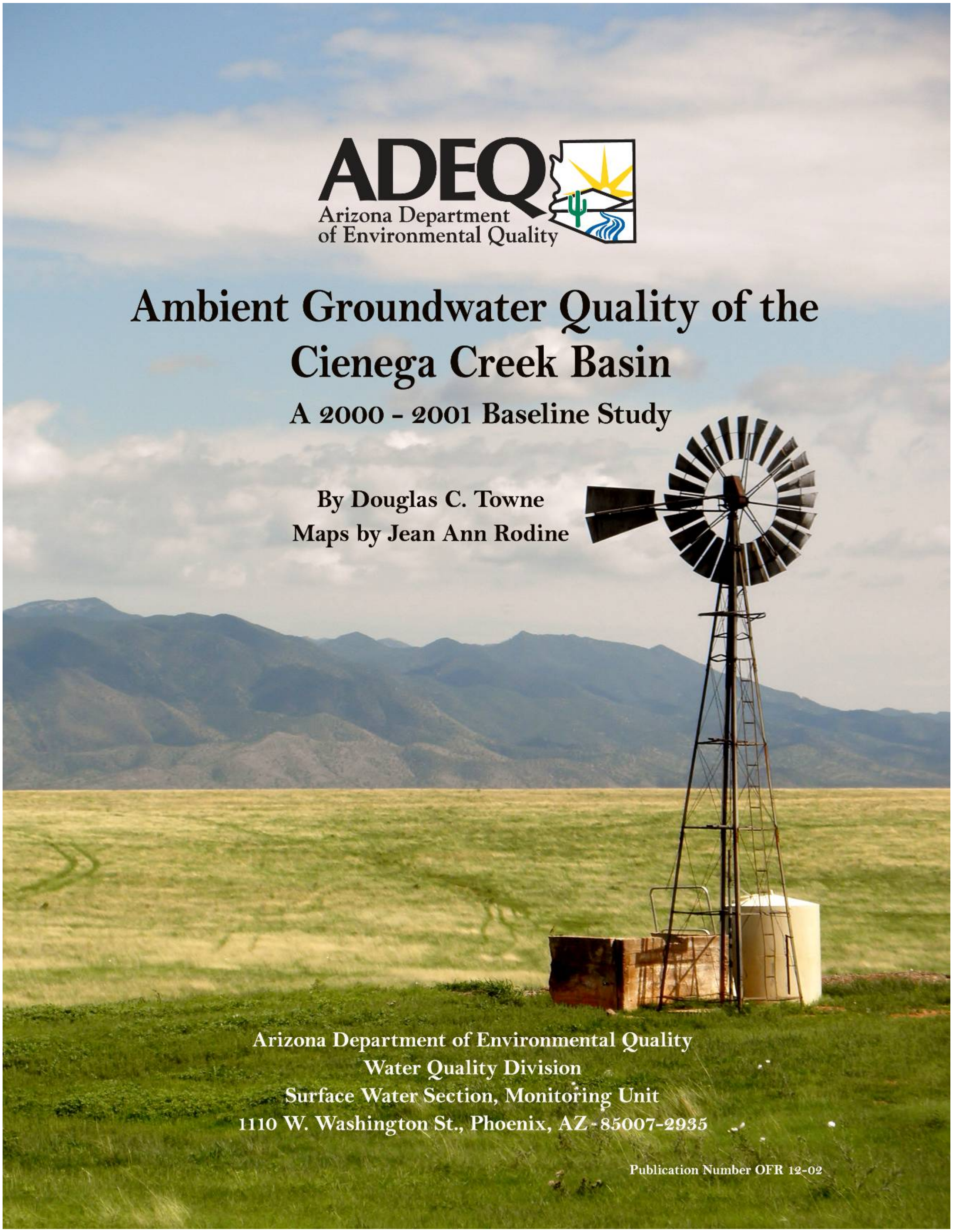

ADEQ
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Ambient Groundwater Quality of the Cienega Creek Basin

A 2000 - 2001 Baseline Study

By Douglas C. Towne
Maps by Jean Ann Rodine

Arizona Department of Environmental Quality
Water Quality Division
Surface Water Section, Monitoring Unit
1110 W. Washington St., Phoenix, AZ 85007-2935

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Open File Report 12-02

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Thanks:

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

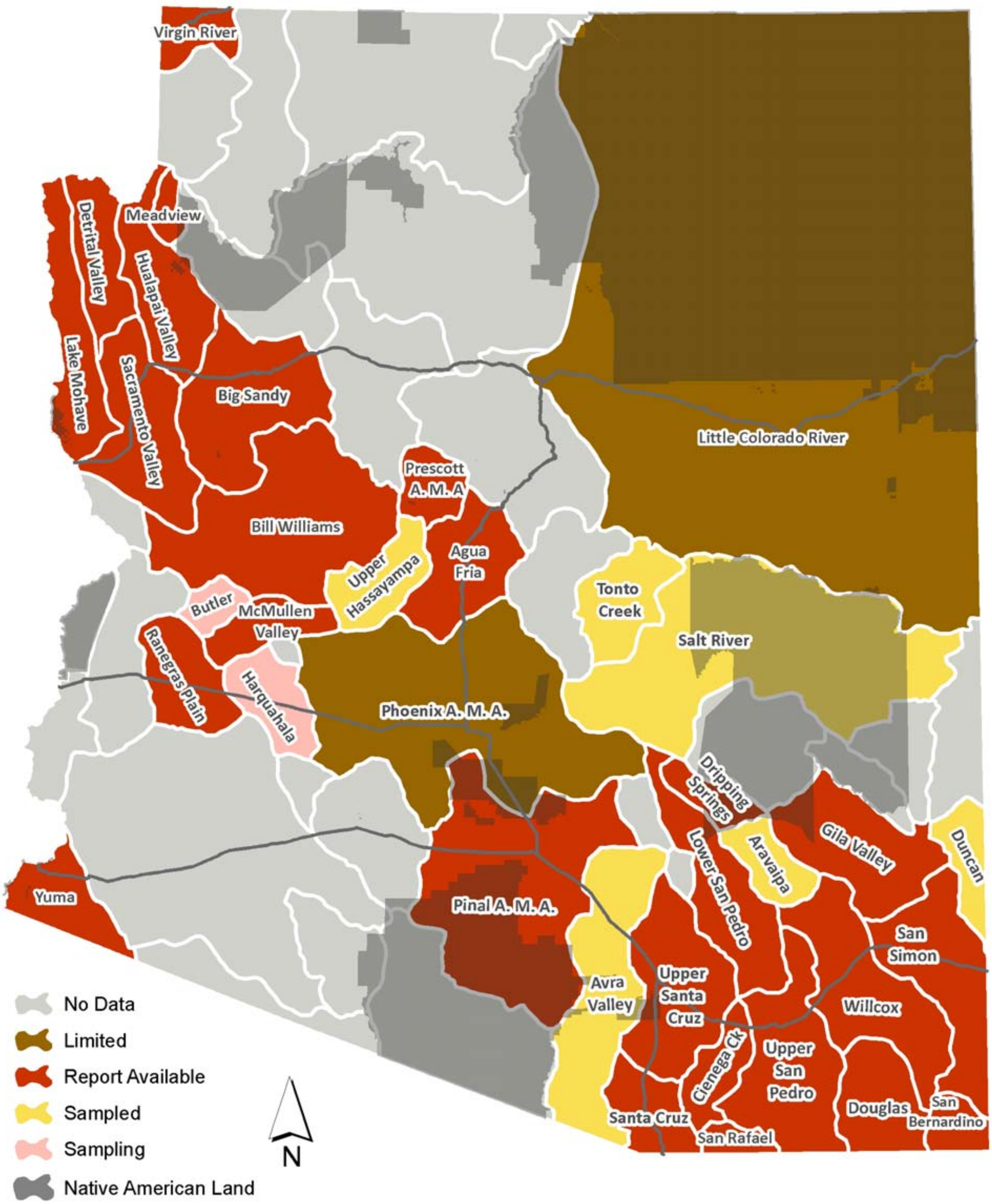
Report Cover: Windmills are a popular method of pumping groundwater in the Cienega Creek basin. This well is located near the town of Sonoita in grasslands made verdant by monsoon precipitation.

Other Publications of the ADEQ Ambient Groundwater Monitoring Program

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

Cienega Creek Basin	OFR 12-02, 46 p.	FS 12-05, 4 p.
Ranegras Plain Basin	OFR 11-07, 63 p.	FS 12-04, 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 on-line at:
www.azdeq.gov/environ/water/assessment/ambient.html



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

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Abbreviations

amsl	above mean sea level
ac-ft	acre-feet
af/yr	acre-feet per year
ADEQ	Arizona Department of Environmental Quality
ADHS	Arizona Department of Health Services
ADWR	Arizona Department of Water Resources
ARRA	Arizona Radiation Regulatory Agency
AZGS	Arizona Geological Survey
As	arsenic
bls	below land surface
BLM	U.S. Department of the Interior Bureau of Land Management
BRW	Babocomari River watershed
CAP	Central Arizona Project
^{o}C	degrees Celsius
CCK	Cienega Creek groundwater basin
CCW	Cienega Creek watershed
$CI_{0.95}$	95 percent Confidence Interval
Cl	chloride
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
gpm	gallons per minute
GWPL	Groundwater Protection List active ingredient
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
SCW	Sonoita Creek watershed
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

Ambient Groundwater Quality of the Cienega Creek Basin: A 2000-2001 Baseline Study

Abstract - In 2000-2001, the Arizona Department of Environmental Quality (ADEQ) conducted a baseline groundwater quality study of the Cienega Creek basin located in southeastern Arizona. The long, narrow basin comprises 605 square miles within Cochise, Pima and Santa Cruz counties and includes the towns of Patagonia and Sonoita.[4] In 2000, the basin had a population of 4,355.[4] Land ownership consists of federal lands managed by the Forest Service (41 percent) and the Bureau of Land Management (12 percent). State land (24 percent) and private land (23 percent) constitute the remainder of the basin.[4] Mining activity has occurred throughout much of the basin's mountains. Although no mines are currently in operation within the Cienega Creek basin, the proposed Rosemont Copper Mine is located in the Santa Rita Mountains.

The basin is divided into three watersheds separated by an inconspicuous topographical divide near the town of Sonoita: Cienega Creek flows to the north, Sonoita Creek flows to the south, and the Babocomari River flows to the east. Groundwater is used for all domestic, public, stock and irrigation purposes except for stock ponds that retain surface water.[4] Aquifers found in the basin include streambed alluvium and basin-fill deposits; in the north the Pantano Formation produces limited groundwater. Small quantities of groundwater can also be found in some mountain locations. [4]

Streambed alluvium, consisting of unconsolidated silt, sand, and gravel deposits, occurs in the floodplain of Cienega Creek, Sonoita Creek, and their major tributaries. Thicker, basin-fill deposits composed of interbedded clay, silt, sand, and gravel layers are found at deeper depths. While the basin-fill aquifer is productive in the Cienega Creek watershed; in the Sonoita Creek watershed the aquifer is largely dewatered by washes which dissect the aquifer.[4]

To characterize regional groundwater quality, samples were collected from 20 sites (19 wells and 1 spring). Water from the wells was predominantly used for domestic (15 wells) and stock (4 wells) uses; the spring provided water for stock purposes. Inorganic samples were collected from all sites. Samples for radionuclide, radon, and volatile organic compound (VOC) analysis were collected from 10 sites.

Health-based, Primary Maximum Contaminant Levels (MCLs) were exceeded at 3 of the 20 sites (15 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. [19] Constituents exceeding Primary MCLs include arsenic (one site) and gross alpha (two sites). Elevated concentrations of arsenic and gross alpha likely occur naturally though the latter can be exacerbated by mining activities.[13] Aesthetics-based, Secondary MCLs were exceeded at 2 of 20 sites (10 percent). These are unenforceable aesthetics guidelines that define the maximum constituent concentration that can be present in drinking water without an unpleasant taste, color, or odor.[19] Constituents above Secondary MCLs include iron (one site), manganese (one site), sulfate (one site), and total dissolved solids (TDS) (two sites).

Groundwater in the basin is typically *slightly-alkaline*, *fresh* and *moderately hard* to *very hard*, based on pH levels along with TDS and hardness concentrations. [7, 10] Water chemistry in the basin is predominantly calcium-bicarbonate. Barium, fluoride, and zinc are the only trace elements detected at more than 25 percent of sites. Groundwater parameters varied by watershed and aquifer. Constituents such as well depth, groundwater depth and pH were significantly greater in the Cienega Creek watershed than the Sonoita Creek watershed; specific conductivity, TDS, hardness, calcium, and sulfate had the opposite pattern. Well depth, groundwater depth, and pH-lab were greater in the basin-fill aquifer than the streambed alluvium aquifer. Well depth, groundwater depth, pH-field, pH-lab, hardness, calcium, and magnesium were generally greater in the Sonoita Creek streambed aquifer than the Cienega Creek streambed or basin-fill aquifers (Kruskal-Wallis with Tukey test, $p \leq 0.05$).

Groundwater quality parameter differences between the Cienega Creek and Sonoita Creek watersheds may be explained by aquifer characteristics. The Cienega Creek watershed's main aquifer is the deep basin fill deposits; this influences the greater well and groundwater depths. The higher pH levels are the result of older, more evolved groundwater found in the deeper aquifer. [15] In contrast, the Sonoita Creek watershed's main aquifer is shallow, streambed alluvium. The watershed's higher concentrations of calcium and hardness are reflective of recent recharge occurring from perennial stream flow. The higher concentrations of sulfate, and to a lesser degree, TDS, may be influenced by historic mining that occurred in area particularly in the Patagonia and Santa Rita mountains. [13, 17]

INTRODUCTION

Purpose and Scope

The Cienega Creek basin (CCK) comprises approximately 606 square miles within Cochise, Pima, and Santa Cruz Counties in southern Arizona (Map 1).[4] The long, narrow basin is located to the southeast of Tucson and extends almost to the border with Mexico. In 2000, the basin had a population of 4,355 which included the towns of Patagonia and Sonoita.[4] Main roads traversing the basin include Interstate 10 in the north and, further south, Arizona Highway 82 and Highway 83.

There are no known surface water diversions in the basin; groundwater is the source for all domestic, public supply, irrigation, and stock purposes except for some minor stock uses. [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 Cienega Creek basin identifying water quality variations between watersheds and aquifers.
- A process for evaluating potential groundwater quality impacts arising from mineralization, mining, livestock, septic tanks, and/or poor well construction.
- A guide for identifying future locations of public supply wells.

Physical Characteristics

Geography – Located within the Basin and Range physiographic province, the Cienega Creek basin is a narrow, northwest-trending alluvial valley surrounded by fault-block mountains.[4] The basin is bounded on the west by the Santa Rita and Empire Mountains, on the north by the Rincon Mountains, on the east by the Whetstone and Mustang Mountains, and on the south by the Canelo Hills and Patagonia Mountains. In the central part of the basin is Empire Valley which narrows to the north and southwest where surface water drainages exit the basin.

A surface water divide southwest of the town of Sonoita separates the Cienega Creek watershed in the north from the Sonoita Creek watershed in the south and the Babocomari River watershed in the east. Riparian vegetation along these waterways include mixed broadleaf and mesquite trees.[4]

The basin's central valley is semi-arid grassland with elevations ranging from 3,000 to 5,000 feet above mean sea level (amsl). The mountains surrounding the valley range in elevation from 6,000 to 8,000 amsl and consist of evergreen woodlands along with limited areas of conifer forest. [4]

Employment in the basin includes trade and service industries. There are also several ranches, vineyards, and wineries. Many homes have been built in the area as new residents have been drawn by the scenery and temperate climate.

