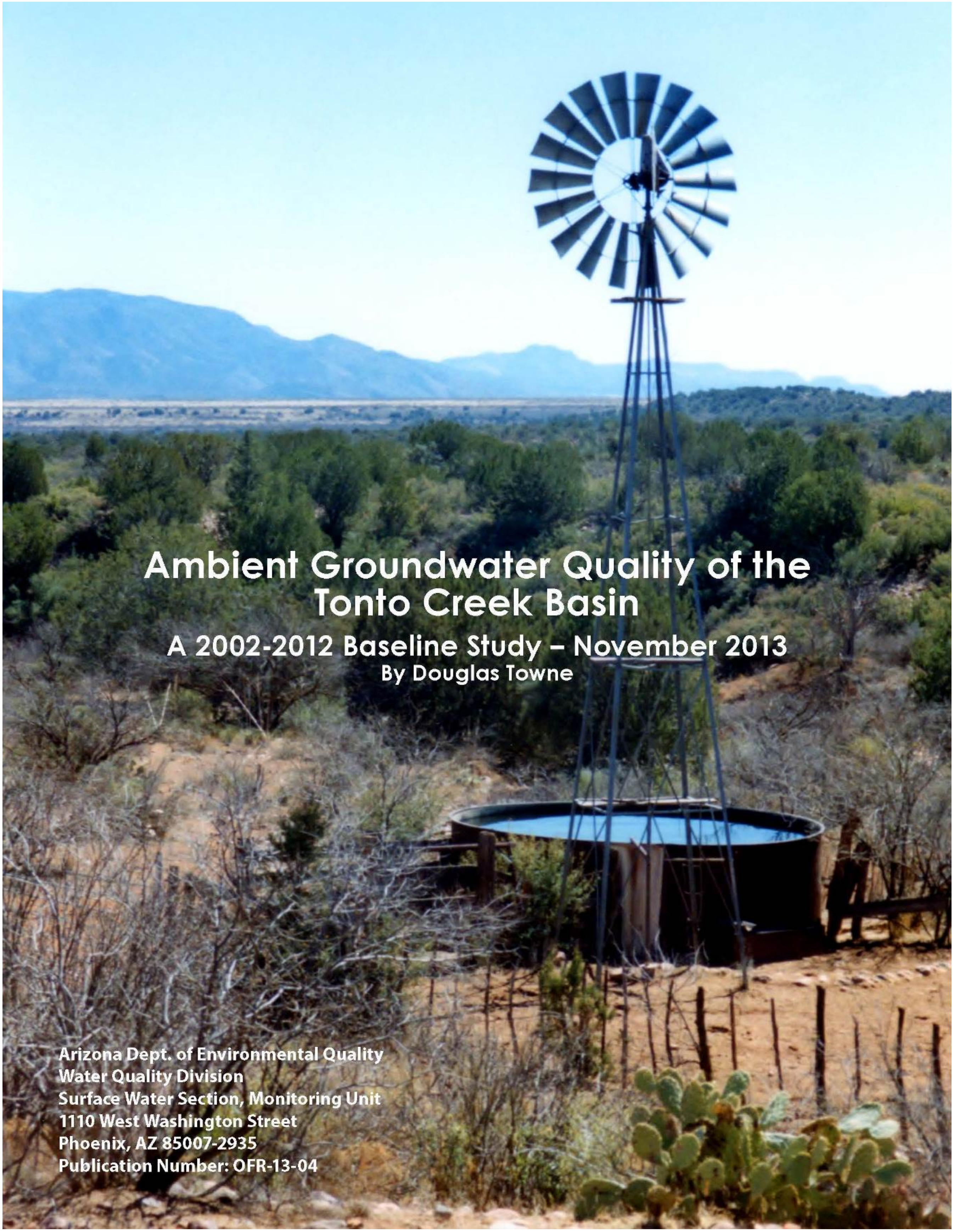

Ambient Groundwater Quality of the Tonto Creek Basin

A 2002-2012 Baseline Study – November 2013

By Douglas Towne

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Ambient Groundwater Quality of the Tonto Creek Basin: A 2002-2012 Baseline Study

By Douglas C. Towne

Arizona Department of Environmental Quality
Open File Report 13-04

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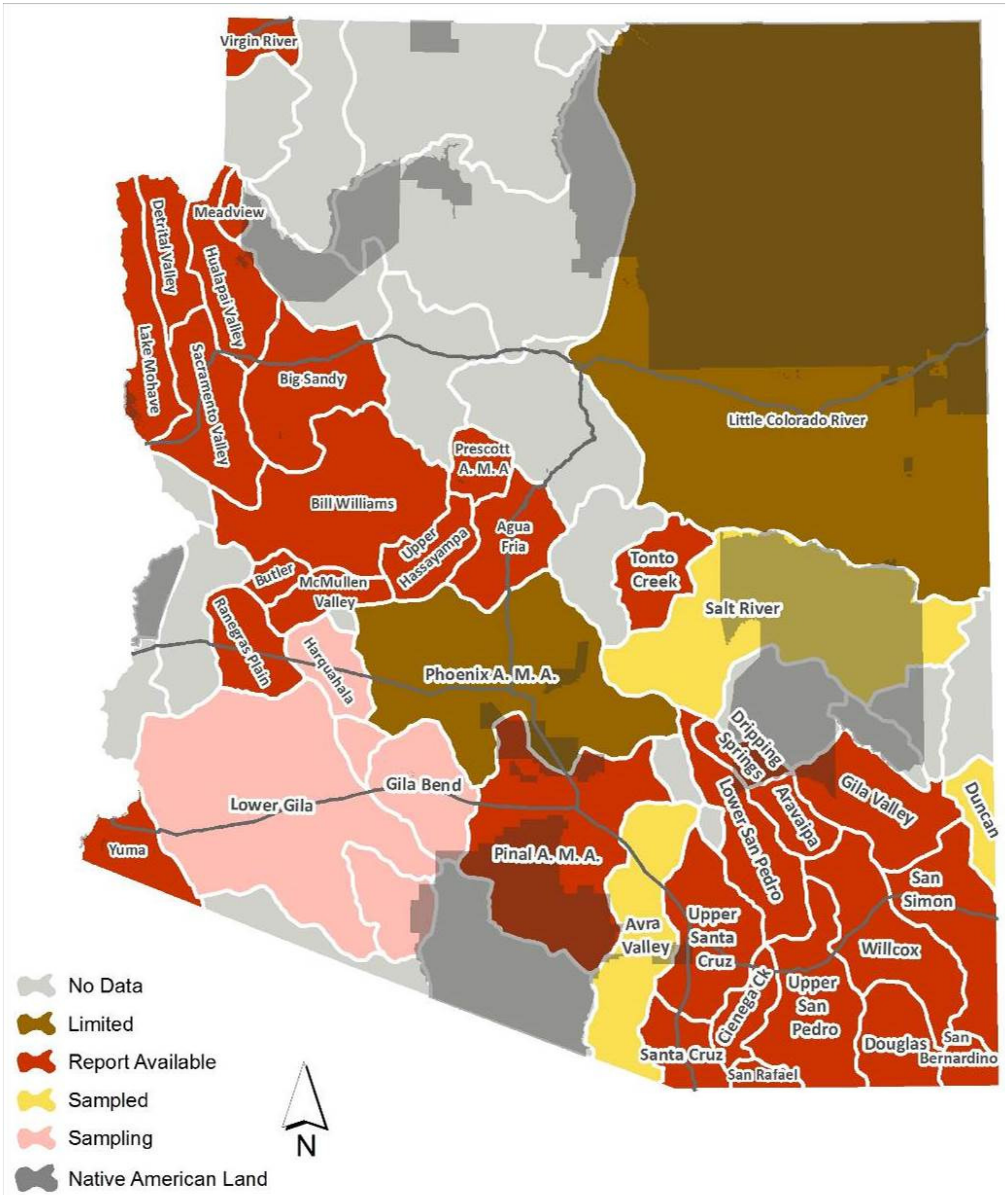
Thanks:

