One sample, SBV-5, has a relatively high magnesium concentration which likely indicates the groundwater is interacting with basalt. [17]

Irrigation water quality is good in the basin with low alkali hazard and medium salinity hazard, a finding reported in earlier studies. [17]

Isotope Analysis - Isotope values of samples collected in the basin are much lighter and depleted than would be expected from recharge originating in the basin's low elevations. [10] Most sample sites appear to consist of recharge originating at high elevations in the Chiricahua Mountains.[10] Previous studies estimate the basin receives at least 70 percent of its water from the Chiricahua Mountains located to the north that enters the San Bernardino Valley basin through preferential flowpaths such as faults.[10] These findings indicate that the northern boundary of the basin is likely more of a surface water divide than a groundwater demarcation as water recharged in Chiricahua Mountains serves as the source of much of the groundwater in the San Bernardino Valley .

Samples from some shallow wells in the basin have the most enriched isotope values that likely indicate a limited amount of recharge occurs locally from low elevation mountains or from alluvial channels in the San Bernardino Valley.[10] Previous studies have estimated 20 percent of the basin's recharge is provided by the Peloncillos Mountains and 10 percent from the Perilla and Pedregosa ranges. [10]

Samples from some deep wells have isotope values so depleted that they are unlikely to consist of recharge from even the Chiricahua Mountains. These wells produce paleowater that was likely predominantly recharged during the Pleistocene around 8,000 – 12,000 years ago when the basin was cooler and subject to much less evaporation.[10, 27]

Groundwater Patterns - Wells pumping paleowater and Chiricahua Mountain recharge were significantly deeper than wells pumping water that included low elevation recharge mixed with that from the Chiricahua Mountains (Kruskal-Wallis with Tukey test, $p \leq 0.05$). TDS, SC, and sodium concentrations were significantly higher in paleowater than Chiricahua Mountain recharge. Similarly sodium and fluoride concentrations in paleowater were significantly higher than in recharge that included local Valley precipitation (Kruskal-Wallis with Tukey test, $p \leq 0.05$). These constituents are often elevated in groundwater having a long aquifer residence time. [20]

Other spatial comparisons were conducted using a simplified geologic system. Samples collected from wells located in alluvial, basalt, and consolidated rocks were compared for significant differences. However, perhaps because of the basin's lithologic heterogeneity, few constituent concentration patterns were found.

REFERENCES

[1] Arizona Department of Environmental Quality, 1991, Quality Assurance Project Plan*:* Arizona Department of Environmental Quality Standards Unit, 209 p.

[2] Arizona Department of Environmental Quality, 2009-20010, Arizona Laws Relating to Environmental Quality: St. Paul, Minnesota, West Group Publishing, §49-221-224, p 134-137.

[3] Arizona State Land Department, 1997, "Land Ownership - Arizona" GIS coverage: Arizona Land Resource Information Systems, downloaded, 4/7/07.

[4] Arizona Department of Water Resources website, 2010, www.azwater.gov/azdwr/default.aspx, accessed 05/25/10.

[5] Arizona Water Resources Research Center, 1995, Field Manual for Water-Quality Sampling: Tucson, University of Arizona College of Agriculture, 51 p.

[6] Brown, S.L., Yu, W.K., and Munson, B.E., 1996, The impact of agricultural runoff on the pesticide contamination of a river system - A case study on the middle Gila River: Arizona Department of Environmental Quality Open File Report 96-1: Phoenix, Arizona, 50 p.

[7] Craig, H., 1961, Isotopic variations in meteoric waters. Science, 133, pp. 1702-1703.

[8] Crockett, J.K., 1995. Idaho statewide groundwater quality monitoring program–Summary of results, 1991 through 1993: Idaho Department of Water Resources, Water Information Bulletin No. 50, Part 2, p. 60.

[9] Del Mar Laboratory, 2009, Personal communication from Del Mar staff.

[10] Earman, Sam, et al, 2003, An investigation of the properties of the San Bernardino groundwater basin, Arizona and Sonora, Mexico: Hydrology program, New Mexico Institute of Mining and Technology, 283 p.

[11] Graf, Charles, 1990, An overview of groundwater contamination in Arizona: Problems and principals: Arizona Department of Environmental Quality seminar, 21 p.

[12] Heath, R.C., 1989, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 84 p.

[13] Helsel, D.R. and Hirsch, R.M., 1992, *Statistical methods in water resources*: New York, Elsevier, 529 p.

[14] Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water [Third edition]: U.S. Geological Survey Water-Supply Paper 2254, 264 p.

[15] Longsworth, S.A., 1991, Geohydrology and chemical quality of ground water , San Bernardino National Wildlife Refuge, Arizona : U.S. Geological Survey Water-Resources Investigations Open File Report 90-4190, 28 p.