The basin consists of federal land (53 percent) including Coronado National Forest lands managed by the Forest Service (41 percent) and the Bureau of Land Management (12 percent) which administers the Las Cienegas National Conservation Area. State Trust lands (24 percent) and private land (23 percent) constitute the remainder of lands in the basin. [3]

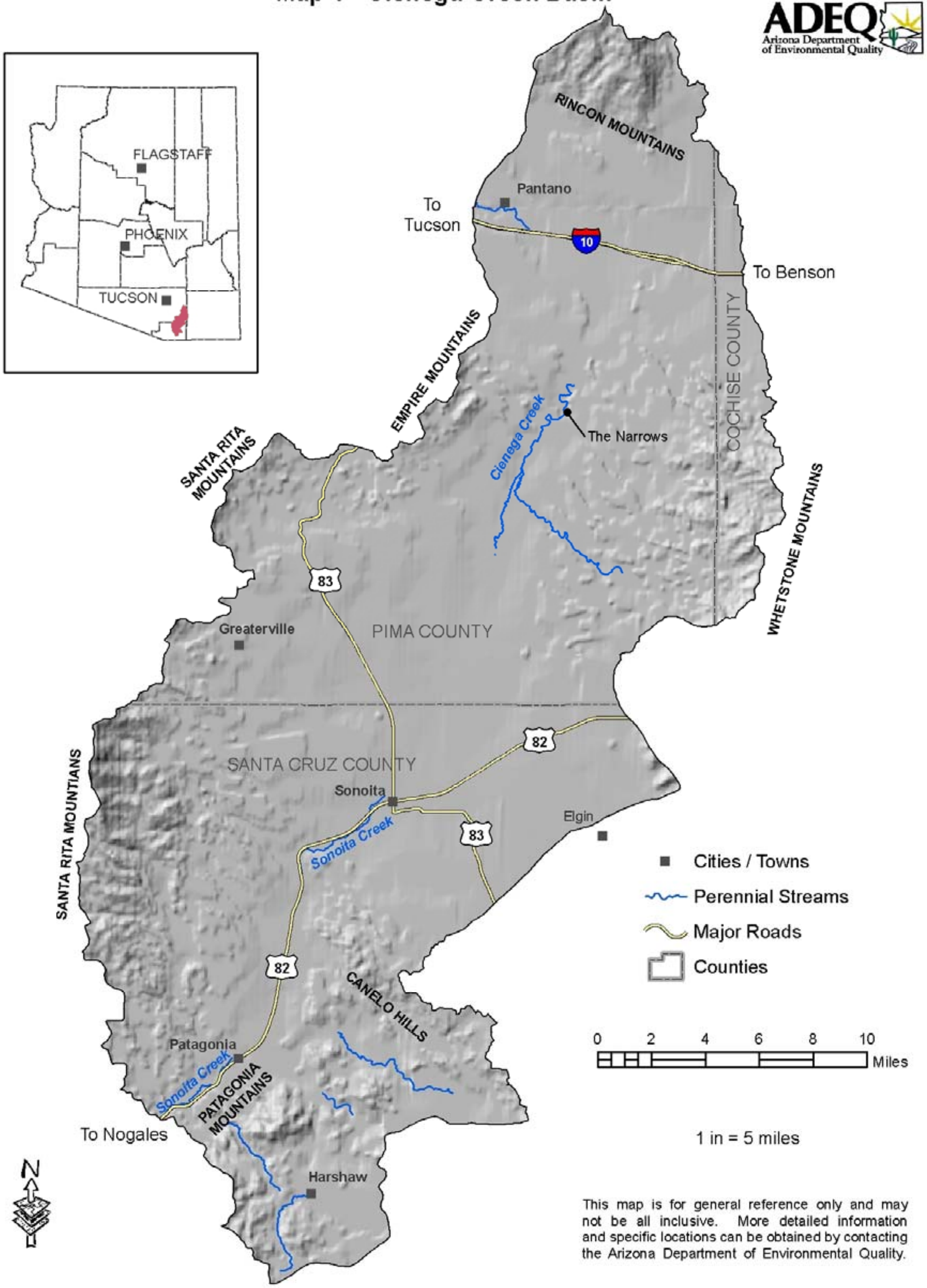
Climate – The Cienega Creek basin has a semi-arid climate characterized by hot, dry summers and mild winters. Precipitation varies with elevation in basin, ranging from 16 inches annually along Interstate 10 in the north to over 38 inches in the Santa Rita Mountains. Precipitation occurs predominantly as rain in either late summer, localized monsoon thunderstorms or, less often, as widespread, low intensity winter rain that also includes snow particularly at higher elevations. [4]

HYDROLOGY

There are three main drainages in the basin: Cienega Creek, Sonoita Creek and Babocomari River.

Cienega Creek is an intermittent stream with perennial stretches that drains north out of the basin into the Tucson Active Management Area.

Map 1 - Cienega Creek Basin



The creek contains upper and lower sections that are divided at a bedrock formation called “the Narrows.” The upper section is a broad valley that has ephemeral flow occurring from local storm events. The lower section is a narrow valley that debouches into Pantano Wash and has perennial reaches where groundwater is forced to surface by bedrock. Cienega Creek has an annual surface discharge averaging 1,900 acre-feet per year. [4]

Sonoita Creek is a perennial stream that flows to the southwest through a narrow valley and debouches into the Santa Cruz River north of Nogales. Surface flow in the creek averages 5,850 acre-feet per year. [4]

The headwaters of the ephemeral Babocomari River are located to the east of the town of Sonoita.

Groundwater Characteristics

Groundwater in the Cienega Creek basin occurs in two main aquifers: streambed alluvium and basin-fill deposits. In addition, groundwater is found in limited amounts in the Pantano Formation (located only in the lower Cienega Creek section) and the bedrock of the surrounding fault-block mountains.

Cienega Creek Watershed – the upper section includes most of the basin’s central valley and has two primary aquifers: streambed alluvium and basin-fill. The streambed alluvium is composed of sand and gravel deposited along Cienega Creek and its major tributaries and has a maximum thickness of 200 feet bls. It is a minor aquifer because of limited spatial extent. [4]

The main aquifer in the upper section is the basin-fill alluvium which is composed of interbedded clay, silt, sand, and gravel layers. The basin-fill is an unconfined aquifer except where clay layers create confining conditions northeast of the town of Sonoita. [4]

The lower section consists of the area north of “the Narrows.” Streambed alluvium is the main aquifer and consists of unconsolidated silt, sand, and gravel deposits. Aquifer tests indicate wells in this aquifer could yield up to 1,500 gallons per minute. [4]

Underlying the streambed alluvium is the basin-fill aquifer which consists of loosely-to-moderately lithified clay, silt, sand, gravel, and boulder-sized rocks. The aquifer ranges from 25 to over 525 feet thick and interbedded clay layers create a leaky, confined aquifer that produce water levels varying from land surface to 340 feet bls. Wells in the basin-fill aquifer yield an average of 25 gallons per minute. [4]

The Pantano Formation is found below the basin-fill sediments and is composed of moderately-to-well lithified conglomerates, breccias, and fanglomerates. Wells completed in this formation range in yield from 3 to 30 gallons per minute. [4]

Sonoita Creek Watershed – the primary aquifer is the streambed alluvium that forms the floodplain of Sonoita Creek and its major tributaries. Composed of unconsolidated silt, sand and gravel deposits, the aquifer is up to 90-feet thick. Yields from wells completed in the streambed alluvium can average up to 10 gallons per minute. [4]

The few wells completed in the basin-fill or igneous rocks of the surrounding mountains are low yielding. The washes which dissect the basin-fill, dewater the formation making it dry except where it extends below the level of Sonoita Creek. The basin-fill consists of terrace deposits consisting of silt, sand, gravel, and boulders. [4]

Babocomari River Watershed – composes a very limited portion of the basin; groundwater is found both in streambed alluvium and basin-fill deposits.

Groundwater Use and Recharge - The total amount of recoverable groundwater in storage to a depth of 1,200 acre-feet bls is estimated to be 5.1 million acre-feet.[4] An average of 1,200 acre-feet is pumped annually. Groundwater usage is roughly equal to recharge as suggested by little significant change in long-term water levels. Recharge occurs along mountain-fronts and the infiltration of runoff along major streams. [4]

INVESTIGATION METHODS

ADEQ collected samples from 20 groundwater sites to characterize regional groundwater quality in the Cienega Creek basin (Map 2). Specifically, the following types of samples were collected:

- inorganics at 20 sites
- radionuclides at 10 sites
- radon at 10 sites
- volatile organic compounds (VOCs) at 10 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. [9]

Wells pumping groundwater for domestic and stock purposes were sampled for the study provided each well

Figure 1 – The sample collected (CCK-1) from this 360-foot-deep, domestic well near the Whetstone Mountains had a gross alpha concentration of 20 pCi/L which exceeded the 15 pCi/L health-based, water quality standard. The sample was also unusual in that it was the only site that had sodium as the dominant cation.

Figure 2 – The duplicate samples (CCK-13/14) collected from this domestic well located east of the town of Sonoita met all health and aesthetics-based water quality standards. The sample's calcium-bicarbonate chemistry and low TDS concentration (220 mg/L) suggests the groundwater consists of recent, mountain-front recharge.

Figure 3 – Located north of Interstate 10 near the Rincon Mountains, this former windmill is now powered by a submersible pump. The sample (CCK-23) collected by ADEQ's Maureen Freark from this 600-foot-deep well met all health and aesthetics-based water quality standards.

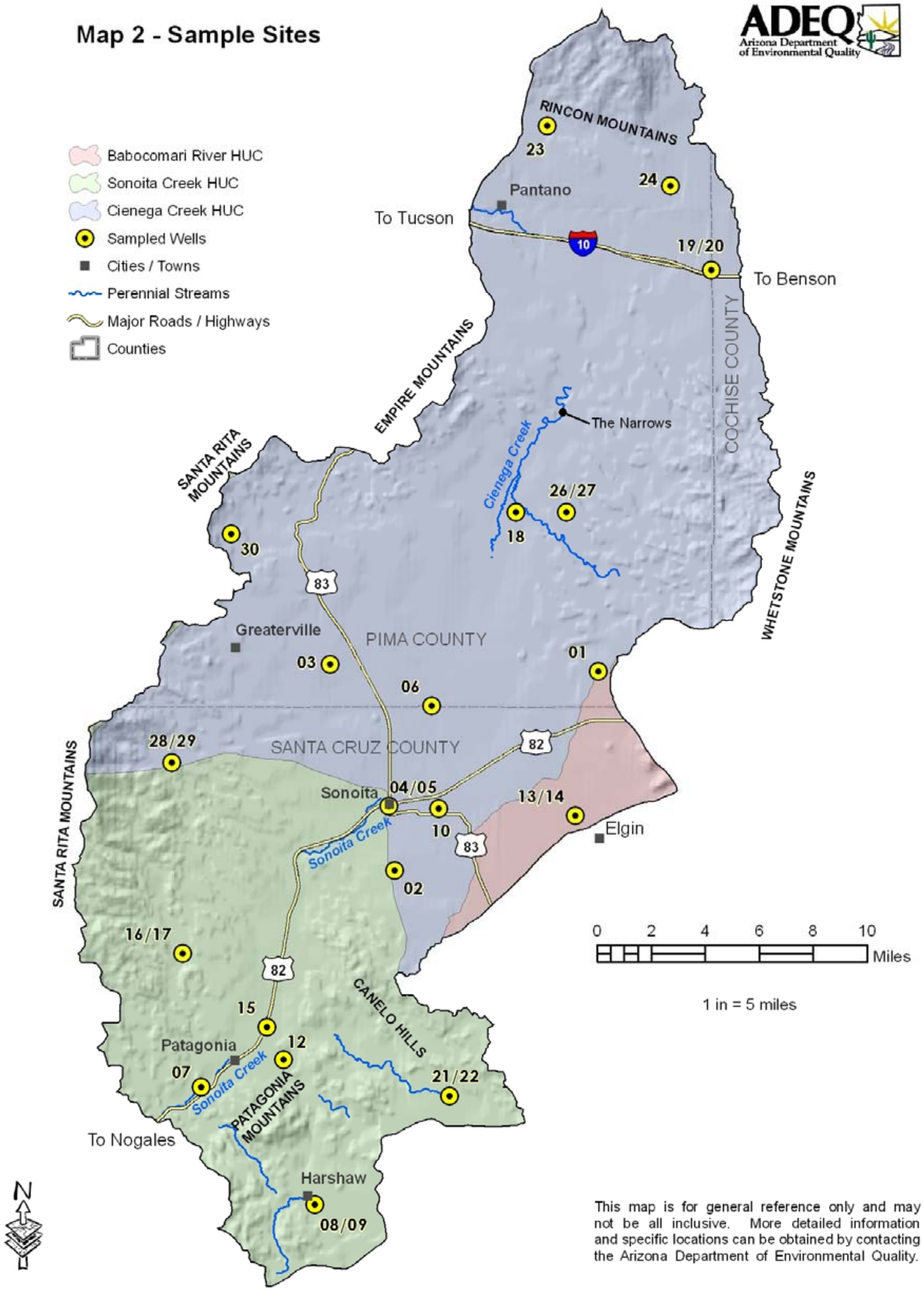
Figure 4 – The Coronado Well is located near the head of Red Rock Canyon Creek in the southeast part of the basin. The well's submersible pump is powered by solar panels. The split samples (CCK-21/22) collected from the well exceeded aesthetic-based standards for TDS, iron and manganese. The sample's TDS concentration of 695 mg/L was the highest of the 20 sites sampled in the Cienega Creek basin.

Figure 5 – Norman and Ruth Hale pose in front of their well located near the former silver-mining community of Harshaw. A duplicate sample (CCK-8/9) was collected from their well for laboratory and field quality assurance purposes.

Figure 6 – Located on the Empire Cienega Resource Conservation Area, the BLM windmill is located near a perennial stretch of Cienega Creek. The sample (CCK-18) collected from the windmill met all health and aesthetics-based water quality standards.

Figure 7 – Sample CCK-7, which met all water quality standards, was collected from a faucet located atop a 180-foot-deep well located in the Nature Conservancy's Patagonia-Sonoita Creek Preserve. Sonoita Creek is perennial in the preserve and supports a verdant riparian area rich in biodiversity.

Figure 8 – The faucet atop Grader Well (CCK-3) provides an optimal sampling location to obtain freshly pumped groundwater. The well located northwest of the town of Sonoita, met all health and aesthetics-based water quality standards.


Map 2 - Sample Sites
ADEQ
Arizona Department of Environmental Quality
Babocomari River HUC
Sonoita Creek HUC
Cienega Creek HUC
Sampled Wells
Cities / Towns
Perennial Streams
Major Roads / Highways
Counties
RINCON MOUNTAINS
23
24
Pantano
To Tucson
10
19/20
To Benson
COCHISE COUNTY
EMPIRE MOUNTAINS
The Narrows
Cienega Creek
SANTA RITA MOUNTAINS
26/27
18
30
WHETSTONE MOUNTAINS
83
Greaterville
PIMA COUNTY
03
01
06
28/29
SANTA CRUZ COUNTY
82
Sonoita
04/05
13/14
10
Elgin
Sonoita Creek
83
02
SANTA RITA MOUNTAINS
0 2 4 6 8 10
Miles
1 in = 5 miles
16/17
82
CANELO HILLS
15
12
Patagonia
07
Sonoita Creek
21/22
PATAGONIA MOUNTAINS
To Nogales
Harshaw
08/09
N
This map is for general reference only and may not be all inclusive. More detailed information and specific locations can be obtained by contacting the Arizona Department of Environmental Quality.