Field Assistance:	Elizabeth Boettcher, Susan Determann, Jade Dickens, Joe Harmon, Angela Lucci, and Joanie Rhyner. Special recognition is extended to the many well owners who were kind enough to give permission to collect groundwater data on their property.
Photo and Map Credits:	Douglas Towne
Report Cover:	Clover Well consists of a windmill, storage tank, and pipelines transporting water to troughs for livestock use. The windmill is located west of the community of Rye at the base of the Mazatzal Mountains in the Tonto Creek Basin.

Other Publications of the ADEQ Ambient Groundwater Monitoring Program

Tonto Creek Basin	OFR 13-04, 50 p.	FS 13-18, 4 p.
Upper Hassayampa Basin	OFR 13-03, 52 p.	FS 13-11, 3 p.
Aravaipa Canyon Basin	OFR 13-01, 46 p.	FS 13-04, 4 p.
Butler Valley Basin	OFR 12-06, 44 p.	FS 12-10, 5.p.
Cienega Creek Basin	OFR 12-02, 46 p.	FS 12-05, 4.p.
Ranegras Plain Basin	OFR 11-07, 63 p.	FS 12-01, 4.p.
Groundwater Quality in Arizona	OFR 11-04, 26 p.	-
Bill Williams Basin	OFR 11-06, 77 p.	FS 12-01, 4.p.
San Bernardino Valley Basin	OFR 10-03, 43 p.	FS 10-31, 4 p.
Dripping Springs Wash Basin	OFR 10-02, 33 p.	FS 11-02, 4 p.
McMullen Valley Basin	OFR 11-02, 94 p.	FS 11-03, 6 p.
Gila Valley Sub-basin	OFR 09-12, 99 p.	FS 09-28, 8 p.
Agua Fria Basin	OFR 08-02, 60 p.	FS 08-15, 4 p.
Pinal Active Management Area	OFR 08-01, 97 p.	FS 07-27, 7 p.
Hualapai Valley Basin	OFR 07-05, 53 p.	FS 07-10, 4 p.
Big Sandy Basin	OFR 06-09, 66 p.	FS 06-24, 4 p.
Lake Mohave Basin	OFR 05-08, 66 p.	FS 05-21, 4 p.
Meadview Basin	OFR 05-01, 29 p.	FS 05-01, 4 p.
San Simon Sub-Basin	OFR 04-02, 78 p.	FS 04-06, 4 p.
Detrital Valley Basin	OFR 03-03, 65 p.	FS 03-07, 4 p.
San Rafael Basin	OFR 03-01, 42 p.	FS 03-03, 4 p.
Lower San Pedro Basin	OFR 02-01, 74 p.	FS 02-09, 4 p.
Willcox Basin	OFR 01-09, 55 p.	FS 01-13, 4 p.
Sacramento Valley Basin	OFR 01-04, 77 p.	FS 01-10, 4 p
Upper Santa Cruz Basin (w/ USGS)	OFR 00-06, 55 p.	-
Prescott Active Management Area	OFR 00-01, 77 p.	FS 00-13, 4 p.
Upper San Pedro Basin (w/ USGS)	OFR 99-12, 50 p.	FS 97-08, 2 p.
Douglas Basin	OFR 99-11, 155 p.	FS 00-08, 4 p.
Virgin River Basin	OFR 99-04, 98 p.	FS 01-02, 4 p.
Yuma Basin	OFR 98-07, 121 p.	FS 01-03, 4 p.

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



Map 1. ADEQ Ambient Groundwater Monitoring Program Studies

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Abbreviations

amsl	above mean sea level
ac-ft	acre-feet
af/yr	acre-feet per year
ADEQ	Arizona Department of Environmental Quality
ADHS	Arizona Department of Health Services
ADWR	Arizona Department of Water Resources
ARRA	Arizona Radiation Regulatory Agency
AZGS	Arizona Geological Survey
As	arsenic
bls	below land surface
BLM	U.S. Department of the Interior Bureau of Land Management
CAP	Central Arizona Project
^oC	degrees Celsius
$CI_{0.95}$	95 percent Confidence Interval
Cl	chloride
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
gpm	gallons per minute
GWPL	Groundwater Protection List 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 Limit
ns	not significant
ntu	nephelometric turbidity unit
pCi/L	picocuries per liter
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
SAR	Sodium Adsorption Ratio
SDW	Safe Drinking Water
SC	Specific Conductivity
su	standard pH units
SO_4	sulfate
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
TON	Tonto Basin Groundwater Basin
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound
WQARF	Water Quality Assurance Revolving Fund
*	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 Tonto Creek Basin: A 2002-2012 Baseline Study

Abstract - From 2002-2012, the Arizona Department of Environmental Quality conducted a baseline groundwater quality study of the Tonto Creek basin located approximately 40 miles northeast of Phoenix. The basin comprises 955 square miles within Gila County and includes the communities of Gisela, Kohl's Ranch, Punkin Center, Rye, and Star Valley. The basin consists of rugged mountains formed by faulting and trends north-south. Low-intensity livestock grazing and recreational activities are the main land uses. Land ownership consists of federal land (97.5 percent) managed by the U.S. Forest Service as part of the Tonto National Forest. The remainder is private inholdings (2.4 percent) and Tonto Apache tribal lands (0.1 percent).[3] The basin is drained by Tonto Creek which heads just below the Mogollon Rim near Kohl's Ranch and exits the basin about eight miles south of Punkin Center to later enter Theodore Roosevelt Lake, contributing an annual average discharge of 105,000 acre-feet. [4] Major perennial tributaries include Rye, Spring, Haigler, Houston, Christopher, and Greenback creeks.