[16] Madison, R.J., and Brunett, J.O., 1984, Overview of the occurrence of nitrate in ground water of the United States, *in* National Water Summary 1984-Water Quality Issues: U.S. Geological Survey Water Supply Paper 2275, pp. 93-105.

[17] New Mexico Resources Research Institute, 2000, Trans-International boundary aquifers in southwestern New Mexico: with New Mexico State University and California State University, Los Angeles, pp. 110-119.

[18] Richard, S.M., Reynolds, S.J., Spencer, J.E. and Pearthree, Pa, P.A., 2000, Geologic map of Arizona: Arizona Geological Survey Map 35, scale 1:1,000,000.

[19] Roberts, Isaac, 2008, Personal communication from ADHS staff.

[20] Robertson, F.N., 1991, Geochemistry of ground water in alluvial basins of Arizona and adjacent parts of Nevada, New Mexico, and California: U.S. Geological Survey Professional Paper 1406-C, 90 p.

[21] Schwab, K.J., 1992, Maps showing groundwater conditions in the San Bernardino Valley Basin, Cochise County, Arizona and Hidalgo County, New Mexico—1991: Department of Water Resources Hydrologic Map Series Report 24, 1 sheet, scale 1:125,000.

[22] Towne, D.C., 2004, Ambient groundwater quality of the San Simon sub-basin: A 2002 baseline study: Arizona Department of Environmental Quality Open File Report 04-02, 77 p.

[23] U.S. Environmental Protection Agency website, www.epa.gov/waterscience/criteria/humanhealth/, accessed 3/05/10.

[24] U.S. Salinity Laboratory, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Department of Agriculture, Agricultural Research Service, Agriculture Handbook No. 60, 160 p.

[25] Wilkinson, L., and Hill, M.A., 1996. *Using Systat 6.0 for Windows*, Systat: Evanston, Illinois, p. 71-275.

[26] Wilson, R.P., 1976, Maps showing ground-water conditions in the San Bernardino Valley area, Cochise County, Arizona—1975: U.S. Geological Survey Water-Resources Investigations Open File Report 76-81, 2 sheets, scale 1:125,000.

[27] Uhlman, Kristine, 2010, Personal communication from Univ. Arizona Water Resources Research Center staff.

Appendix A. Data for Sample Sites, San Bernardino Valley Basin, 2002

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Recharge Source
1st Field Trip, November 6-7, 2002 - Boettcher & Lucci									
SBV-1/1D/1D two dups	D(24-31)10ccc windmill	31°21'06.790" 109°10'44.496"	632854	44463	Choate Well	Inorganic, Radon O & H Isotopes	235'	217’	Paleowater
SBV-2/2S/2D split / dup	D(23-32)31aca submersible	31°23'15.499" 109°07'10.820"	537575	60361	Pic Handle Well	Inorganic, Radon O, H isotopes	600'	418’	Paleowater
SBV-3/3D duplicate	D(24-32)06aac submersible	31°22'31.830" 109°07'40.252"	555652	60362	Rosewood Well	Inorganic, Radon O, H isotopes	800’	-	Paleowater
SBV-4	D(24-30)14cbd artesian	31°20'44.640" 109°15'41.067"	627163	60363	Artesian Well	Inorganic, Radon O & H Isotopes	541’	-	Chiricahua Mountains
SBV-5	D(23-30)33aaa windmill	31°23'34.004" 109°17'16.151"	601087	44147	Glenn Well	Inorganic, Radon O, H isotopes	200’	80’	Chiricahua/ Valley Mix
SBV-6	D(21-29)24dda windmill	31°35'06.995" 109°20'14.589"	629766	43135	Boss HouseWell	Inorganic, Radon O, H isotopes	75’	-	Chiricahua/ Valley Mix
2nd Field Trip, November 19-20, 2002 - Boettcher & Lucci									
SBV-7 duplicate	D(21-31)08da submersible	31°36'50.880" 109°12'12.486"	642414	59792	Gibbons Well	Inorganic, Radon O, H isotopes	700’	600’	Chiricahua Mountains
SBV-8 split	D(22-29)28dbd ?	31°27'48.784" 109°23'02.554"	644186	50930	Silver Ck Rnch Well	Inorganic, Radon O, H isotopes	120’	60’	Chiricahua/ Valley Mix
SBV-9	D(22-30)08ada windmill	31°31'58.108" 109°18'05.976"	629763	43610	Boss Hwy 80 Wndml	Inorganic, Radon O, H isotopes	790’	-	Paleowater
SBV-10	D(21-30)32aca windmill	31°33'46.105" 109°18'32.153"	629764	43140	Boss Wndmll #2	Inorganic, Radon O, H isotopes	200’	-	Chiricahua/ Valley Mix
SBV-11	D(22-31)05cdd submersible	31°32'17.772" 109°32'17.685"	630127	43614	Krentz Well	Inorganic, Radon O, H isotopes	567’	455’	Chiricahua Mountains
SBV-12	D(24-29)11bdc submersible	31°21'26.870" 109°22'00.785"	529709	44434	Garland Well	Inorganic, Radon O, H isotopes	312’	62’	Chiricahua/ Valley Mix
SBV-13	D(23-29)34cbb windmill	31°23'03.017" 109°23'16.971"	616442	60551	Garland Windmill	Inorganic, Radon O, H isotopes	15’-	10’	Chiricahua/ Valley Mix
SBV-14	D(23-31)04caa windmill	31°27'25.293" 109°11'39.634"	630030	44149	McDonald Windmill	Inorganic O, H isotopes	475’	350’	Chiricahua Mountains