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]

For this study, ADEQ personnel sampled 19 wells all served by submersible pumps except for one windmill. One spring used for stock watering was also sampled for the study. Of the 19 wells sampled, their primary purposes were domestic (15 wells) and stock (4 wells). 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—were monitored at least every five minutes using an YSI multi-parameter instrument.

A sample representative of the aquifer was collected from a point as close to the wellhead as possible to assure obtaining fresh water from the aquifer. In certain instances, it was not possible to purge three bore volumes. In these cases, at least one bore volume was evacuated. In all cases physical parameters were allowed to stabilize within 10 percent of the reading five minutes previous.

Sample bottles were filled in the following order:

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

VOC samples were collected in two, 40-ml amber glass vials which contained 10 drops 1:1 hydrochloric (HCl) acid preservative prepared by the laboratory. Before sealing the vials with Teflon caps, pH test strips were used to confirm the pH of the sample was below 2 su; additional HCl acid was added if necessary to lower the pH. VOC samples were also checked to make sure there was no air contained in the vials. [16]

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.[18]

The inorganic constituents were collected in three, 1-liter polyethylene bottles: samples to be analyzed for dissolved metals were 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. [16]

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. [8]

All samples were kept at 4^{o}C with ice in an insulated cooler with the exception of radiochemistry samples. [8] Chain of custody procedures were followed in sample handling. Samples for this study were collected during four field trips between July 2000 and February 2001.

Laboratory Methods

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

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

Radionuclide analyses were conducted by the Arizona Radiation Agency Laboratory in Phoenix. The following EPA SDW protocols were used: Gross alpha was analyzed, and if levels exceeded 5 picocuries per liter (pCi/L), then radium-226 was measured. If radium-226 exceeded 3 pCi/L, radium-228 was measured. If gross alpha levels exceeded 15 pCi/L initially, then radium-226/228 and total uranium were measured. [8]

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	SM2320B / M2320 B	2 / 5
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 / --
TDS	Gravimetric	SM2540C	10 / 20
Turbidity (NTU)	Nephelometric	EPA 180.1	0.01 / 1.0
Major Ions			
Calcium	ICP-AES	EPA 200.7	5 / 2
Magnesium	ICP-AES	EPA 200.7	1 / 0.5
Sodium	ICP-AES	EPA 200.7	5
Potassium	Flame AA	EPA 200.7	0.5 / 1
Bicarbonate	Calculation	Calculation / / M2320 B	2
Carbonate	Calculation	Calculation / / M2320 B	2
Chloride	Potentiometric Titration	SM 4500 CL D / E300	1 / 5
Sulfate	Colorimetric	EPA 375.4 / E300	10 / 0.5
Nutrients			
Nitrate as N	Colorimetric	EPA 353.2	0.02 / 0.1
Nitrite as N	Colorimetric	EPA 353.2	0.02 / 0.1
Ammonia	Colorimetric	EPA 350.1/ EPA 350.3	0.02 / 0.5
TKN	Colorimetric	EPA 351.2 / M4500-NH3	0.05 / 0.50
Total Phosphorus	Colorimetric	EPA 365.4 / M4500-PB	0.02 / 0.05

All units are mg/L except as noted
Source [16, 18]

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

Constituent	Instrumentation	ADHS / Del Mar Water Method	ADHS / Del Mar Minimum Reporting Level
Trace Elements			
Aluminum	ICP-AES	EPA 200.7	0.5
Antimony	Graphite Furnace AA	EPA 200.8	0.005 / 0.004
Arsenic	Graphite Furnace AA	EPA 200.9 / EPA 200.8	0.01 / 0.003
Barium	ICP-AES	EPA 200.8 / EPA 200.7	0.1 / 0.01
Beryllium	Graphite Furnace AA	EPA 200.9 / EPA 200.8	0.0005
Boron	ICP-AES	EPA 200.7	0.1 / 0.5
Cadmium	Graphite Furnace AA	EPA 200.8	0.001 / 0.0005
Chromium	Graphite Furnace AA	EPA 200.8 / EPA 200.7	0.01 / 0.004
Copper	Graphite Furnace AA	EPA 200.8 / EPA 200.7	0.01 / 0.004
Fluoride	Ion Selective Electrode	SM 4500 F-C	0.2 / 0.1
Iron	ICP-AES	EPA 200.7	0.1
Lead	Graphite Furnace AA	EPA 200.8	0.005 / 0.001
Manganese	ICP-AES	EPA 200.7	0.05 / 0.02
Mercury	Cold Vapor AA	SM 3112 B / EPA 245.1	0.0005 / 0.0002
Nickel	ICP-AES	EPA 200.7	0.1 / 0.05
Selenium	Graphite Furnace AA	EPA 200.9 / EPA 200.8	0.005 / 0.004
Silver	Graphite Furnace AA	EPA 200.9 / EPA 200.7	0.001 / 0.005
Thallium	Graphite Furnace AA	EPA 200.9 / EPA 200.8	0.002
Zinc	ICP-AES	EPA 200.7	0.05
Radionuclides			
Gross alpha beta	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 [8, 16, 18]

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

Volatile Organic Compounds (VOCs)	
Benzene	Cis-1,2-Dichloroethene
Bromodichloromethane	Trans-1,2-Dichloroethene
Bromoform	1,2-Dichloropropane
Bromomethane	Cis-1,3-Dichloropropene
Carbon Tetrachloride	Trans-1,3-Dichloropropene
Chlorobenzene	Ethylbenzene
Chloroethane	Methylene Chloride
Chloroform	Methyl T-Butyl Ether
Chloromethane	1,1,2,2-Tetrachloroethane
Dibromochloromethane	Tetrachloroethene
1,2-Dichlorobenzene	Toluene
1,3-Dichlorobenzene	1,1,1-Trichloroethane
1,4-Dichlorobenzene	1,1,2-Trichloroethane
Dichlorodifluoromethane	Trichloroethene
1,1-Dichloroethane	Trichlorofluoromethane
1,2-Dichloroethane	Vinyl Chloride
1,1-Dichloroethene	Xylenes, Total

Note: all analysis was conducted with a PID-GC/Hall Detector, using EPA method 601/602, and having a minimum reporting level of 1 ug/L Source [16]

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 Cienega Creek 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: (4 duplicates, 4 splits, and 4 blanks).
- Radionuclide: (no QA/QC samples)
- Radon: (1 duplicate)
- VOC: (4 blanks)

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

Blanks – Four equipment blanks for inorganic analyses were collected and delivered to the ADHS laboratory 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] Equipment blank samples for major ion and nutrient analyses were collected by filling unpreserved and sulfuric acid preserved bottles with de-ionized water. Equipment blank samples for trace element analyses were collected with de-ionized water that had been filtered into nitric acid preserved bottles.

Only three equipment blanks were able to be evaluated as CCK-11 was accidentally filled with potassium-chloride solution instead of de-ionized water. Systematic contamination was judged to occur if more than 50 percent of the equipment blank samples contained measurable quantities of a particular groundwater quality constituent. The equipment blanks contained specific conductivity (SC)-lab and turbidity contamination at levels expected due to impurities in the source water used for the samples. The blank results indicated systematic contamination with SC and turbidity that were each detected in all three equipment blanks.

For SC, the three equipment blanks had a mean value (1.2 uS/cm) which was less than 1 percent of the SC mean concentration for the study and was not considered significantly affecting the sample results. The SC detections may be explained in two ways: water passed through a de-ionizing exchange unit will normally have an SC value of at least 1 uS/cm, and carbon dioxide from the air can dissolve in de-ionized water with the resulting bicarbonate and hydrogen ions imparting the observed conductivity.[16]

For turbidity, the three equipment blanks had a mean level of 0.35 nephelometric turbidity units (ntu) less than 1 percent of the turbidity mean level for the study and was not considered significantly affecting the sample results. Testing indicates turbidity is present at 0.01 ntu in the de-ionized water supplied by the ADHS laboratory, and levels increase with time due to storage in ADEQ carboys.[16]

Four organic travel blanks had no detections of VOCs except that the blank carried in the fourth field trip had the chloromethane result listed as "present."

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 or unique constituent concentrations as judged by SC-field and pH-field values.

Four duplicate samples was collected and submitted to the ADHS laboratory for this study. Analytical results indicate that of the 40 constituents examined, 19 had concentrations above the MRL. The duplicate samples had an excellent correlation as the median variation between constituents was less than 5 percent (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] Four inorganic split samples were collected and distributed between the ADHS and Del Mar labs. The analytical results were evaluated by examining the variability in constituent concentrations in terms of absolute levels and as the percent difference.

Analytical results indicate that of the 36 constituents examined, 19 had concentrations above MRLs for both ADHS and Test America laboratories (Table 3). The maximum variation between constituents was 25 percent; over half of the constituents had maximum variations below 10 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

Table 2. Summary Results of Cienega Creek Basin Duplicate Sample from ADHS Laboratory

Parameter	Number of Dup. Sites	Difference in Percent			Difference in Concentrations		
		Minimum	Maximum	Median	Minimum	Maximum	Median
Physical Parameters and General Mineral Characteristics							
Alk., Total	4	0 %	2 %	0 %	0	7	0
SC (uS/cm)	4	0 %	2 %	0 %	0	10	0
Hardness	4	0 %	0 %	0 %	0	0	0
pH (su)	4	0 %	1 %	1 %	0	0.2	0.1
TDS	4	0 %	2 %	0 %	0	10	0
Turb. (ntu)	2	0 %	20 %	0 %	0	-	0.3
Major Ions							
Calcium	4	0 %	1 %	1 %	0	1	1
Magnesium	4	0 %	1 %	0 %	0	0.2	0
Sodium	4	0 %	1 %	0 %	0	0.2	0
Potassium	4	0 %	20 %	3 %	0	1.7	0.1
Bicarbonate	4	0 %	3 %	0 %	0	13	0
Chloride	4	4 %	8 %	5 %	0.3	0.5	0.5
Sulfate	3	0 %	6 %	0 %	0	2	0
Nutrients							
Nitrate (as N)	4	0 %	8 %	0 %	0	0.012	0
Phosphorus, T.	1	-	-	13 %	-	-	0.011
Trace Elements							
Arsenic	1	-	-	2 %	-	-	0.001
Barium	2	0 %	0 %	-	0	0	-
Fluoride	2	0 %	3 %	-	0	13	-
Zinc	1	-	-	5 %	-	-	0.1
Radon							
Radon	1	-	-	1 %	-	-	21

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

Table 3. Summary Results of Cienega Creek Basin Split Samples between ADHS / Del Mar Labs

Constituents	Number of Split Sites	Difference in Percent		Difference in Levels		Significance
		Minimum	Maximum	Minimum	Maximum	
Physical Parameters and General Mineral Characteristics						
Alkalinity, total	4	0 %	3 %	0	10	ns
SC (uS/cm)	4	0 %	2 %	0	10	ns
Hardness	4	0 %	8 %	0	20	ns
pH (su)	4	2 %	4 %	0.33	0.55	ns
TDS	4	1 %	12 %	10	50	ns
Turbidity (ntu)	2	12 %	23 %	1.6	8	ns
Major Ions						
Calcium	4	0 %	5 %	0	5	ns
Magnesium	4	2 %	7 %	0.1	7	ns
Sodium	4	1 %	5 %	1	2	ns
Potassium	4	3 %	5 %	0.1	0.3	ns
Chloride	4	3 %	11 %	0.6	1.3	ns
Sulfate	3	0 %	12 %	0	50	ns
Nutrients						
Nitrate as N	3	0 %	5 %	0	0.04	ns
Phosphorus, T.	1	-	24 %	-	0.05	ns
Trace Elements						
Barium	1	-	0 %	-	0	ns
Fluoride	4	5 %	25 %	0.03	0.15	ns
Iron	1	-	1 %	-	0.01	ns
Manganese	1	-	4 %	-	0.01	ns
Zinc	3	8 %	16 %	0.02	0.19	ns

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

analytical results.[14] There were no significant differences in constituent concentrations between the labs (Sign test, $p \leq 0.05$).

Based on the results of blanks, duplicate, and split samples collected for this study, no significant QA/QC problems were apparent with the study.

Data Validation

The analytical work for this study was subjected to four QA/QC correlations and considered valid based on the following results. [12]

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. 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.[12]

Overall, cation/anion meq/L balances of Cienega Creek basin samples were significantly correlated (regression analysis, $p \leq 0.01$). Of the 20 samples, 16 met the acceptance criteria (within +/-2 percent) and 4 were within +/-5 percent. Of the 20 samples, 19 had high cation/low anion sums and 1 sample (CCK-30) had a low cation/high anion sum (see Appendix B).

SC/TDS - The SC and TDS concentrations measured by contract laboratories were significantly correlated as were SC-field and TDS concentrations (regression analysis, $r = 0.98$, $p \leq 0.01$). The TDS concentration in mg/L should be from 0.55 to 0.75 times the SC in µS/cm for groundwater up to several thousand TDS mg/L.[12] 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.[12]

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.[12] 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, $r = 0.79$, $p \leq 0.01$).

Temperature / GW Depth /Well Depth – Groundwater temperature measured in the field was compared to well depth and groundwater depth. Groundwater temperature should increase with depth, at a rate of approximately 3 degrees Celsius with every 100 meters or 328 feet. [12] However, groundwater depth was not significantly correlated with temperature (regression analysis, $r = 0.04$, $p \leq 0.05$). Well depth was also not significantly correlated with temperature (regression analysis, $r = 0.02$, $p \leq 0.05$).

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.[21]

Data Normality: Data associated with 22 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 8 of the 22 constituents (groundwater depth, pH-field, pH-lab, magnesium, potassium, bicarbonate, nitrate, and gross alpha) examined are 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 watersheds or aquifers were the same. The Kruskal-Wallis test uses the differences, but also incorporates information about the magnitude of each difference.[21] 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 test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.[11]

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.[11]

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. [21] The Pearson test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.[11]

GROUNDWATER SAMPLING RESULTS

Water Quality Standards/Guidelines

The ADEQ ambient groundwater program goal is to characterize regional groundwater quality. An important determination the agency 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 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.[19]

- 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 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.[19]

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

Overall Results - Of the 20 sites sampled in the Cienega Creek basin, 15 (75 percent) met all SDW Primary and Secondary MCLs, 2 (10 percent) exceeded Secondary MCLs, and 3 (15 percent) exceeded Primary MCLs.

Inorganic Constituent Results – Health-based Primary MCL water quality standards and State aquifer water quality standards were exceeded at 1 of 20 sites (5 percent; Map 3; Table 4). The constituent that exceeded a Primary MCL was arsenic at one site.[2, 19] Potential health effects of this chronic Primary MCL exceedance is provided in Table 4.

Aesthetics-based Secondary MCL water quality guidelines were exceeded at 2 of 20 sites (10 percent; Map 3; Table 5). Constituents above Secondary MCLs include TDS (2 sites), sulfate (1 site), iron (1 site), and manganese (1 site). Potential impacts of these Secondary MCL exceedances are provided in Table 5.