Groundwater occurs in the Tonto Creek basin in four geologic categories: stream alluvium, basin-fill sediments, Paleozoic sedimentary rocks, and Precambrian igneous, metamorphic, and sedimentary rocks. The primary aquifer is the unconsolidated sediments including stream alluvium (along Tonto Creek and its major tributaries) and basin fill that underlie much of the basin south of Rye. Paleozoic sedimentary rocks along the Mogollon Rim can also produce abundant water from a limestone aquifer whose source is the C-aquifer in the adjacent Little Colorado River basin. Precambrian igneous, metamorphic, and sedimentary rocks in the basin's margins sometimes produce limited groundwater. [4, 10, 21] Groundwater is used for all municipal and domestic uses and most irrigation and stock uses in the basin. Small diversions on Tonto Creek and its tributaries supply surface water for irrigation such as near Gisela.

Thirty-one sites (20 wells and 11 springs) were sampled for the study. Inorganic constituents were collected at each site while radionuclide (19), oxygen and deuterium isotopes (10), volatile organic compounds or VOCs (8), and radon (5) samples were collected at selected sites. Of the 31 sites sampled, 22 sites met all drinking water quality standards not including the proposed radon standard. Of the five sites sampled for radon, none exceeded the proposed 4,000 picocuries per liter (pCi/L) standard while all five sites (100 percent) exceeded the proposed 300 pCi/L standard. [26] There were no VOC detections.

Health-based, Primary Maximum Contaminant Levels (MCLs) were exceeded at eight sites (26 percent). These enforceable standards define the maximum constituent concentration allowed in drinking water provided by a public water system and are based on a lifetime consumption of two liters per day. [26] Constituents above Primary MCLs include arsenic (6 sites), gross alpha (2 sites), and 1 site each for nitrate, radium-226+228, and uranium. Aesthetics-based, Secondary MCLs were exceeded at four sites (13 percent). These unenforceable guidelines define the maximum constituent concentration that can be present in drinking water without an unpleasant taste, color, or odor.[26] Constituents above Secondary MCLs include fluoride (1 site), manganese (1 site), and total dissolved solids or TDS (3 sites).

Groundwater in the basin typically has calcium or mixed-bicarbonate chemistry and is *slightly-alkaline*, *fresh*, and *moderately hard* to *very hard*, based on pH levels along with TDS and hardness concentrations.[9, 12] Oxygen and deuterium isotope values at most sites reflected the elevation at which the samples were collected.[11]

Groundwater constituent concentrations were influenced by geology.[10, 18] Constituents such as temperature, specific conductivity (SC)-field, SC-lab, TDS, sodium, potassium, chloride, strontium, oxygen-18, and deuterium had significantly higher constituent concentrations/levels at sites in unconsolidated sediment than at sites in consolidated rocks (Kruskal-Wallis test, $p \leq 0.05$). Constituents such as temperature, SC-field, SC-lab, TDS, sodium, potassium, chloride, strontium, oxygen-18, and gross alpha generally had significantly greater concentrations/levels in sites located in stream alluvium than in basin fill, and consolidated or sedimentary rock (Kruskal-Wallis test, $p \leq 0.05$).

Groundwater in the Tonto Creek basin is generally suitable for drinking water uses based on results from this ADEQ study and research by the U.S. Geological Survey.[10, 21] Most samples were of calcium or mixed-bicarbonate chemistry which is characteristic of recently recharged groundwater having low concentrations of TDS, nutrients, and trace elements. [20] The limestone aquifer along the Mogollon Rim produces especially pure water. Groundwater from wells tapping the fine-grained facies of the upper part of the basin fill south of Rye however, should be avoided as a drinking water source because of potentially elevated concentrations of arsenic, fluoride, and TDS. [10, 21]

INTRODUCTION

Purpose and Scope

The Tonto Creek groundwater basin comprises approximately 955 square miles within Gila County in the east central portion of the state (Map 1).[4] The basin is located about 40 miles northeast of Phoenix and includes the communities of Gisela, Kohl's Ranch, Punkin Center, Rye, and Star Valley. The Town of Payson is located just outside the basin to the northwest. The basin consists of rugged mountains formed by faulting and trends north-south, drained by Tonto Creek which heads just below the Mogollon Rim near Kohl's Ranch and exits the basin about eight miles south of Punkin Center. Groundwater is used for all municipal and domestic uses and many irrigation and stock uses.[4] Small diversions on Tonto Creek and its tributaries supply water for irrigation use.

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 scientific sampling techniques and quantitative analyses, is designed to provide the following benefits:

- A characterization of regional groundwater quality conditions in the Tonto Creek basin identifying water quality variations between groundwater originating from different sources.
- Protecting human health by assessing compliance of the analytical results of the collected samples with various drinking water quality standards.
- A process for evaluating potential groundwater quality impacts arising from mineralization, mining, livestock, septic tanks, and poor well construction.
- A guide for determining areas where further groundwater quality research is needed.

Physical and Cultural Characteristics

Geography – The Tonto Creek basin is located within the Central highlands physiographic province of central Arizona. The basin is characterized by mid-elevation mountains and valleys. Vegetation is composed of Arizona upland Sonoran desertscrub, semi-desert grassland, interior chaparral, Great Basin conifer and madrean evergreen woodlands, and montane conifer forests. Riparian vegetation includes mixed broadleaf, mesquite, and tamarisk along Tonto Creek and its major tributaries. [4]