Appendix B. Groundwater Quality Data, San Bernardino Valley, 2002

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)
SBV-1/1D/1D	TDS, pH, F, Fe	26.5	**6.41**	*7.0*	1651	1800	**1100**	600	575	*3.55*
SBV-2/2S/2D	F, Fe	29.6	6.57	*7.105*	1376	1550	910	515	510	*15.5*
SBV-3/3D	TDS	20.5	7.64	*7.7*	1216	1300	**770**	100	100	*0.52*
SBV-4		36.9	7.94	*7.8*	899	440	250	100	100	0.04
SBV-5		23.8	8.01	*7.7*	386	430	200	140	140	1.4
SBV-6		20.6	7.88	*7.6*	572	570	360	270	270	0.52
SBV-7/7D		22.5	7.86	*7.95*	312	300	195	115	120	0.145
SBV-8/8S	TDS	20.5	7.83	*8.02*	953	975	**635**	390	390	*0.05*
SBV-9	pH	21.9	**8.79**	*8.4*	415	400	240	36	38	0.78
SBV-10		22.0	8.44	*7.9*	433	430	260	180	180	0.17
SBV-11	pH	21.2	**8.54**	*8.2*	339	327	180	73	76	38
SBV-12	TDS	20.3	7.91	*7.7*	936	920	**590**	190	190	0.08
SBV-13		19.5	8.35	*8.0*	480	470	320	150	150	0.34
SBV-14		27.5	8.49	*8.1*	392	400	220	100	110	1.3

italics = constituent exceeded holding time
bold = constituent exceeded a Primary or Secondary MCL

Appendix B. Groundwater Quality Data, San Bernardino Valley, 2002--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)
SBV-1/1D/1D	160	43.5	180	34	955	1165	ND	19.5	60
SBV-2/2S/2D	137	41	150	23	770	900	ND	16.5	55
SBV-3/3D	25	8.95	230	6.6	160	200	ND	97	240
SBV-4	17	13	59	2.4	206	250	ND	5.8	12
SBV-5	17	24	31	9.4	190	230	ND	7.4	ND
SBV-6	68	24	31	1.4	290	350	ND	14	35
SBV-7/7D	38.35	5.9	13.3	5.3	131	160.5	ND	6..55	5.05
SBV-8/8S	110	29.5	62	2.7	324	388	ND	16.5	190
SBV-9	5.6	5.8	80	5.0	192	234	ND	4.0	10
SBV-10	50	13	19	2.8	170	210	ND	7.8	21
SBV-11	14	10	38	7.0	150	180	ND	6.1	5.2
SBV-12	53	13	140	2.5	290	350	ND	29	130
SBV-13	45	10	52	1.2	220	270	ND	7.3	18
SBV-14	14	18	40	8.8	180	220	ND	5.0	9.0

Appendix B. Groundwater Quality Data, San Bernardino Valley, 2002--Continued

Site #	Nitrate-Nitrite-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (mg/l)	TKN (mg/l)	Ammonia-N (mg/L)	T. Phosphorus (mg/l)	SAR (value)	Irrigation Quality
SBV-1/1D/1D	0.054	0.054	*ND*	ND	ND	ND	3.3	C3 – S1
SBV-2/2S/2D	0.17	0.17	*ND*	0.080	ND	ND	3.1	C3 – S1
SBV-3/3D	*See notes*	5	***See notes***	0.56	0.49	ND	9.9	C3 – S2
SBV-4	0.66	0.66	ND	0.059	ND	ND	2.6	C3 – S1
SBV-5	1.9	1.9	ND	0.14	ND	ND	1.1	C2 – S1
SBV-6	0.25	0.25	ND	0.14	ND	0.029	0.8	C2 – S1
SBV-7/7D	0.575	0.575	*ND*	0.105	-	ND	0.5	C2 – S1
SBV-8/8S	2.0	2.0	*ND*	*0.13*	-	ND	1.3	C3 – S1
SBV-9	0.26	0.26	ND	*ND*	-	0.030	5.7	C2 – S1
SBV-10	3.1	3.1	ND	*0.083*	-	ND	0.6	C2 – S1
SBV-11	1.07	0.83	0.24	*0.079*	-	0.026	1.9	C2 – S1
SBV-12	3.2	3.2	ND	*0.13*	-	ND	4.5	C3 – S1
SBV-13	0.94	0.94	ND	*0.088*	-	0.033	1.8	C2 – S1
SBV-14	0.74	0.74	ND	ND	-	ND	1.7	C2 – S1

italics = constituent exceeded holding time

The nitrite concentration of 10.0 mg/L provided by the laboratory for SBV-3/3D was not used because it was a tremendous outlier that could not be confirmed. See QA/QC notes for more information.