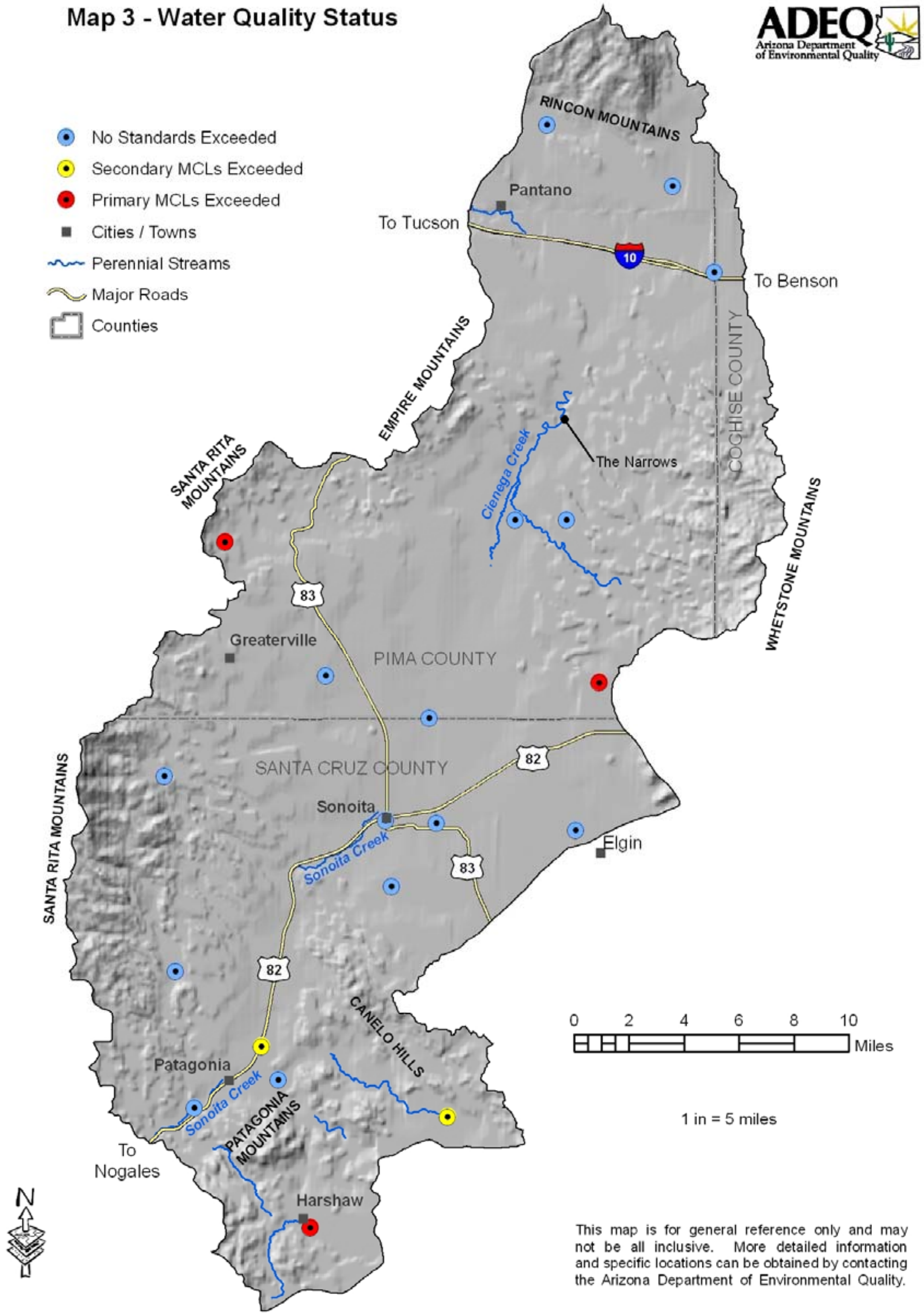
Radiochemical / Radon Results – Of the 10 sites sampled for radionuclides, 2 exceeded SDW Primary MCLs for gross alpha.

Of the 10 sites sampled for radon one 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. Nine (9) sites exceeded the proposed 300 pCi/L standard that would apply if Arizona doesn't develop a multimedia program. [19]

VOC Results – Of the 10 sites sampled for VOCs, no organic compounds were detected.

Analytical Results

Analytical inorganic and radiochemistry results of the Cienega Creek basin sample sites are summarized (Table 6) using the following indices: minimum reporting levels (MRLs), number of sample sites over the MRL, upper and lower 95 percent confidence intervals ($CI_{95\%}$), median, and mean. Confidence intervals are a statistical tool which indicates that 95 percent of a constituent's population lies within the stated confidence interval.[21] Specific constituent information is contained in Appendix B.



Map 3 - Water Quality Status
ADEQ
Arizona Department of Environmental Quality
No Standards Exceeded
Secondary MCLs Exceeded
Primary MCLs Exceeded
Cities / Towns
Perennial Streams
Major Roads
Counties
RINCON MOUNTAINS
Pantano
To Tucson
10
To Benson
COCHISE COUNTY
EMPIRE MOUNTAINS
The Narrows
Cienega Creek
SANTA RITA MOUNTAINS
WHETSTONE MOUNTAINS
83
Greaterville
PIMA COUNTY
SANTA CRUZ COUNTY
82
Sonoita
Sonoita Creek
Elgin
SANTA RITA MOUNTAINS
83
82
CANELO HILLS
0 2 4 6 8 10
Miles
Patagonia
Sonoita Creek
PATAGONIA MOUNTAINS
1 in = 5 miles
To Nogales
Harshaw
N
This map is for general reference only and may not be all inclusive. More detailed information and specific locations can be obtained by contacting the Arizona Department of Environmental Quality.

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

Constituent	Primary MCL	Number of Sites Exceeding Primary MCL	Highest Concentration	Potential Health Effects of MCL Exceedances *
		Nutrients		
Nitrite (NO_2-N)	1.0	0	-	-
Nitrate (NO_3-N)	10.0	0	-	-
		Trace Elements		
Antimony (Sb)	0.006	0	-	-
Arsenic (As)	0.01	**1**	0.0295	dermal and nervous system toxicity
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	0	-	-
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	**2**	**20**	cancer
Ra-226+Ra-228	5	0	-	-
Radon **	300	**8**	3,918	cancer
Radon **	4,000	**1**	3,918	cancer
Uranium	30	0	-	-

All units are mg/L except gross alpha, radium-226+228 and radon (pCi/L), and uranium (ug/L).
* Health-based drinking water quality standards are based on a lifetime consumption of two liters of water per day over a 70-year life span.[19]
** Proposed EPA Safe Drinking Water Act standards for radon in drinking water.[19]

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

Constituents	Secondary MCL	Number of Sites Exceeding Secondary MCLs	Concentration Range of Exceedances	Aesthetic Effects of MCL Exceedances
		Physical Parameters		
pH - field	< 6.5	0	-	-
pH - field	> 8.5	0	-	-
		General Mineral Characteristics		
TDS	500	**2**	1,100	hardness; deposits; colored water; staining; salty taste
		Major Ions		
Chloride (Cl)	250	0	-	-
Sulfate (SO_4)	250	**1**	250	salty taste
		Trace Elements		
Fluoride (F)	2.0	0	-	-
Iron (Fe)	0.3	**1**	0.565	rusty color, reddish stains and metallic tastes
Manganese (Mn)	0.05	**1**	0.125	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: [19]

Table 6. Summary Statistics for Cienega Creek 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	20 / 20	20.7	18.3	20.0	21.6
pH-field (su)	0.01	20 / 20	7.43	7.26	7.43	7.60
pH-lab (su)	0.01	20 / 20	7.66	7.52	7.67	7.82
Turbidity (ntu)	0.01	20 / 18	0.10	0.55	10.52	20.49
			General Mineral Characteristics			
T. Alkalinity	2.0	20 / 20	190	173	198	223
Phenol. Alk.	2.0	20 / 0		> 50% of data below MRL		
SC-field (uS/cm)	N/A	20 / 20	426	386	472	558
SC-lab (uS/cm)	N/A	20 / 20	455	413	507	602
Hardness-lab	10	20 / 20	185	169	223	276
TDS	10	20 / 20	285	254	317	380
			Major Ions			
Calcium	5	20 / 20	57	53	68	83
Magnesium	1.0	20 / 20	9.7	8.6	13.5	23.4
Sodium	5	20 / 20	19	16	19	31
Potassium	0.5	20 / 20	1.9	1.6	2.1	2.5
Bicarbonate	2.0	20 / 20	230	212	241	272
Carbonate	2.0	20 / 0		> 50% of data below MRL		
Chloride	1	20 / 20	5.8	4.9	8.8	12.6
Sulfate	10	20 / 15	21	20	57	95
			Nutrients			
Nitrate (as N)	0.02	20 / 20	0.54	0.40	0.72	1.04
Nitrite (as N)	0.02	20 / 0		> 50% of data below MRL		
TKN	0.05	20 / 0		> 50% of data below MRL		
Ammonia	0.02	20 / 1		> 50% of data below MRL		
T. Phosphorus	0.02	20 / 5		> 50% of data below MRL		

Table 6. Summary Statistics for Cienega Creek Basin Groundwater Quality Data— Continued

Constituent	Minimum Reporting Limit (MRL)*	# of Samples / Samples Over MRL	Median	Lower 95% Confidence Interval	Mean	Upper 95% Confidence Interval
Trace Elements						
Aluminum	0.5	20 / 0	> 50% of data below MRL			
Antimony	0.005	20 / 0	> 50% of data below MRL			
Arsenic	0.01	20 / 1	> 50% of data below MRL			
Barium	0.1	20 / 9	> 50% of data below MRL			
Beryllium	0.0005	20 / 0	> 50% of data below MRL			
Boron	0.1	20 / 3	> 50% of data below MRL			
Cadmium	0.001	20 / 0	> 50% of data below MRL			
Chromium	0.01	20 / 0	> 50% of data below MRL			
Copper	0.01	20 / 0	> 50% of data below MRL			
Fluoride	0.2	20 / 17	0.29	0.24	0.33	0.43
Iron	0.1	20 / 1	> 50% of data below MRL			
Lead	0.005	20 / 0	> 50% of data below MRL			
Manganese	0.05	20 / 1	> 50% of data below MRL			
Mercury	0.0005	20 / 0	> 50% of data below MRL			
Nickel	0.1	20 / 0	> 50% of data below MRL			
Selenium	0.005	20 / 0	>50% of data below MRL			
Silver	0.001	20 / 0	> 50% of data below MRL			
Thallium	0.002	20 / 0	> 50% of data below MRL			
Zinc	0.05	20 / 8	> 50% of data below MRL			
Radiochemical						
Gross Alpha *	Varies	10 / 10	5.4	3.0	7.4	11.7
Gross Beta *	Varies	10 / 7	4.7	3.1	5.0	6.9
Radon *	Varies	10 / 10	752	251	1063	1876

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

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 salt and sodium are known to cause physical deterioration of the soil and vegetation. Irrigation water may be classified using specific conductivity (SC) and the Sodium Adsorption Ratio (SAR) in conjunction with one another. [20] Groundwater sites in the Cienega Creek basin have a limited range of classifications (Table 7). The 20 sample sites are divided into the following sodium hazards: low (19), medium (0), high (1), and very high (0). The 20 sample sites are divided into the following salinity hazards: low (0), medium (17), high (3), and very high (0).

Table 7. Sodium and Salinity Hazards for Sampled Sites in the Cienega Creek Basin

Hazard	Total Sites	Low	Medium	High	Very High
Sodium Hazard					
Sodium Adsorption Ratio (SAR)		0 - 10	11- 18	19 - 26	> 26
Sample Sites	20	19	0	1	0
Salinity Hazard					
Specific Conductivity (uS/cm)		100–249	250 – 749	750-2250	>2250
Sample Sites	20	0	17	3	0

GROUNDWATER COMPOSITION

General Summary

The water chemistry at the 20 sample sites in the Cienega Creek basin (Map 4) was calcium-bicarbonate (16 sites), calcium-sulfate (2 sites), and mixed-bicarbonate and sodium-bicarbonate (1 site each). (Diagram 1 – middle diagram).

Of the 20 sample sites in the Cienega Creek basin, the dominant cation was calcium at 18 sites, sodium at 1 site and at 1 site, the composition was mixed as there was no dominant cation (Diagram 1 – left diagram).

The dominant anion was bicarbonate at 18 sites and sulfate at 2 sites (Diagram 1 – right diagram).