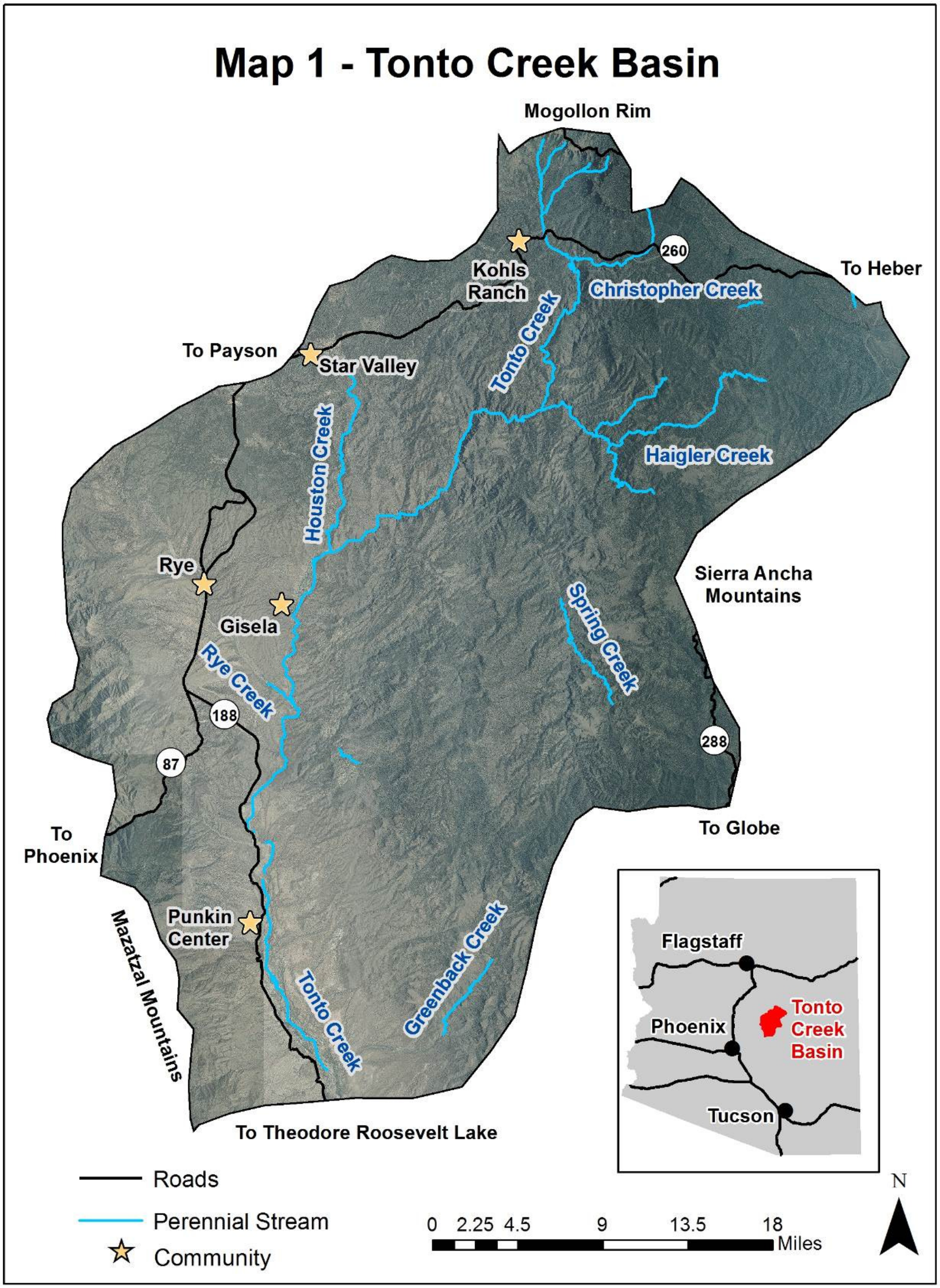
The basin is bounded on the north by the Mogollon Rim, on the east by the Sierra Ancha Mountains, and on the west by the Mazatzal Mountains. To the south, the basin ends about eight miles south of Punkin Center along Tonto Creek at a gaging station just upstream of Theodore Roosevelt Lake. Elevations in the basin range from a high of approximately 7,888 feet above mean sea level (amsl) atop Mazatzal Mountain to a low of approximately 5,000 feet amsl where Tonto Creek exits into the Salt River basin.

The Tonto Creek basin consists of federal land (97.5 percent) managed by the U.S. Forest Service as part of the Tonto National Forest. These include a portion of the 250,053 acre Mazatzal Wilderness and the entire 37,399 acre Hellsgate Wilderness. The remainder of the basin is composed of small private inholdings (2.4 percent) and Tonto Apache tribal lands (0.1 percent) near Payson.[3]

Climate – The Tonto Creek basin is in a semiarid climate characterized by hot, dry summers and mild winters. There is wide variation in precipitation amounts which range annually from 14 inches in the southern portion near Punkin Center to 38 inches in the highest elevations along the Mogollon Rim. Precipitation occurs predominantly as rain in either late summer, localized thunderstorms or, less often, as widespread, low intensity winter rain that includes snow, especially at higher elevations. [4]

Surface Water Characteristics

The basin is drained by Tonto Creek, a perennial tributary to the Salt River, which flows from north to south in the basin. Major tributaries to Tonto Creek include Rye Creek coming from the west and Spring and Haigler creeks flowing from the eastern portion of the basin. Other perennial streams include Houston, Christopher, and Greenback Creeks. Tonto Creek has annual average discharge of 105,000 af into Theodore Roosevelt Lake. [4]



Map 1 - Tonto Creek Basin
Mogollon Rim
Kohls Ranch
260
Christopher Creek
To Heber
To Payson
Star Valley
Tonto Creek
Houston Creek
Haigler Creek
Rye
Gisela
Sierra Ancha Mountains
Spring Creek
Rye Creek
188
87
288
To Phoenix
To Globe
Punkin Center
Mazatzal Mountains
Tonto Creek
Greenback Creek
To Theodore Roosevelt Lake
Flagstaff
Phoenix
Tucson
Tonto Creek Basin
Roads
Perennial Stream
Community
0 2.25 4.5 9 13.5 18
Miles
N

The basin has ten major springs with discharges exceeding ten gallons per minute (gpm) with the largest being Tonto Spring at 1,291 gpm. These high-flow springs are mostly located along the Mogollon Rim near Kohl's Ranch. There are around 170 springs in the basin identified by the U.S. Geological Survey. [4]

Groundwater Characteristics

Groundwater occurs in the Tonto Creek basin in stream alluvium, basin-fill sediments, Paleozoic sedimentary rocks, and Precambrian igneous, metamorphic, and sedimentary rocks. The basin's primary aquifer is the unconsolidated sediments including basin fill and stream alluvium that underlie the basin from Rye downgradient to the southern basin boundary. The amount of groundwater found in rocks varies widely depending on the water-bearing characteristics of the rocks, the amount of faulting or fracturing, and the relative topographic location of the rocks. [10]