Appendix B. Groundwater Quality Data, San Bernardino Valley, 2002--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)
SBV-1/1D/1D	ND	ND	0.13	0.0017	0.16	ND	ND	0.013	**3.05**
SBV-2/2S/2D	ND	ND	0.14	0.00088	0.145	ND	ND	ND	**2.85**
SBV-3/3D	ND	ND	ND	ND	1.5	ND	0.011	ND	0.38
SBV-4	ND	ND	ND	ND	ND	ND	ND	ND	0.42
SBV-5	ND	ND	ND	ND	ND	ND	ND	ND	0.34
SBV-6	ND	ND	0.21	ND	ND	ND	ND	0.048	0.31
SBV-7/7D	ND	ND	ND	ND	ND	ND	ND	ND	1.25
SBV-8/8S	ND	ND	0.12	ND	ND	ND	ND	ND	0.35
SBV-9	ND	ND	ND	ND	ND	ND	ND	ND	0.59
SBV-10	ND	ND	ND	ND	ND	ND	ND	0.010	0.24
SBV-11	ND	ND	ND	ND	ND	ND	ND	ND	0.72
SBV-12	ND	ND	ND	ND	ND	ND	ND	ND	0.45
SBV-13	ND	ND	ND	ND	ND	ND	ND	ND	0.52
SBV-14	ND	ND	ND	ND	ND	ND	ND	ND	0.62

bold = constituent exceeded a Primary or Secondary MCL

Appendix B. Groundwater Quality Data, San Bernardino Valley, 2002--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)
SBV-1/1D/1D	**0.32**	ND	ND	ND	ND	ND	ND	ND	3.4
SBV-2/2S/2D	**0.76**	ND	ND	ND	ND	ND	ND	ND	0.34
SBV-3/3D	ND	ND	ND	ND	ND	ND	ND	ND	0.88
SBV-4	ND	ND	ND	ND	ND	ND	ND	ND	ND
SBV-5	ND	ND	ND	ND	ND	ND	ND	ND	ND
SBV-6	ND	ND	ND	ND	ND	ND	ND	ND	0.35
SBV-7/7D	ND	ND	ND	ND	ND	ND	ND	ND	0.15
SBV-8/8S	ND	ND	ND	ND	ND	ND	ND	ND	ND
SBV-9	0.17	ND	ND	ND	ND	ND	ND	ND	0.080
SBV-10	ND	ND	ND	ND	ND	ND	ND	ND	0.10
SBV-11	ND	ND	ND	ND	ND	ND	ND	ND	0.078
SBV-12	ND	ND	ND	ND	ND	ND	ND	ND	ND
SBV-13	ND	ND	ND	ND	ND	ND	ND	ND	0.064
SBV-14	ND	ND	ND	ND	ND	ND	ND	ND	0.098

bold = constituent exceeded a Primary or Secondary MCL

Appendix B. Groundwater Quality Data, San Bernardino Valley, 2002--Continued

Site #	Radon-222 (pCi/L)	δ^{18} O ($^{0}/_{00}$)	δ D ($^{0}/_{00}$)	Type of Chemistry
SBV-1/1D/1D	**334**	-10.4	-76	mixed-bicarbonate
SBV-2/2S/2D	ND	-10.3	-75	mixed-bicarbonate
SBV-3/3D	ND	-9.4	-71	sodium-mixed
SBV-4	414	-8.9	-66	sodium-bicarbonate
SBV-5	**633**	-8.0	-59	mixed-bicarbonate
SBV-6	**321**	-8.5	-61	calcium-bicarbonate
SBV-7/7D	**764**	-9.0	-64	calcium-bicarbonate
SBV-8/8S	131	-7.3	-56	calcium-bicarbonate
SBV-9	298	-11.1	-81	sodium-bicarbonate
SBV-10	66	-8.1	-61	calcium-bicarbonate
SBV-11	50	-8.7	-63	mixed-bicarbonate
SBV-12	**452**	-8.0	-57	sodium-bicarbonate
SBV-13	251	-7.6	-59	mixed-bicarbonate
SBV-14	-	-8.9	-64	mixed-bicarbonate

bold = constituent exceeded a Primary or Secondary MCL