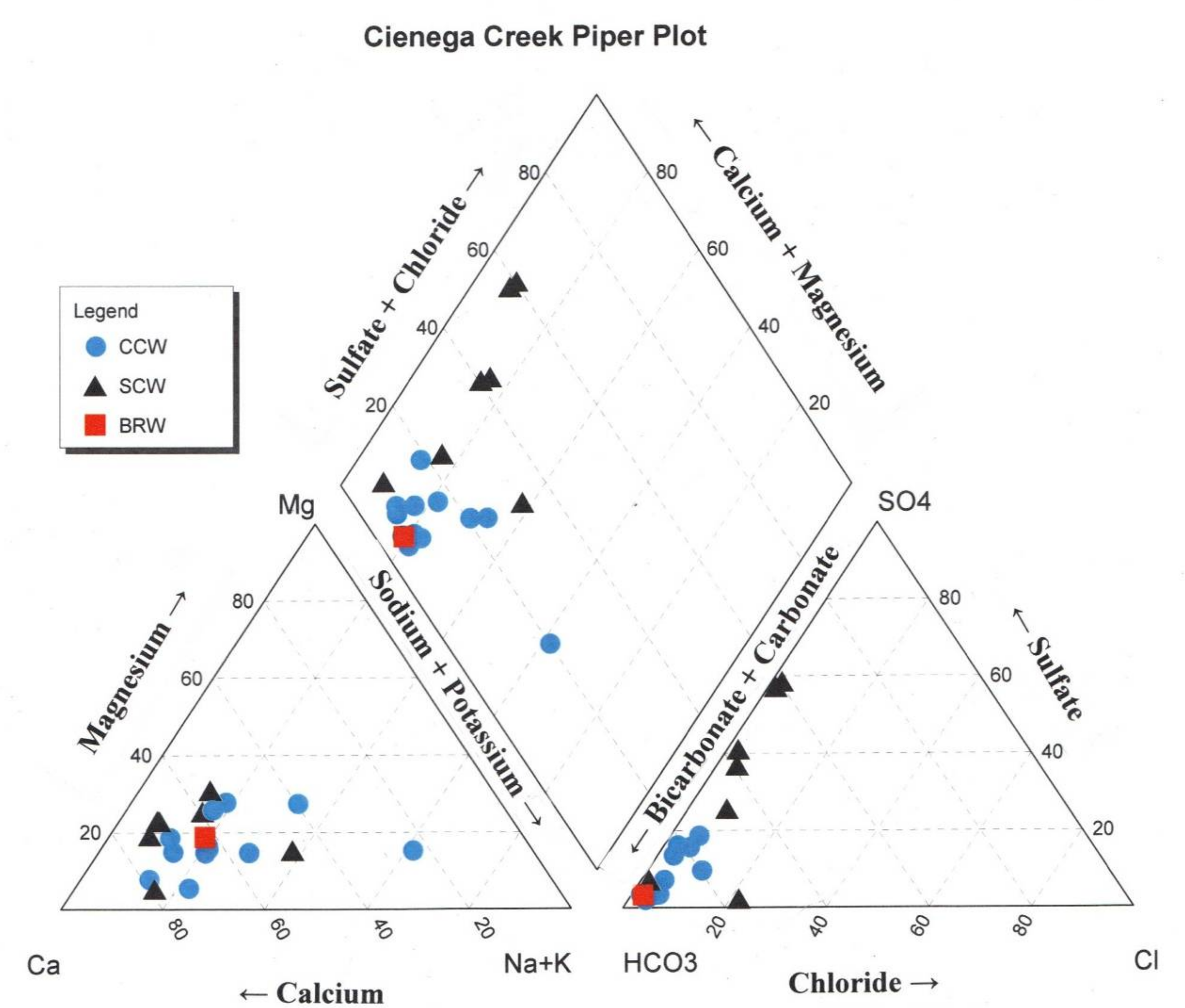
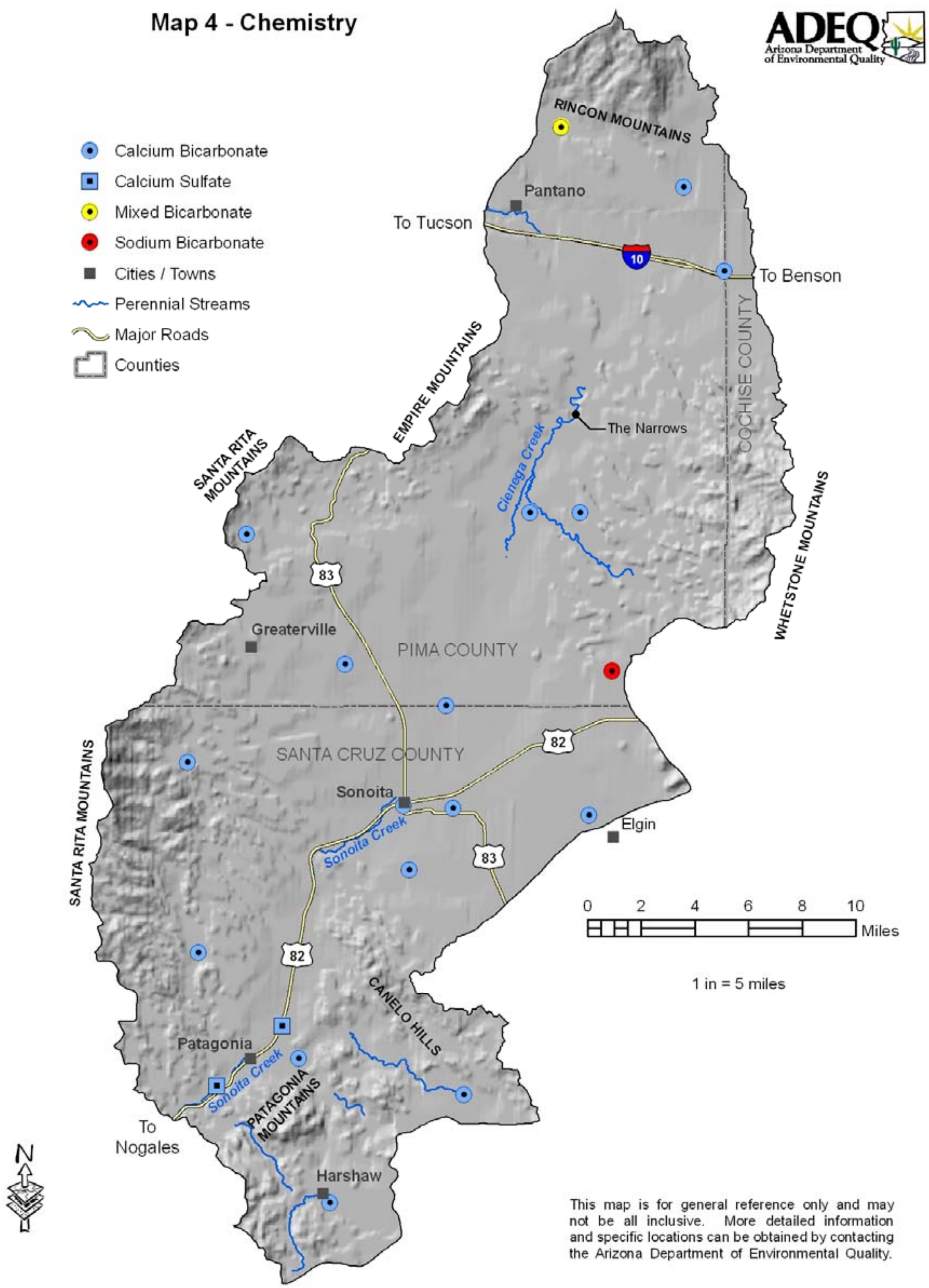


Diagram 1 – Samples were collected from 20 sites in the Cienega Creek basin including 12 in the Cienega Creek watershed (CCW), 7 in the Sonoita Creek watershed (SCW), and 1 in the Babocomari River (BRW) watershed. Groundwater in the basin is predominantly a calcium-bicarbonate chemistry. This indicates water in the basin is likely of recent origin occurring from precipitation in the nearby mountains that recharges along mountain fronts and along major streams . [15, 17] The two sample sites with a predominant sulfate anion chemistry are probably impacted by either gypsum deposits or mining activity that disturbs land and tends to mobilize sulfate ions when they come into contact with water. [17]



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

At all 18 sites, levels of pH-field were *slightly alkaline* (above 7 su) with 1 site above 8 su. Two sites had pH levels that were *slightly acidic* (below 7 su). [10]

TDS concentrations were considered *fresh* (below 999 mg/L) at all 20 sites (Map 5).[10]

Hardness concentrations were *soft* (below 75 mg/L) at 0 sites, *moderately hard* (75 – 150 mg/L) at 7 sites, *hard* (150 – 300 mg/L) at 9 sites, *very hard* (300 - 600 mg/L) at 4 sites (Diagram 2 and Map 6).[7]

Nitrate (as nitrogen) concentrations at most sites do not appear to have been influenced by human activities. Nitrate concentrations were divided into natural background (4 sites at < 0.2 mg/L), may or may not indicate human influence (16 sites at 0.2 – 3.0 mg/L), may result from human activities (0 sites at 3.0 – 10 mg/L), and probably result from human activities (0 sites > 10mg/L).[14]

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

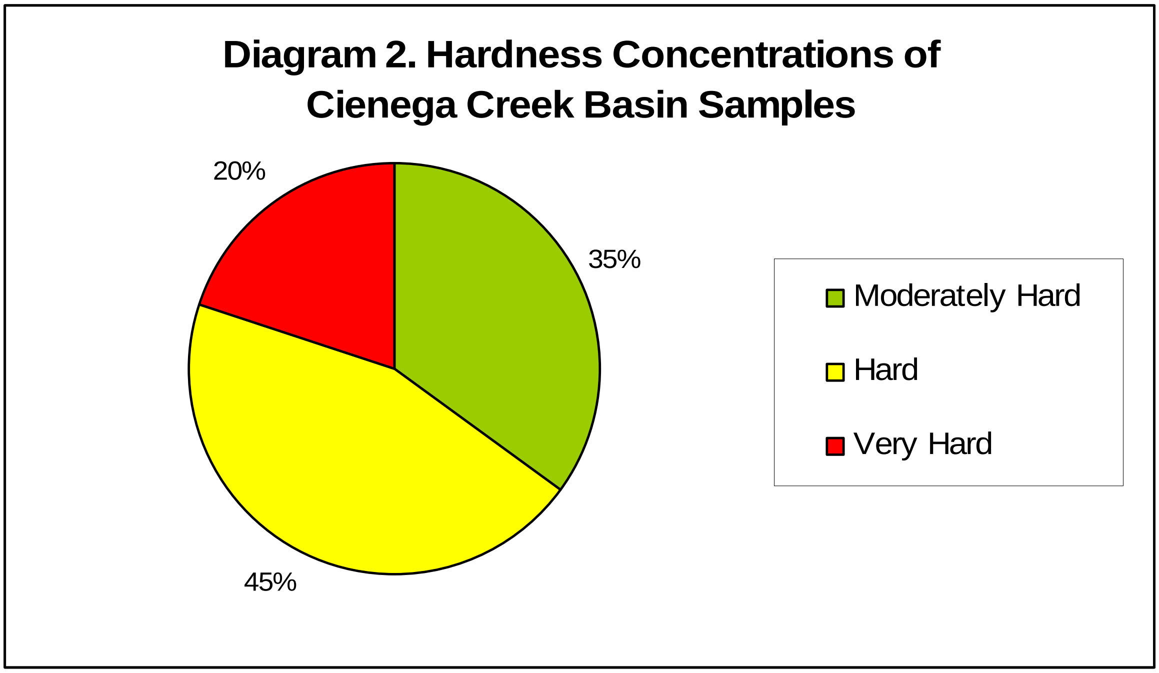
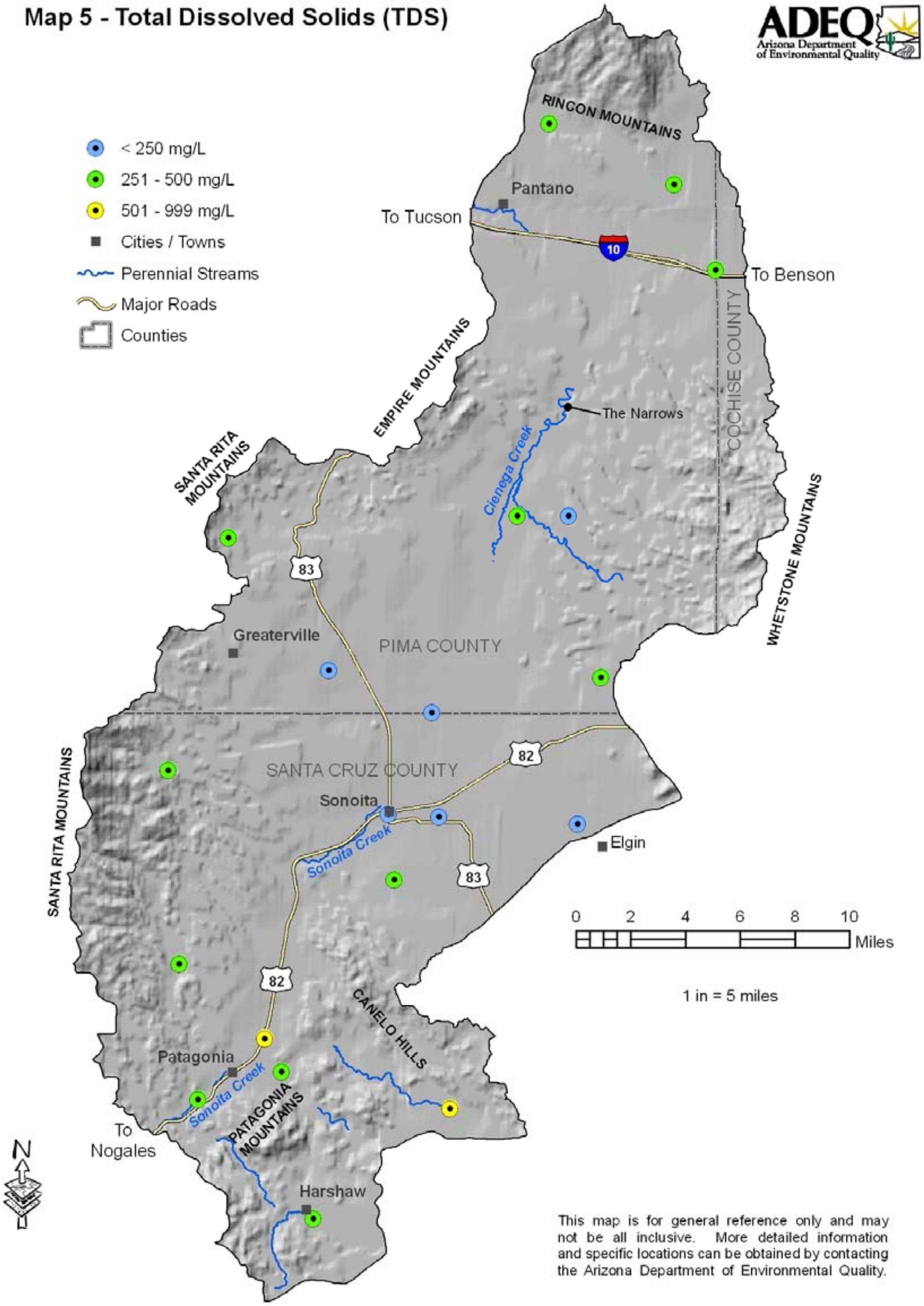
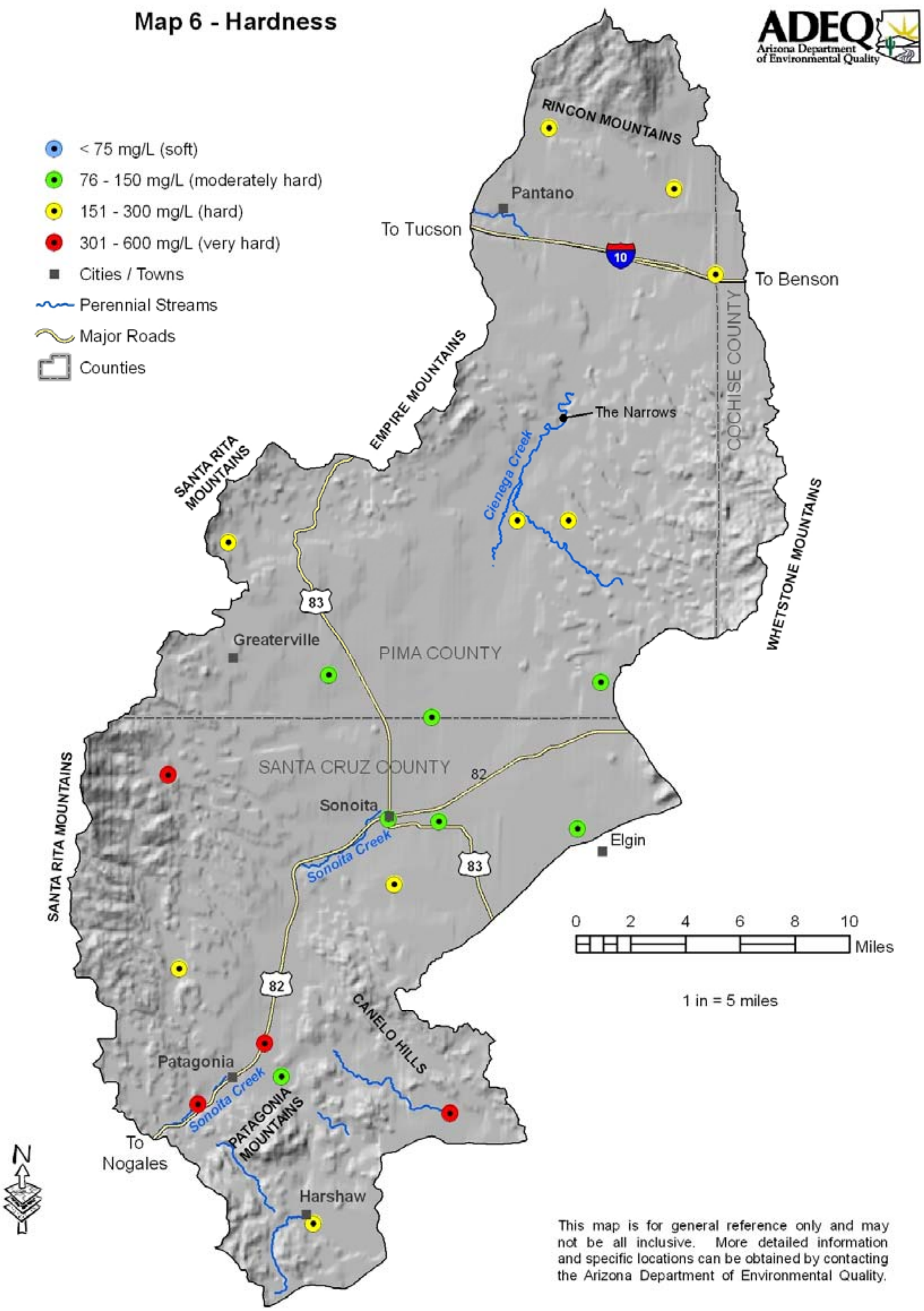


Diagram 2 – In the Cienega Creek basin hardness concentrations range from 100 to 535 mg/L. Samples collected from sites in the Sonoita Creek watershed are significantly higher than those collected in the Cienega Creek watershed. The main aquifer in the Sonoita Creek watershed in the shallow streambed alluvium that receives recharge from perennial streamflow that has a calcium-biarbonate chemistry.