Stream alluvium composed of gravel and sand along with small amounts of clay and silt is found along Tonto Creek downstream from Gisela and along lower parts of major tributaries. Alluvium may be up to 65 feet thick and is highly permeable, yielding 2,500 gallons per minute (gpm) in some locations. Stream alluvium is recharged primarily by infiltration of surface flow but also from adjacent groundwater units. [4, 21]

The basin-fill is divided into two parts: a lower and an upper unit. The lower unit overlies Precambrian schist and consists of unconsolidated-to-semiconsolidated interbedded gravel, sand, and sandstone. The cementation and poor sorting of the lower unit result in a low-to-moderate permeability that yields only small to moderate quantities of water suitable for domestic or stock use if a sufficient saturated thickness of material is penetrated. [4, 10, 21]

The upper unit of the basin fill overlies the lower unit and consists of coarse-grained and fine-grained facies or depositional components. The coarse-grained facies are moderately permeable but because it is generally located above the water table, it is not an important groundwater source. The coarse-gravel facies exists in a narrow band along the margins of basin but is limited in areal extent and gradually dissipates into the fine-grained facies toward the center of the basin. The fine-grained facies consists of poorly consolidated silt and clay with minor amounts of sand, gypsum, marl, and tuff. Most of the upper unit is largely impermeable, although thin sand layers yield small amounts of water to wells near Punkin Center. The upper unit serves as a confining layer for underlying water-bearing units. Wells generally produce less than 10 gpm though some can produce up to 200 gpm which indicates the sediment in those areas contains more sand and gravel or is less cemented. [4, 10, 21]

Paleozoic sedimentary rocks and Precambrian igneous, metamorphic, and sedimentary rocks often contain little groundwater. In the northern portion of the basin, limestone faults, fractures, and solution cavities along the Mogollon Rim produce abundant water. Water in the aquifer comes from the C-aquifer in the Little Colorado basin and is recharged from precipitation on southern edge of the Colorado Plateau. Although major springs, some producing over 1,000 gpm, are found in the area, wells generally produce less than 100 gpm. [4]

Groundwater development in the basin is limited because of its rugged topography and predominant federal land ownership. Most wells are low-yield domestic and stock wells though some irrigation wells along the lower reaches of Tonto Creek produce up to 2,500 gpm.[4] Groundwater flows generally from north to south. Depth to groundwater varies significantly across the basin from just 40 feet below land surface (bls) along stretches of the lower Tonto Creek to over 100 feet bls in most other areas of the basin. Natural recharge estimates for the basin vary from 17,000 to 37,000 acre-feet per year (af/yr) while groundwater use is estimated to be less than 500 af/yr. Natural discharges from the basin include 105,000 af of surface flow via Tonto Creek, 4,000 acre-feet of subsurface flow into the Salt River basin, and 13,000 af of riparian evapotranspiration. Total estimated recoverable groundwater in storage in the basin-fill sediments to a depth of 1,200 feet bls is estimated to be between 2.0 and 9.4 million af. [4, 21]

INVESTIGATION METHODS

ADEQ collected samples from 31 sites to characterize regional groundwater quality in the Tonto Creek basin (Map 2). Specifically, the following types of samples were collected:

- inorganic suites at 31 sites
- radionuclides at 19 sites
- oxygen and deuterium isotopes at 10 sites
- volatile organic compounds (VOCs) at 8 sites
- radon at 5 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. [12]

Map 2 - Sample Sites

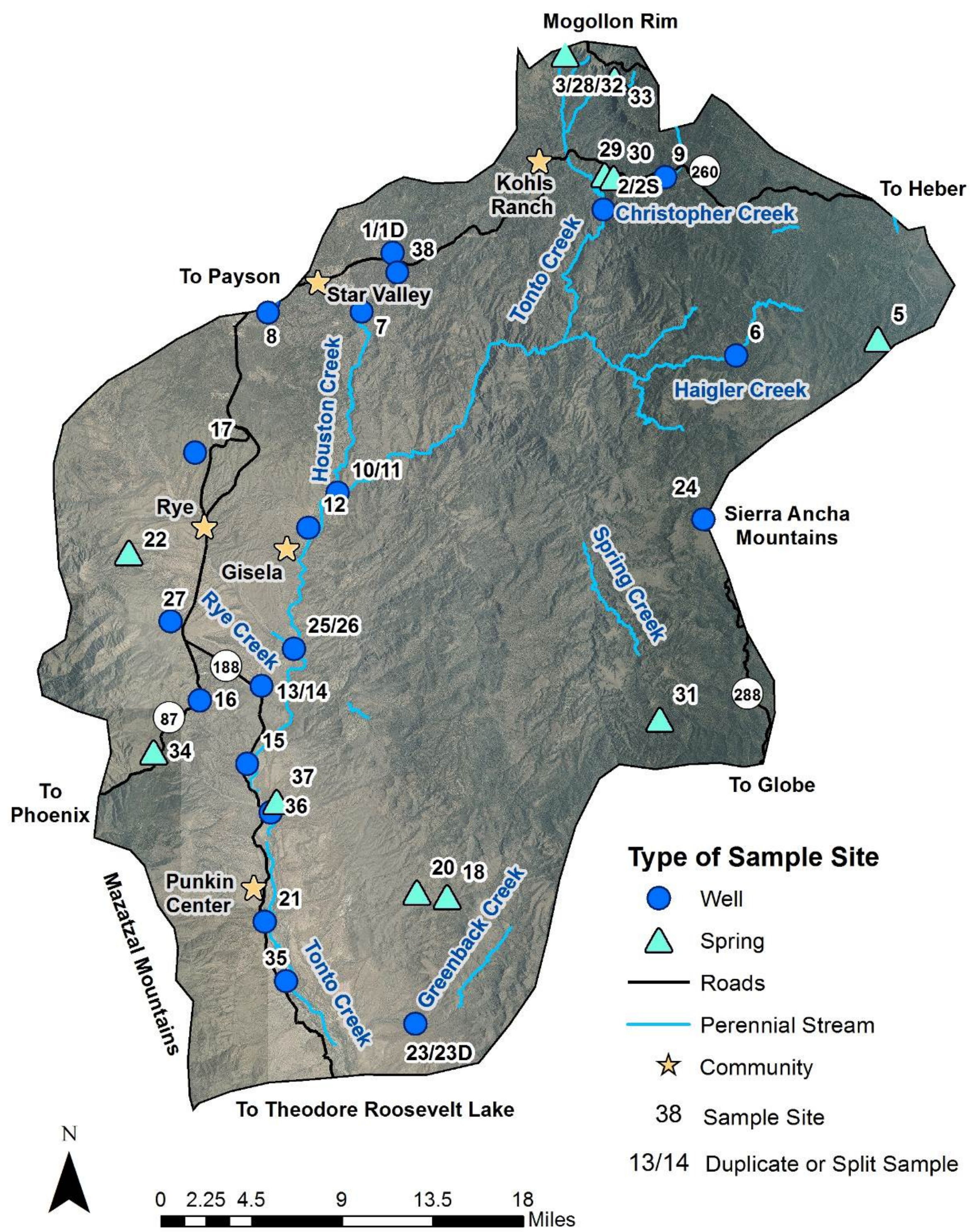


Figure 1 – Tonto Creek, shown upgradient of the community of Gisela, has perennial flow throughout the basin which it exits before emptying into Theodore Roosevelt Lake in the Salt River basin. [4] Other important perennial streams that feed into Tonto Creek include Christopher, Haigler, and Houston creeks.

Figure 2 – Former ADEQ employee Susan Determann, samples R-C Spring (TON-30) which is piped across a creek to a lake and used for recreational purposes by the R-C Scout Ranch. R-C Spring discharges an average of 800 gpm, making it the basin's second largest spring. [4] Analytical results indicated the water met all drinking water quality standards.

Figure 3 – The sample from Payson Concrete and Materials Well #1 (TON-36) that is used for industrial purposes met all drinking water quality standards.

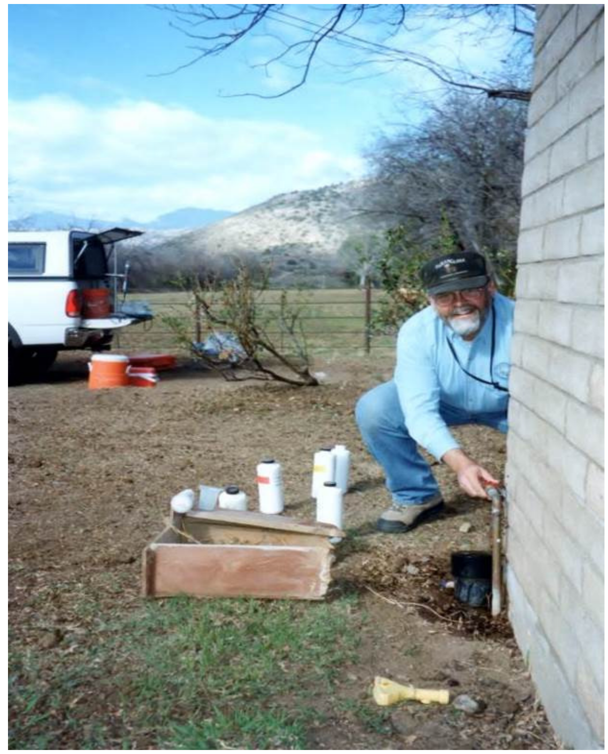


Figure 5 – Former ADEQ employee Joe Harmon collects a sample (TON-10) from a well in Gisela along Tonto Creek that exceeded standards for gross alpha.

Figure 4 – ADEQ's Jade Dickens and Elizabeth Boettcher collect a sample (TON-33) from Horton Spring which discharges an average of 392 gpm just below the Mogollon Rim. [4]

Figure 6 – Former ADEQ employee Susan Determann collects a sample from Tonto Spring just below the Mogollon Rim. Tonto is the largest spring in the basin with an average discharge of 1,291 gpm. [4]

Figure 7 – Harris Windmill located north of the community of Rye was sampled on a windy day in March 2002. Samples (TON-17) from the 130-foot-deep well met all water quality standards.

Figure 8 – Water for livestock produced by Gold Creek Windmill flows into the adjacent tank located along U.S. Highway 87 south of the Arizona Department of Transportation rest area. The sample (TON-16) from the well met all water quality standards.

Figure 9 – Kayler Spring located on the east side of Tonto Creek below Punkin Center creates its own riparian area as shown in this fall photograph.

Figure 10 – ADEQ's Joanie Rhyner collects a sample (TON-37) from Kayler Spring a short distance after it emerges from the ground. The arsenic concentration (0.026 mg/L) in the field-filtered sample exceeded the drinking water standard of 0.010 mg/L.

.

Wells pumping groundwater for domestic, stock, and irrigation purposes were sampled for the study, provided each well met ADEQ requirements. A well was considered suitable for sampling when the following conditions were met: 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 20 wells served by 17 submersible pumps, 2 windmills, and 1 turbine pump. The wells were primarily used for domestic and/or stock use. Eleven springs were also sampled that were primarily used for stock or wildlife watering with one used by a fish hatchery.

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 three bore-hole volumes was calculated from well log and on-site information. Physical parameters—temperature, pH, and specific conductivity—were monitored 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, it was not possible to purge three bore volumes. In these cases, at least one bore volume was evacuated and the physical parameters had stabilized within 10 percent.

Sample bottles were filled in the following order:

1. Radon
2. VOCs
3. Inorganics
4. Radionuclide
5. Isotopes

Radon is a naturally occurring, intermediate breakdown from the radioactive decay of uranium-238 to lead-206. These samples were collected in two unpreserved, 40 milliliter (ml) clear glass vials. Radon samples were filled to minimize volatilization and sealed so that no headspace remained.[5, 22]

VOC samples were collected in two, 40-ml amber glass vials which contained 10 drops of 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 standard units (su); additional HCl acid was added if necessary. VOC samples were also checked to make sure there were no air bubbles in the vials. [19]

The inorganic constituents were collected in three, one-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.[5, 19, 22]

Radiochemistry samples were collected in two collapsible four-liter plastic containers and preserved with 5 ml nitric acid to reduce the pH below 2.5 su. [5] Oxygen and hydrogen isotope samples were collected in a 250 ml polyethylene bottle with no preservative.[5, 25]

All samples were kept at $4^{o}C$ with ice in an insulated cooler, with the exception of the oxygen and hydrogen isotope samples.[5, 19, 22, 25] Chain of custody procedures were followed in sample handling. Samples for this study were collected during eight field trips conducted between 2002 and 2012.

Laboratory Methods

All VOC samples and the inorganic analyses for the first 22 inorganic samples, except two split samples, were conducted by the Arizona Department of Health Services (ADHS) Laboratory in Phoenix, Arizona. The inorganic analyses for the last nine inorganic samples plus three split samples (TON-3S, TON-14, and TON-24S) were conducted by Test America Laboratory in Phoenix, Arizona. A complete listing of inorganic parameters, including laboratory method and Minimum Reporting Limit (MRL) for each

.