Map 5 - Total Dissolved Solids (TDS)
ADEQ
Arizona Department of Environmental Quality
< 250 mg/L
251 - 500 mg/L
501 - 999 mg/L
Cities / Towns
Perennial Streams
Major Roads
Counties
RINCON MOUNTAINS
Pantano
To Tucson
10
To Benson
COCHISE COUNTY
EMPIRE MOUNTAINS
The Narrows
Cienega Creek
SANTA RITA MOUNTAINS
WHETSTONE MOUNTAINS
83
Greaterville
PIMA COUNTY
SANTA CRUZ COUNTY
82
Sonoita
Sonoita Creek
Elgin
0 2 4 6 8 10
Miles
1 in = 5 miles
CANELO HILLS
Patagonia
PATAGONIA MOUNTAINS
To Nogales
Harshaw
N
This map is for general reference only and may not be all inclusive. More detailed information and specific locations can be obtained by contacting the Arizona Department of Environmental Quality.


Map 6 - Hardness
ADEQ
Arizona Department of Environmental Quality
< 75 mg/L (soft)
76 - 150 mg/L (moderately hard)
151 - 300 mg/L (hard)
301 - 600 mg/L (very hard)
Cities / Towns
Perennial Streams
Major Roads
Counties
RINCON MOUNTAINS
Pantano
To Tucson
10
To Benson
COCHISE COUNTY
EMPIRE MOUNTAINS
The Narrows
Cienega Creek
SANTA RITA MOUNTAINS
WHETSTONE MOUNTAINS
83
Greaterville
PIMA COUNTY
SANTA CRUZ COUNTY
82
Sonoita
Elgin
Sonoita Creek
SANTA RITA MOUNTAINS
0 2 4 6 8 10
Miles
1 in = 5 miles
CANELO HILLS
Patagonia
PATAGONIA MOUNTAINS
To Nogales
Harshaw
N
This map is for general reference only and may not be all inclusive. More detailed information and specific locations can be obtained by contacting the Arizona Department of Environmental Quality.

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. 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.[21]

Several significant correlations occurred among the 20 sample sites (Table 8, Pearson Correlation Coefficient test, $p \leq 0.05$). Three general groups of correlations were identified:

- TDS, SC, hardness, calcium, magnesium, bicarbonate, and sulfate were all positively correlated with one another (Diagram 3).

- pH-field and pH-lab were positively correlated with one another and were negatively correlated with TDS, SC, hardness, calcium, magnesium and sulfate.

- Groundwater depth had a positive correlation with well depth and negative correlations with TDS, SC, hardness, calcium, magnesium, and sulfate.

TDS concentrations are best predicted among major ions by sulfate concentrations (standard coefficient = 0.50), among cations by calcium concentrations (standard coefficient = 0.75) and among anions, by sulfate concentrations (standard coefficient = 0.79) (multiple regression analysis, $p \leq 0.01$).

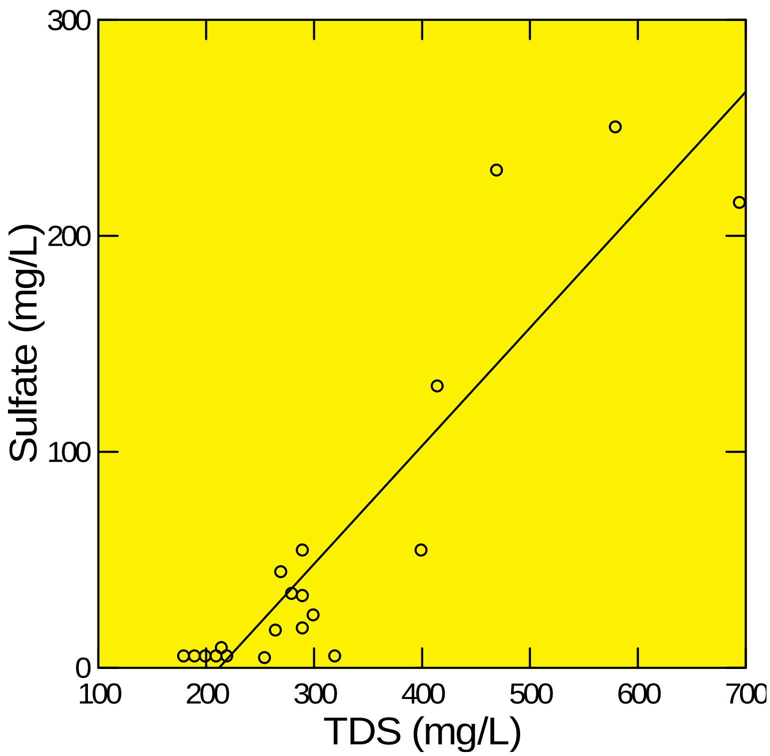


Diagram 3 – The graph illustrates a positive correlation between two constituents, TDS and sulfate. TDS concentrations in the Cienega Creek basin are best predicted among major ions by sulfate concentrations (multiple regression analysis, $p \leq 0.01$). Sulfate concentrations alone accounts for 50 percent of the variability of the TDS concentrations. While sulfate was not detected at the MRL of 10 mg/L at a third of sites sampled; elevated concentrations up to the 250 mg/L aesthetics-based, drinking water standard were found at sites in the southern part of the basin. Historically, this area has been the location of extensive mining activity. Ore deposits are the source of sulfate in many Arizona basins. [17] Mining activities expose greater amounts of rock surfaces to weathering; sulfides are oxidized to yield sulfate ions that are carried off in the water.

Table 8. Correlation Among Cienega Creek Basin Groundwater Quality Constituent Concentrations Using Pearson Correlation Probabilities

Constituent	Temp	pH-f	pH-l	SC-f	SC-f	TDS	Hard	Ca	Mg	Na	K	Bic	Cl	SO_4	NO_3	F	Well Depth	GW Depth
Physical Parameters																		
Temperature					+		+	+				++						
pH-field			**	+	+	++	+	++	+					++				
pH-lab							+	+						+				
General Mineral Characteristics																		
SC - field					**	**	**	**	**			**		**				++
SC - lab						**	**	**	**			**		**				++
TDS							**	**	**			**		**				++
Hardness								**	**			**		**				++
Major Ions																		
Calcium									**			**		**			+	++
Magnesium												**		**				+
Sodium													*			*		
Potassium																		
Bicarbonate															+			
Chloride																		
Sulfate																		++
Nutrients																		
Nitrate																*		
Trace Elements																		
Fluoride																	*	
Well Characteristics																		
Well Depth																		**
GW Depth																		

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

Groundwater Quality Variation

Between Two Watersheds – Because of the geohydrology differences between the two main watersheds in the basin, an assessment was made to see if any significant variability exists in constituent concentrations between them. Twenty-two (22) groundwater quality constituent concentrations were compared between the Cienega Creek watershed (12 sites) and the Sonoita Creek watershed (7 sites). The one sample collected within the Babocomari River watershed was not used in the analysis.

Significant concentration differences were found with 17 constituents: well depth, groundwater depth, pH-field (Diagram 4), pH-lab, SC-field, SC-lab, TDS (Diagram 5), hardness (Diagram 6), calcium, and sulfate (Diagram 7) (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 watershed groups are in Table 10.

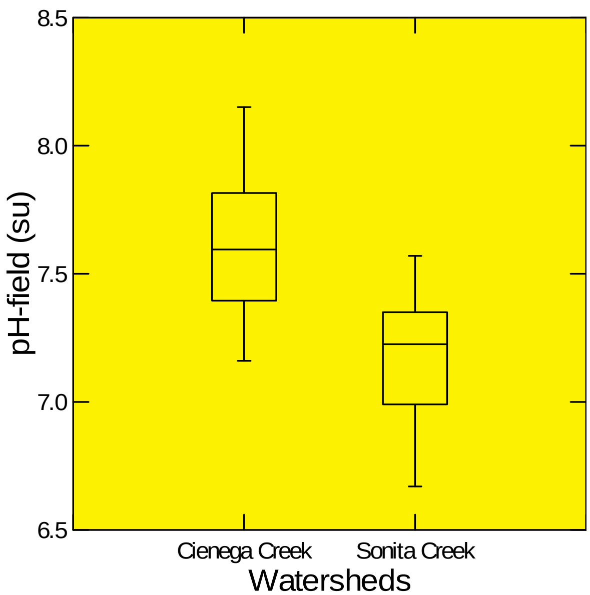


Diagram 4 – Sample sites in the Cienega Creek watershed have significantly higher pH levels than sample sites in the Sonoita Creek watershed (Kruskal-Wallis, $p \leq 0.01$). The main aquifer in the Sonoita Creek watershed is the shallow, streambed alluvium that receives recharge from the perennial flow in the creek. This recent recharge creates groundwater that is usually near neutral (7.0 su). In contrast, when water moves downgradient such as into the basin-fill deposits prevalent in the Cienega Creek watershed, pH values increase through hydrolysis reactions. [17]

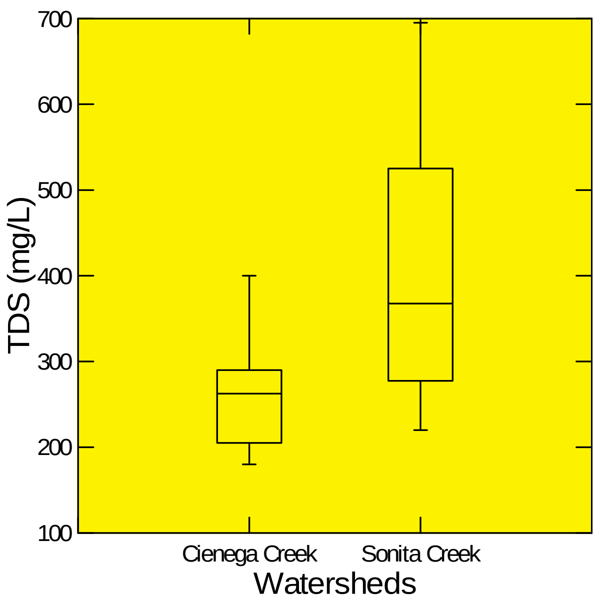


Diagram 5 – Sample sites in the Sonoita Creek watershed have significantly higher TDS concentrations than sample sites in the Cienega Creek watershed (Kruskal-Wallis, $p \leq 0.01$). TDS is often elevated in groundwater having a long aquifer residence time; however, another factor appears to be important in the Cienega Creek basin. Historic mining activity in the Sonoita Creek watershed may have impacted TDS concentrations by providing an opportunity to dissolve and transport minerals from disturbed lands. [17]

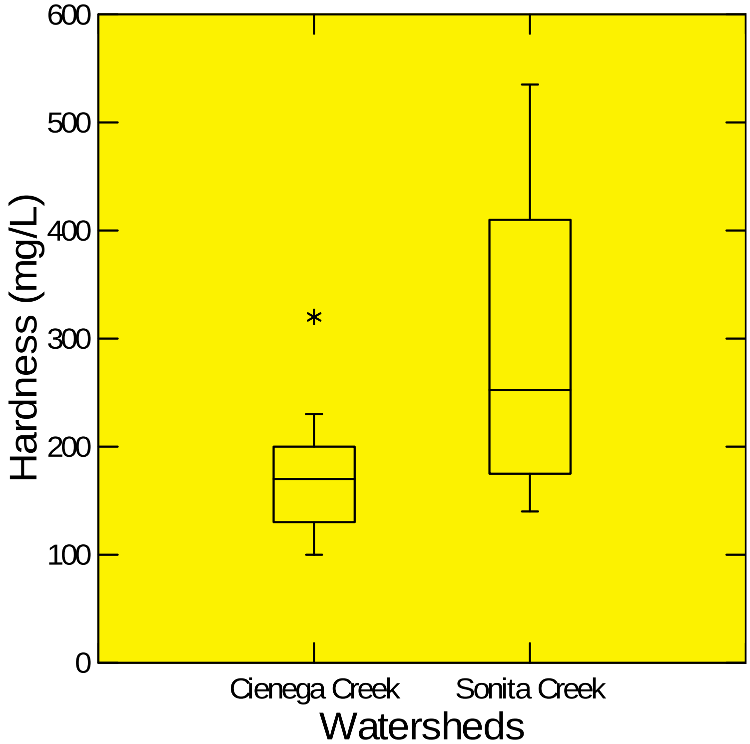


Diagram 6 – Sample sites located in the Sonoita Creek watershed have significantly higher hardness concentrations than those located in the Cienega Creek watershed (Kruskal-Wallis, $p \leq 0.05$). Elevated hardness concentrations are often associated with recharge areas.[17] The main aquifer in the Sonoita Creek watershed is the shallow, streambed alluvium that is recharged by a perennial stream. In contrast, the Cienega Creek watershed's main aquifer is the deep alluvial deposits which have a slower recharge rate which allows natural softening of the groundwater.[17]

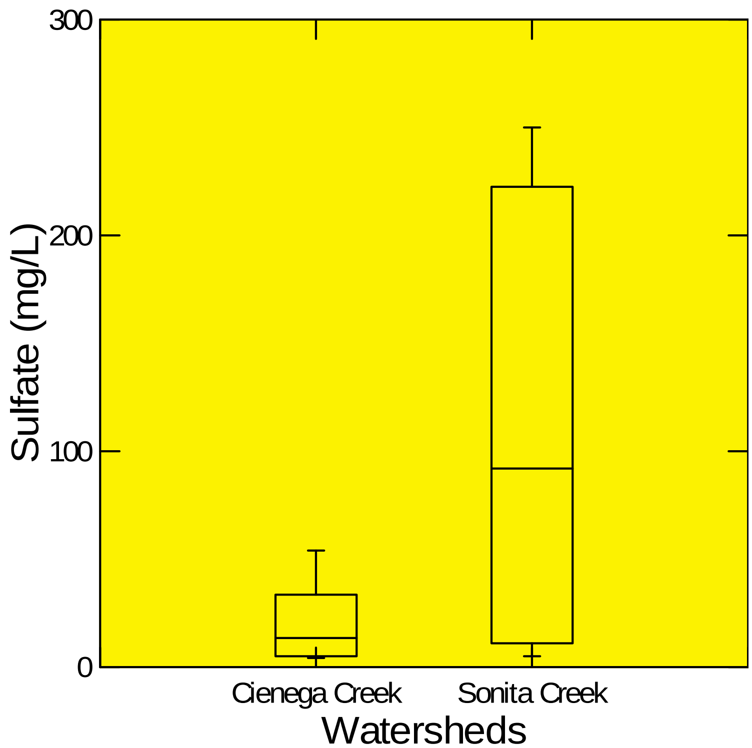


Diagram 7 – Sample sites located in the Sonoita Creek watershed have significantly higher sulfate concentrations than sample sites located in the Cienega Creek watershed (Kruskal-Wallis, $p \leq 0.05$). Historic mining activity in the Sonoita Creek watershed likely impacts sulfate concentrations. Sulfides often are found in ores of economic importance and mining activity exposes rock surfaces to weathering. Sulfides are oxidized to yield sulfate ions which are carried off in the water.[17]