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

Constituent	Instrumentation	ADHS / Test America Water Method	ADHS / Test America Minimum Reporting Level
Physical Parameters and General Mineral Characteristics			
Alkalinity	Electrometric Titration	SM 2320B / M 2320 B	2 / 6
SC (µS/cm)	Electrometric	EPA 120.1/ M 2510 B	- / 2
Hardness	Titrimetric, EDTA	SM 2340 C / SM 2340B	10 / 1
Hardness	Calculation	SM 2340 B	--
pH (su)	Electrometric	SM 4500 H-B	0.1
TDS	Gravimetric	SM 2540C	10
Turbidity (NTU)	Nephelometric	EPA 180.1	0.01 / 0.2
Major Ions			
Calcium	ICP-AES	EPA 200.7	1 / 2
Magnesium	ICP-AES	EPA 200.7	1 / 0.25
Sodium	ICP-AES	EPA 200.7	1 / 2
Potassium	Flame AA	EPA 200.7	0.5 / 2
Bicarbonate	Calculation	Calculation / M 2320 B	2
Carbonate	Calculation	Calculation / M 2320 B	2
Chloride	Potentiometric Titration	SM 4500 CL D / E 300	5 / 2
Sulfate	Colorimetric	EPA 375.4 / E 300	1 / 2
Nutrients			
Nitrate as N	Colorimetric	EPA 353.2	0.02 / 0.1
Nitrite as N	Colorimetric	EPA 353.2	0.02 / 0.1
Ammonia	Colorimetric	EPA 350.1/ EPA 350.3	0.02 / 0.5
TKN	Colorimetric	EPA 351.2 / M 4500-NH3	0.05 / 1.3
Total Phosphorus	Colorimetric	EPA 365.4 / M 4500-PB	0.02 / 0.1

All units are mg/L except as noted
Source [19, 22]

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

Constituent	Instrumentation	ADHS / Test America Water Method	ADHS / Test America Minimum Reporting Level
		Trace Elements	
Aluminum	ICP-AES	EPA 200.7	0.5 / 0.2
Antimony	Graphite Furnace AA	EPA 200.8	0.005 / 0.003
Arsenic	Graphite Furnace AA	EPA 200.9 / EPA 200.8	0.005 / 0.001
Barium	ICP-AES	EPA 200.8 / EPA 200.7	0.005 to 0.1 / 0.01
Beryllium	Graphite Furnace AA	EPA 200.9 / EPA 200.8	0.0005 / 0.001
Boron	ICP-AES	EPA 200.7	0.1 / 0.2
Cadmium	Graphite Furnace AA	EPA 200.8	0.0005 / 0.001
Chromium	Graphite Furnace AA	EPA 200.8 / EPA 200.7	0.01 / 0.01
Copper	Graphite Furnace AA	EPA 200.8 / EPA 200.7	0.01 / 0.01
Fluoride	Ion Selective Electrode	SM 4500 F-C	0.1 / 0.4
Iron	ICP-AES	EPA 200.7	0.1 / 0.05
Lead	Graphite Furnace AA	EPA 200.8	0.005 / 0.001
Manganese	ICP-AES	EPA 200.7	0.05 / 0.01
Mercury	Cold Vapor AA	SM 3112 B / EPA 245.1	0.0002
Nickel	ICP-AES	EPA 200.7	0.1 / 0.01
Selenium	Graphite Furnace AA	EPA 200.9 / EPA 200.8	0.005 / 0.002
Silver	Graphite Furnace AA	EPA 200.9 / EPA 200.7	0.001 / 0.01
Strontium	ICP-AES	EPA 200.7	0.1 / 0.1
Thallium	Graphite Furnace AA	EPA 200.9 / EPA 200.8	0.002 / 0.001
Zinc	ICP-AES	EPA 200.7	0.05
		Radionuclides	
Radon	Liquid scintillation counter	EPA 913.1	varies

All units are mg/L Source [19, 22]

Table 2. Volatile Organic Compounds (VOCs) Analyte List

Benzene	1,4-Dichlorobenzene	Methyl-T-butyl ether
Bromodichloromethane	Dichlorodifluoromethane	1,1,1,2-Tetrachloroethane
Bromoform	1,1-Dichloroethane	Tetrachloroethylene
Bromomethane	1,2-Dichloroethane	Toluene
Carbon Tetrachloride	1,1-Dichloroethene	1,1,1-Trichlorobenzene
Chlorobenzene	cis-1,2-Dichloroethene	1,1,2-Trichloroethane
Chloroethane	trans-1,2-Dichloroethene	Trichloroethylene
Chloroform	1,2-Dichloropropane	Trichlorofluoromethane
Chloromethane	cis-1,3-Dichloropropene	Vinyl chloride
Dibromomethane	trans-1,3-Dichloropropene	Total xylenes
1,2-Dichlorobenzene	Ethylbenzene	
1,3-Dichlorobenzene	Methylene chloride	

Source [19]

laboratory is provided in Table 1. The VOCs analyte list is provided in Table 2.

Radionuclide analyses for samples TON-1 through TON-27 were conducted by the Arizona Radiation Agency Laboratory in Phoenix. For samples TON-28 through TON-38, radionuclide analysis was conducted by Radiation Safety Engineering, Inc. Laboratory in Chandler, Arizona. The following EPA SDW protocols were used: Gross alpha was analyzed, and if levels exceeded 5 picocuries per liter (pCi/L), then radium-226 was measured. 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. [1]

Radon samples were submitted to Test America Laboratory and analyzed by Radiation Safety Engineering, Inc. Laboratory in Chandler, Arizona. Isotope samples were analyzed by the Department of Geosciences, Laboratory of Isotope Geochemistry at the University of Arizona in Tucson, Arizona.

DATA EVALUATION

Quality Assurance

Quality-assurance (QA) procedures were followed and quality-control (QC) samples were collected to quantify data bias and variability for the Tonto 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 inorganic samples collected for this study include four duplicates and three splits.

Blanks – One equipment blank for inorganic analyses was 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] The equipment blank sample for major ion and nutrient analyses were collected by filling unpreserved and sulfuric acid preserved bottles with de-ionized water. The equipment blank sample for trace element analysis was collected with de-ionized water that had been filtered into nitric acid preserved bottles.

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 turbidity and specific conductivity (SC-lab) at expected levels due to impurities in the source water used for the samples.

For turbidity, the blank had a level of 0.08 nephelometric turbidity units (ntu) less than 1 percent of the turbidity mean level for the study and was not considered to be 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.[19]

For SC, the equipment blank had a value of 1.8 micro-siemens per cm (uS/cm) which was less than 1 percent of the SC mean concentration for the study and was not considered to be significantly affecting the sample results. The SC detections may have occurred when water passing through a de-ionizing exchange unit normally has an SC value of at least 1 uS/cm. Carbon dioxide from the air can also dissolve in de-ionized water with the resulting bicarbonate and hydrogen ions imparting the observed conductivity.[19]

The four VOC travel blanks revealed no contamination issues with any of the 34 compounds.