Table 9. Variation in Groundwater Quality Constituent Concentrations between Two Watersheds Using Kruskal-Wallis Test

Constituent	Significance	Significant Differences Among Watersheds
Well Depth (feet bls)	*	Cienega Creek > Sonita Creek
GW Depth (feet bls)	**	Cienega Creek > Sonita Creek
Temperature – field (degrees Celsius)	ns	-
pH – field	**	Cienega Creek > Sonita Creek
pH – lab	**	Cienega Creek > Sonita Creek
SC – field (uS/cm)	*	Sonita Creek > Cienega Creek
SC – lab (uS/cm)	*	Sonita Creek > Cienega Creek
TDS	**	Sonita Creek > Cienega Creek
Turbidity	ns	-
Hardness	*	Sonita Creek > Cienega Creek
Calcium	**	Sonita Creek > Cienega Creek
Magnesium	ns	-
Sodium	ns	-
Potassium	ns	-
Bicarbonate	ns	-
Chloride	ns	-
Sulfate	*	Sonita Creek > Cienega Creek
Nitrate (as N)	ns	-
Fluoride	ns	-
Gross Alpha	ns	-
Radon	ns	-

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

Table 10. Variation in Groundwater Quality Constituent Concentrations between Two Watersheds Using Kruskal-Wallis Test and 95 Percent Confidence Intervals

Constituent	Significance	Cienega Creek Watershed	Sonita Creek Watershed
Well Depth (feet bls)	*	215 to 411	96 to 204
GW Depth (feet bls)	**	106 to 232	12 to 82
Temperature – field (degrees Celsius)	ns	-	-
pH – field	**	7.41 to 7.80	6.87 to 7.36
pH – lab	**	7.65 to 7.97	7.16 to 7.69
SC – field (uS/cm)	*	331 to 469	421 to 816
SC – lab (uS/cm)	*	357 to 501	443 to 891
TDS	**	217 to 296	286 to 581
Turbidity	ns	-	-
Hardness	*	137 to 213	186 to 446
Calcium	**	43 to 65	64 to 128
Magnesium	ns	-	-
Sodium	ns	-	-
Potassium	ns	-	-
Bicarbonate	ns	-	-
Chloride	ns	-	-
Sulfate	*	9 to 31	32 to 226
Nitrate (as N)	ns	-	-
Fluoride	ns	-	-
Gross Alpha	ns	-	-
Radon	ns	-	-

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

Groundwater Quality Variation

Between Two Aquifers – Because of the geohydrology differences between the two main aquifers in the basin, an assessment was made to see if any significant variability exists in constituent concentrations between them. Twenty-two (22) groundwater quality constituent concentrations were compared between the basin-fill aquifer watershed (11 sites) and the streambed aquifer (9 sites).

Significant concentration differences were found with three constituents: well depth (Diagram 8), groundwater depth, and pH-lab (Kruskal-Wallis test, $p \leq 0.05$).

Among Four Aquifers/Watersheds – Twenty-two (22) groundwater quality constituent concentrations were compared between the following combinations: Cienega Creek basin fill (9 sites), Cienega Creek streambed (3 sites), Sonoita Creek basin-fill (2 sites), and Sonoita Creek streambed (5 sites). The one sample collected within the Babocomari River watershed was not used in the analysis.

Significant concentration differences were found with three constituents: well depth, groundwater depth, pH-field (Diagram 9), pH-lab, hardness (Diagram 10), calcium, and magnesium (Kruskal-Wallis with Tukey test, $p \leq 0.05$).

Complete statistical results are in Table 11 and 95 percent confidence intervals for significantly different groups based on aquifer/watershed groups are in Table 12.

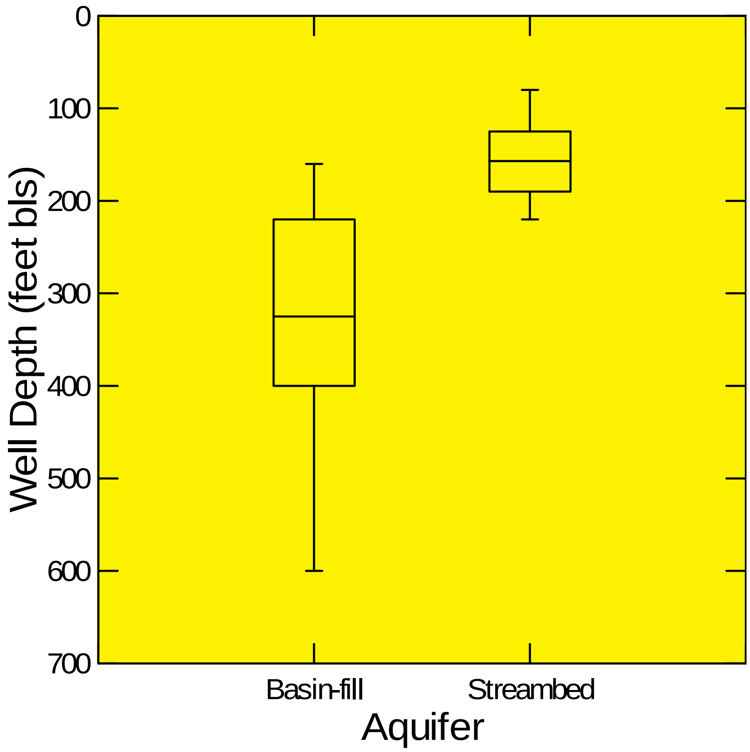


Diagram 8 – Sample sites in the basin fill aquifer have significantly greater well depths than sample sites in the streambed aquifer (Kruskal-Wallis test, $p \leq 0.01$). This pattern is a reflection of the different characteristics of aquifers in the Cienega Creek basin. The shallow streambed aquifer in the Sonoita Creek watershed has a maximum thickness of 90 feet; in the Cienega Creek watershed the streambed aquifer's thickness reaches 200 feet. In contrast, the basin fill aquifer reaches a thickness of up to 525 feet. [15]

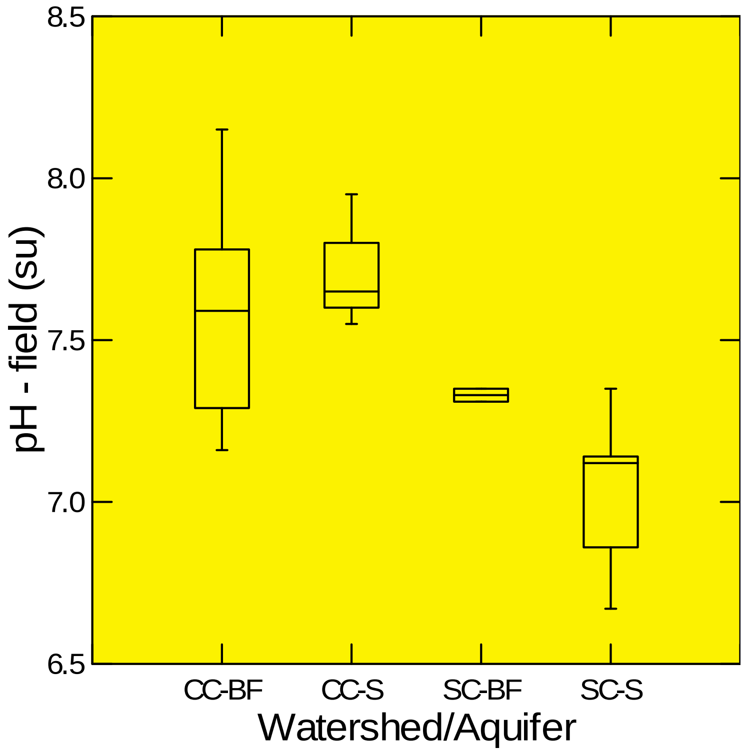


Diagram 9 – Sample sites located in the Sonoita Creek streambed aquifer have significantly lower pH-field levels than those sites located in the Cienega Creek basin fill and streambed aquifers (Kruskal-Wallis with Tukey test, $p \leq 0.05$). The Sonoita Creek streambed aquifer consists of alluvium that receives recharge from the perennial flow in the creek. This recent recharge creates groundwater that is usually near neutral (7.0 su). In contrast, when water moves downgradient such as into the basin-fill deposits prevalent in the Cienega Creek watershed, pH values increase through hydrolysis reactions. [17]

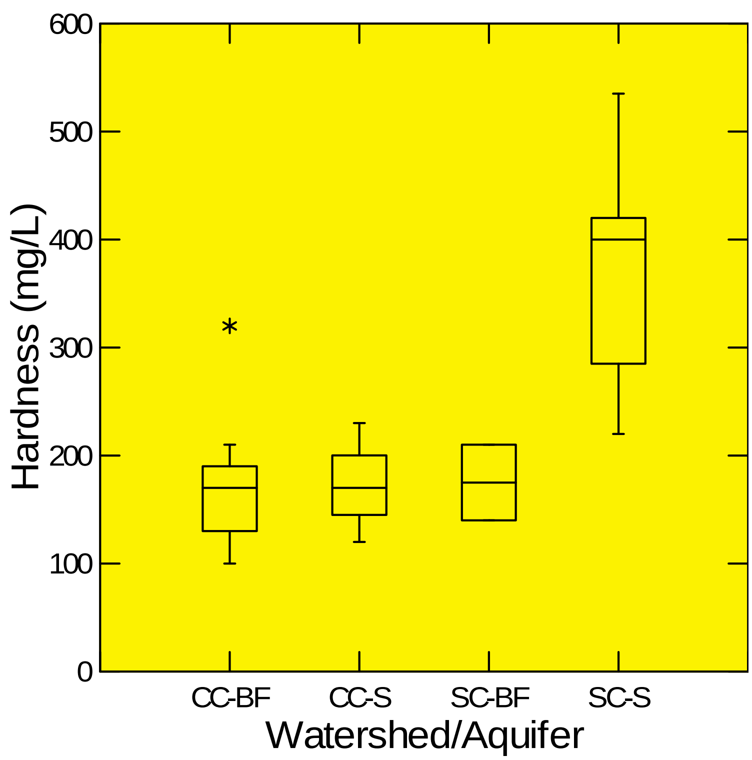


Diagram 10 – Sample sites located in the Sonoita Creek streambed aquifer have significantly higher hardness concentrations than sites located in each of the other four watershed/aquifer combinations (Kruskal-Wallis with Tukey test, $p \leq 0.05$). The main aquifer in the Sonoita Creek watershed is the shallow, streambed alluvium that receives recharge from the perennial flow in the creek. Elevated hardness concentrations are often associated with recharge areas. [17] The elevated calcium and magnesium concentrations that cause hardness typically decrease downgradient in basins containing dilute waters.

Table 11. Variation in Groundwater Quality Constituent Concentrations between Four Watersheds/Aquifers Using Kruskal-Wallis with the Tukey Test

Constituent	Significance	Significant Differences Among Watersheds / Aquifers
Well Depth (feet bls)	**	Cienega Creek basin fill > Cienega Creek streambed * Cienega Creek basin fill > Sonoita Creek streambed **
GW Depth (feet bls)	*	Cienega Creek basin fill > Sonoita Creek streambed **
Temperature – field (degrees Celsius)	ns	-
pH – field	*	Cienega Creek basin fill > Sonoita Creek streambed * Cienega Creek streambed > Sonoita Creek streambed *
pH – lab	**	Cienega Creek basin fill > Sonoita Creek streambed ** Cienega Creek streambed > Sonoita Creek streambed *
SC – field (uS/cm)	ns	-
SC – lab (uS/cm)	ns	-
TDS	ns	-
Turbidity	ns	-
Hardness	*	Cienega Creek basin fill > Sonoita Creek streambed ** Cienega Creek streambed > Sonoita Creek streambed * Sonoita Creek basin fill > Sonoita Creek streambed *
Calcium	*	Cienega Creek basin fill > Sonoita Creek streambed ** Cienega Creek streambed > Sonoita Creek streambed **
Magnesium	*	-
Sodium	ns	-
Potassium	ns	-
Bicarbonate	ns	-
Chloride	ns	-
Sulfate	ns	-
Nitrate (as N)	ns	-
Fluoride	ns	-
Gross Alpha	ns	-
Radon	ns	-

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

Table 12. Variation in Groundwater Quality Constituent Concentrations between Four Watersheds/Aquifers Using Kruskal-Wallis with the Tukey Test and 95 Percent Confidence Intervals

Constituent	Significance	Cienega Creek Basin-Fill	Cienega Creek Streambed	Sonoita Creek Basin-Fill	Sonoita Creek Streambed
Well Depth (feet bls)	**	255 to 479	99 to 237	-	54 to 206
GW Depth (feet bls)	*	128 to 260	-	-	-10 to 74
Temperature – field (degrees Celsius)	ns	-	-	-	-
pH – field	*	7.31 to 7.82	7.20 to 8.23	-	6.70 to 7.36
pH – lab	**	7.61 to 7.99	6.96 to 8.71	-	7.13 to 7.46
SC – field (uS/cm)	ns	-	-	-	-
SC – lab (uS/cm)	ns	-	-	-	-
TDS	ns	-	-	-	-
Turbidity	ns	-	-	-	-
Hardness	*	126 to 225	37 to 310	-270 to 620	120 to 525
Calcium	*	39 to 71	25 to 77	-	73 to 146
Magnesium	*	6 to 14	-3 to 23	-	10 to 42
Sodium	ns	-	-	-	-
Potassium	ns	-	-	-	-
Bicarbonate	ns	-	-	-	-
Chloride	ns	-	-	-	-
Sulfate	ns	-	-	-	-
Nitrate (as N)	ns	-	-	-	-
Fluoride	ns	-	-	-	-
Gross Alpha	ns	-	-	-	-
Radon	ns	-	-	-	-

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

DISCUSSION

Generally, groundwater quality in the Cienega Creek basin is acceptable for domestic, public supply, irrigation, and stock uses. The few constituents elevated over water quality standards could be the result of natural conditions but may have had their concentrations increased by anthropomorphic activities.

Groundwater parameters significantly varied by watershed, aquifers, and combinations of these two hydrologic factors. Groundwater quality parameter differences between the Cienega Creek and Sonoita Creek watersheds may be explained by aquifer characteristics. The Cienega Creek watershed's main aquifer is the deep basin fill deposits; this influences the greater well and groundwater depths. The higher pH levels are the result of older, more evolved groundwater found in the deeper aquifer.

In contrast, the Sonoita Creek watershed's main aquifer is shallow, streambed alluvium. The watershed's higher concentrations of calcium and hardness are reflective of recent recharge occurring from stream flow. The higher concentrations of sulfate, gross alpha, and to a lesser degree, TDS, are likely influenced by the extensive historic mining that occurred in area particularly in the Patagonia and Santa Rita Mountains. Lands disturbed through mining have a higher likelihood of having these constituents mobilized when it comes into contact with a water source. [13]

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Appendix A. Data for Sample Sites, Cienega Creek Basin, 2000-2001

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Sub-basin / Aquifer
1st Field Trip, July 25-27, 2000 – Boettcher & Lucci (Equipment Blank – CCK-11)									
CCK-01	D(19-18)29dac submersible	31°44'59.929" 110°31'22.951"	539167	58811	Sterner Well	Inorganic, Radionuclide	360'	150'	CCW basin-fill
CCK-02	D(21-17)06bbb submersible	31°38'35.799" 110°39'06.238"	518520	58812	McClain Well	Inorganic, Radon, VOCs	160'	85'	SCW basin-fill
CCK-03	D(19-16)27add submersible	31°45'15.009" 110°41'31.829"	512791	58813	Grader Well	Inorganic, Radionuclide	300'	223'	CCW basin-fill
CCK-04/05 split	D(20-16)24dad submersible	31°40'40.685" 110°39'19.138"	518888	58814	Frazier Well	Inorganic, Radon, VOCs	500'	190'	CCW basin-fill
CCK-06	D(19-17)32dcc submersible	31°43'53.877" 110°37'41.545"	531221	58881	Karl Well	Inorganic, Radon, VOCs	154'	40'	CCW streambed
CCK-07	D(22-15)14aaa submersible	31°31'36.057" 110°46'26.779"	548541	58815	Nat. Cons. Well	Inorganic, Radionuclide	160'	8'	SCW streambed
CCK-08/09 duplicate	D(23-16)03acc submersible	31°27'47.068" 110°42'10.079"	604559	58816	Hale Well	Inorganic, Radionuclide	100'	90'	SCW streambed
CCK-10	D(20-17)20cbd submersible	31°40'35.386" 110°37'27.03"	562804	58817	Williams Well	Inorganic, Radon	350'	270'	CCW basin-fill
2nd Field Trip, October 16-18, 2000 – Freark & Lucci (Equipment Blank – CCK-18a)									
CCK-12	D(22-16)09bbd submersible	31°32'28.946" 110°43'19.966"	549795	58882	Finley Well	Inorganic, Radon, VOCs	220'	86'	SCW basin-fill
CCK-13/14 duplicate	D(20-18)30aaa submersible	31°40'20.898" 110°32'17.557"	517247	58883	Matthews Well	Inorganic, Radon, VOCs	220'	46'	BRW streambed
CCK-15	D(21-16)32cdd submersible	31°33'31.771" 110°43'57.288"	542020	58884	Pattty Well	Inorganic, Radon	180'	20'	SCW streambed
CCK-16/17 split	D(21-15)23ba submersible	31°35'55.908" 110°47'07.612"	641595	58885	-	Inorganic, Radionuclide, VOCs	80'	30'	SCW streambed
3rd Field Trip, November 28-30, 2000 – Freark & Lucci (Equipment Blank – CCK-25)									
CCK-18b	D(18-17)26dbd windmill	31°50'09.81" 110°34'29.014"	634324	01262	BLM Well	Inorganic, Radon	150'	-	CCW streambed
CCK-19/20 duplicate	D(17-18)12daa submersible	31°57'57.799" 110°27'03.199"	530483	58900	Anderson Well	Inorganic, Radon	400'	275'	CCW basin-fill
CCK-21/22 split	D(22-17)16ac submersible	31°31'16.38" 110°37'05.044"	640914	58901	Coronado Well	Inorganic, Radionuclide	-	10'	SCW streambed
CCK-23	D(16-17)13ada submersible	-	517973	39553	Proctor Well	Inorganic, Radionuclide	600'	-	CCW basin-fill
CCK-24	D(16-18)26dbb submersible	32°00'41.749" 110°28'34.685"	558197	58902	Daranyi Well	Inorganic, Radon, VOCs	196'	70'	CCW basin-fill
4h Field Trip, January 30 – February 1, 2001 – Boettcher & Lucci (Equipment Blank – CCK-31)									
CCK-26/27 split	(D18-18)20dad submersible	31°50'09.04" 110°32'34.595"	634306	59062	Ferguson Well	Inorganic, Radionuclide, VOCs	232'	180'	CCW basin-fill
CCK-28/29 duplicate	(D20-15)15a spring	31°42'07" 110°47'33"	-	42196	Tunnel Spring	Inorganic, Radionuclide, VOCs	-	-	CCW basin-fill
CCK-30	(D18-16)32cac submersible	31°49'28.944" 110°45'15.287"	804885	59063	S. Rosemnt Well	Inorganic, Radionuclide, VOCs	200'	120'	CCW streambed

Appendix B. Groundwater Quality Data, Cienega Creek Basin, 2000-2001

Site #	MCL Exceedances	Temp (ºC)	pH-field (su)	pH-lab (su)	SC-field (µS/cm)	SC-lab (µS/cm)	TDS (mg/L)	Hard (mg/L)	Hard - cal (mg/L)	Turb (ntu)
CCK-01	Gross Alpha	23.0	7.85	*7.9*	469	510	300	100	110	0.48
CCK-02	-	21.1	7.31	7.5	457	500	320	210	210	0.2
CCK-03	-	22.4	7.59	*7.5*	305	330	210	150	150	1.1
CCK-04/05	-	22.9	7.60	*7.61*	276	305	180	130	120	0.13
CCK-06	-	23.9	7.65	7.5	260	280	190	120	120	ND
CCK-07	-	18.8	7.12	*7.4*	716	780	470	400	400	0.05
CCK-08/09	As	21.8	7.14	***7.3***	420	450	265	220	240	ND
CCK-10	-	22.2	7.16	7.7	271	290	200	130	140	0.05
CCK-12	-	22.3	7.35	*8.0*	420	430	290	140	150	13.0
CCK-13/14	-	21.2	7.57	*7.7*	310	325	220	140	145	0.075
CCK-15	TDS, SO_4	18.7	6.86	*7.1*	755	800	**580**	420	430	0.95
CCK-16/17	-	20.2	7.35	*7.43*	572	610	415	285	290	0.81
CCK-18b	-	20.1	7.55	*7.8*	420	450	280	170	170	0.18
CCK-19/20	-	16.6	7.29	*7.55*	394	430	255	190	195	0.01
CCK-21/22	TDS, Fe, Mn	19.1	6.67	*7.24*	991	1100	**695**	535	560	34
CCK-23	-	19.6	7.78	*8.0*	431	460	270	170	170	2.0
CCK-24	-	21.1	7.18	*7.8*	446	480	290	210	210	7.4
CCK-26/27	-	19.0	7.50	7.93	410	438	215	180	220	3.5
CCK-28/29	-	7.50	8.15	*8.25*	630	665	400	320	350	0.25
CCK-30	Gross Alpha	17.4	7.95	*8.2*	490	510	290	230	230	29.0

italics = constituent exceeded holding time
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level
* = field meter didn't calibrate upon return to ADEQ

Appendix B. Groundwater Quality Data, Cienega Creek Basin, 2000-2001---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)
CCK-01	26	10	76	2.2	210	260	ND	20	24
CCK-02	80	3.2	18	0.77	190	230	ND	38	ND
CCK-03	50	6.3	11	1.3	160	200	ND	4.9	ND
CCK-04/05	48.5	2.15	16.5	1.15	145	180	ND	6.05	ND
CCK-06	39	5.8	14	1.4	150	180	ND	1.9	ND
CCK-07	120	24	15	1.9	175	214	ND	6.3	230
CCK-08/09	75.5	12	6.9	4.25	230	280	ND	2.95	17
CCK-10	51	3	9.2	1.2	141	172	ND	4.8	ND
CCK-12	44	8.7	39	3.1	150	180	ND	12	54
CCK-13/14	45	8.1	14	2.85	156.5	193.5	ND	2.75	ND
CCK-15	130	26	15	2.1	190	230	ND	4.6	**250**
CCK-16/17	81.5	21	22	3.55	185	230	ND	5.2	130
CCK-18b	55	8.7	32	2.0	180	220	ND	8.3	34
CCK-19/20	51.5	16	19	2.2	210	260	ND	5.15	4.2
CCK-21/22	140	47.5	39.5	2.05	360	440	ND	17.5	215
CCK-23	41	17	37	2.6	190	230	ND	9.8	44
CCK-24	69	9.4	25	1.2	210	260	ND	5.5	33
CCK-26/27	58	9.1	20.5	1.9	200	240	ND	5.1	8.85
CCK-28/29	99.5	16	19	1.6	290	350	ND	6.45	54
CCK-30	59	16	19	1.5	240	290	ND	8.3	18

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

Appendix B. Groundwater Quality Data, Cienega Creek Basin, 2000-2001---Continued

Site #	T. Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	T. Phosphorus (mg/L)	SAR (value)	Irrigation Quality	Aluminum (mg/L)
CCK-01	0.6	ND	ND	ND	ND	17.9	C2-S3	ND
CCK-02	0.94	ND	ND	ND	ND	2.8	C2-S1	ND
CCK-03	1.3	ND	ND	ND	ND	2.1	C2-S1	ND
CCK-04/05	0.44	ND	ND	0.024	0.022	3.3	C2-S1	ND
CCK-06	0.22	ND	ND	ND	ND	3.0	C2-S1	ND
CCK-07	0.68	ND	ND	ND	0.026	1.8	C3-S1	ND
CCK-08/09	0.18	ND	ND	ND	ND	1.0	C2-S1	ND
CCK-10	0.82	ND	ND	ND	ND	1.8	C2-S1	ND
CCK-12	2.5	ND	ND	ND	ND	7.6	C2-S1	ND
CCK-13/14	2.4	ND	ND	ND	ND	2.7	C2-S1	ND
CCK-15	0.57	ND	ND	ND	ND	1.7	C3-S1	ND
CCK-16/17	0.40	ND	ND	ND	ND	3.1	C2-S1	ND
CCK-18b	0.83	ND	ND	ND	ND	5.7	C2-S1	ND
CCK-19/20	0.5	ND	ND	ND	ND	3.3	C2-S1	ND
CCK-21/22	ND	ND	ND	ND	0.105	4.1	C3-S1	ND
CCK-23	0.42	ND	ND	ND	ND	6.9	C2-S1	ND
CCK-24	0.088	ND	ND	ND	0.05	4.0	C2-S1	ND
CCK-26/27	1.1	ND	ND	ND	ND	3.5	C2-S1	ND
CCK-28/29	0.075	ND	ND	ND	0.044	2.5	C2-S1	ND
CCK-30	0.28	ND	ND	ND	ND	3.1	C2-S1	ND

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

Appendix B. Groundwater Quality Data, Cienega Creek Basin, 2000-2001---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)
CCK-01	ND	ND	0.11	ND	1.0	ND	ND	ND	0.58
CCK-02	ND	ND	ND	ND	ND	ND	ND	ND	0.21
CCK-03	ND	ND	ND	ND	ND	ND	ND	ND	0.22
CCK-04/05	ND	ND	ND	ND	ND	ND	ND	ND	0.255
CCK-06	ND	ND	0.2	ND	ND	ND	ND	ND	ND
CCK-07	ND	ND	ND	ND	ND	ND	ND	ND	0.32
CCK-08/09	ND	**0.0295**	0.19	ND	ND	ND	ND	ND	ND
CCK-10	ND	ND	ND	ND	ND	ND	ND	ND	0.22
CCK-12	ND	ND	ND	ND	0.12	ND	ND	ND	0.74
CCK-13/14	ND	ND	ND	ND	ND	ND	ND	ND	0.49
CCK-15	ND	ND	ND	ND	ND	ND	ND	ND	0.21
CCK-16/17	ND	ND	ND	ND	ND	ND	ND	ND	0.33
CCK-18b	ND	ND	0.19	ND	ND	ND	ND	ND	0.34
CCK-19/20	ND	ND	ND	ND	ND	ND	ND	ND	0.685
CCK-21/22	ND	ND	ND	ND	ND	ND	ND	ND	0.265
CCK-23	ND	ND	0.13	ND	ND	ND	ND	ND	0.68
CCK-24	ND	ND	0.19	ND	ND	ND	ND	ND	ND
CCK-26/27	ND	ND	0.17	ND	ND	ND	ND	ND	0.325
CCK-28/29	ND	ND	0.13	ND	ND	ND	ND	ND	ND
CCK-30	ND	ND	0.12	ND	0.12	ND	ND	ND	0.35

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

Appendix B. Groundwater Quality Data, Cienega Creek Basin, 2000-2001---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)
CCK-01	ND	ND	ND	ND	ND	ND	ND	ND	ND
CCK-02	ND	ND	ND	ND	ND	ND	ND	ND	0.054
CCK-03	ND	ND	ND	ND	ND	ND	ND	ND	0.061
CCK-04/05	ND	ND	ND	ND	ND	ND	ND	ND	ND
CCK-06	ND	ND	ND	ND	ND	ND	ND	ND	ND
CCK-07	ND	ND	ND	ND	ND	ND	ND	ND	ND
CCK-08/09	ND	ND	ND	ND	ND	ND	ND	ND	0.105
CCK-10	ND	ND	ND	ND	ND	ND	ND	ND	ND
CCK-12	ND	ND	ND	ND	ND	ND	ND	ND	ND
CCK-13/14	ND	ND	ND	ND	ND	ND	ND	ND	ND
CCK-15	ND	ND	ND	ND	ND	ND	ND	ND	ND
CCK-16/17	ND	ND	ND	ND	ND	ND	ND	ND	0.059
CCK-18b	ND	ND	ND	ND	ND	ND	ND	ND	1.2
CCK-19/20	ND	ND	ND	ND	ND	ND	ND	ND	ND
CCK-21/22	**0.565**	ND	**0.125**	ND	ND	ND	ND	ND	0.061
CCK-23	ND	ND	ND	ND	ND	ND	ND	ND	0.17
CCK-24	ND	ND	ND	ND	ND	ND	ND	ND	0.15
CCK-26/27	ND	ND	ND	ND	ND	ND	ND	ND	0.12
CCK-28/29	ND	ND	ND	ND	ND	ND	ND	ND	ND
CCK-30	0.22	ND	ND	ND	ND	ND	ND	ND	ND

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

Appendix B. Groundwater Quality Data, Cienega Creek Basin, 2000-2001---Continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Ra-226 + Ra-228 (pCi/L)	Uranium (µg/L)	Chemistry	Ion Balance % Difference Pass / Fail
CCK-01	--	**20**	3.7	<LLD	8.1	sodium-bicarbonate	0.76 – Yes
CCK-02	**817**	--	--	--	--	calcium-bicarbonate	1.37 – Yes
CCK-03	--	1.1	<LLD	--	--	calcium-bicarbonate	0.04 – Yes
CCK-04/05	**388**	--	--	--	--	calcium-bicarbonate	0.68 - Yes
CCK-06	**793**	--	--	--	--	calcium-bicarbonate	0.77 – Yes
CCK-07	--	3.3	<LLD	--	--	calcium-sulfate	0.74 – Yes
CCK-08/09	--	5.8	4.6	--	--	calcium-bicarbonate	1.55 – Yes
CCK-10	170	--	--	--	--	calcium-bicarbonate	3.14 – No
CCK-12	**3918**	--	--	--	--	mixed-bicarbonate	0.61 - Yes
CCK-13/14	**469**	--	--	--	--	calcium-bicarbonate	0.41 - Yes
CCK-15	**845**	--	--	--	--	calcium-sulfate	0.97 - Yes
CCK-16/17	--	4.0	4.7	--	--	calcium-bicarbonate	1.74 - Yes
CCK-18b	**407**	--	--	--	--	calcium-bicarbonate	2.91 - No
CCK-19/20	**710**	--	--	--	--	calcium-bicarbonate	1.81 - Yes
CCK-21/22	--	6.4	8.4	<LLD	--	calcium-bicarbonate	0.90 - Yes
CCK-23	--	9.1	5.9	<LLD	--	mixed-bicarbonate	0.90 – Yes
CCK-24	**2117**	--	--	--	--	calcium-bicarbonate	2.14 - No
CCK-26/27	--	4.9	1.8	--	--	calcium-bicarbonate	1.72 - Yes
CCK-28/29	--	3.0	<LLD	--	--	calcium-bicarbonate	0.46 - Yes
CCK-30	--	**16**	5.8	<LLD	6.3	calcium-bicarbonate	2.63 - No

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