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 were collected and submitted to the ADHS laboratory for this study. Analytical results indicate that of the 40 constituents examined, 20 had concentrations above the MRL. The duplicate samples had an excellent correlation as the maximum variation between constituents was less than 5 percent except for total phosphorus (9 percent), TKN (10 percent), and turbidity (32 percent) (Table 3).

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] Three inorganic split samples were collected and distributed between the ADHS and Test America 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, 20 had concentrations above MRLs for both ADHS and Test America laboratories (Table 3). The maximum variation between constituents was below 5 percent except for zinc (10 percent), chloride (15 percent), potassium (21 percent), turbidity (28 percent), copper (90 percent), and TKN (95 percent) (Table 4).

Split samples were also evaluated using the non-parametric Sign test to determine if there were any significant differences between ADHS laboratory and Test America laboratory analytical results.[28] There were no significant differences in constituent concentrations between the labs (Sign test, $p \leq 0.05$).

Based on the results of blank, 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. [15]

Cation/Anion Balances – In theory, water samples exhibit electrical neutrality. Therefore, the sum of milliequivalents per liter (meq/L) of cations should equal the sum of meq/L of anions. However, this neutrality rarely occurs due to unavoidable variation inherent in all water quality analyses. Still, if the cation/anion balance is found to be within acceptable limits, it can be assumed there are no gross errors in concentrations reported for major ions.[15]

Overall, cation/anion meq/L balances of Tonto Creek basin samples were significantly correlated (regression analysis, $p \leq 0.01$). Of the 31 samples, all were within +/-5 percent and 25 samples were within +/- 2 percent. Seventeen samples had low cation/high anion sums; 14 samples had high cation/low anion sums.

SC/TDS –- The SC-lab 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.[15]

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 with very high or low concentrations of dissolved solids.[15]

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

Table 3. Summary Results of Duplicate Samples from ADHS Laboratory

Parameter	Number of Dup. Samples	Difference in Percent			Difference in Concentrations		
		Minimum	Maximum	Median	Minimum	Maximum	Median
Physical Parameters and General Mineral Characteristics							
Alk., Total	4	0 %	4 %	0 %	0	20	10
SC (µS/cm)	4	0 %	1 %	0 %	0	10	5
Hardness	4	0 %	1 %	0 %	0	10	0
pH (su)	4	0 %	1 %	1 %	0	0.1	0.1
TDS	4	0 %	2 %	1 %	0	20	10
Turb. (ntu)	4	35 %	40 %	37 %	0.04	3.5	1.6
Major Ions							
Calcium	4	0 %	1 %	0 %	0	1	0
Magnesium	4	0 %	1 %	1 %	0	1	1
Sodium	4	0 %	3 %	1 %	0	5	1
Potassium	4	0 %	3 %	1 %	0	0.2	0.1
Bicarbonate	4	0 %	5 %	1 %	0	30	10
Chloride	4	0 %	4 %	3 %	0	10	5
Sulfate	4	0 %	1 %	0 %	0	1	0
Nutrients							
Nitrate (as N)	4	0 %	3 %	2 %	0	1	0.4
Phosphorus, T.*	2	0 %	7 %	-	0	0.005	-
TKN **	1	-	-	2 %	0	-	0.01
Trace Elements							
Arsenic	1	-	-	0 %	-	-	0
Barium	2	0 %	-	0 %	0	-	0
Boron	1	-	-	0 %	-	-	0
Fluoride	4	0 %	4 %	1 %	0	0.2	0.1
Iron	1	-	-	0 %	-	-	0
Zinc	1	-	-	0 %	-	-	0

All concentration units are mg/L except as noted with certain physical parameters.
* = Total Phosphorus was detected in one sample (TON-23) at a concentration of 0.036 mg/L and not detected in the duplicate (TON-23D)
** = TKN was detected in one sample (TON-23D) at a concentration of 0.05 mg/L and not detected in the duplicate (TON-23)

Table 4. Summary Results of Split Samples between ADHS / Test America 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	3	0 %	3 %	3	10	ns
SC (µS/cm)	3	0 %	2 %	0	10	ns
Hardness	3	3 %	4 %	4	20	ns
pH (su)	3	1 %	5 %	0.11	0.7	ns
TDS	3	1 %	3 %	10	10	ns
Turbidity (ntu)	1	28 %	28 %	1.5	1.5	ns
Major Ions						
Calcium	3	1 %	3 %	1	1	ns
Magnesium	3	0 %	2 %	0	0.2	ns
Sodium	3	2 %	7 %	1	10	ns
Potassium	3	0 %	10 %	0	1.3	ns
Chloride	3	5 %	15 %	0.7	8	ns
Sulfate	3	0 %	4 %	0	1	ns
Nutrients						
Nitrate as N	1	2 %	2 %	0.02	0.02	ns
TKN*	1	91 %	91 %	2.09	2.09	ns
Trace Elements						
Arsenic	1	4 %	4 %	0.005	0.005	ns
Barium	1	2 %	2 %	0.01	0.01	ns
Copper	1	15 %	15 %	0.004	0.004	ns
Fluoride	3	0 %	7 %	0	0.4	ns
Lead	1	6 %	6 %	0.0009	0.0009	ns
Zinc	2	0 %	6 %	0	0.03	ns

ns = No significant ($p \leq 0.05$) difference
All units are mg/L except as noted
* = TKN was detected by Test America in (TON-14) at 0.56 mg/L and not detected in the ADHS split sample (TON-13)
Turbidity was detected by ADHS in (TON-2) at 1.3 ntu and not detected in the Test Am. split sample (TON-2S)

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)]. [15]

pH – The pH value is closely related to the environment of the water and is likely to be altered by sampling and storage.[15] The pH values measured in the field using a YSI meter at the time of sampling (Diagram 1) were significantly correlated with laboratory pH values (regression analysis, r = 0.61, $p \geq 0.05$).

Based on the results of blank, duplicate, and split samples collected for this study, no significant QA/QC problems were apparent with the study. There was however, one contamination issue during the study.

To explore whether any significant changes had occurred in constituent concentrations between 2002 and 2011, Tonto Spring used by Tonto Creek Fish Hatchery was resampled. Analysis of laboratory findings showed no significant change in constituent concentrations with the exception of detections of cadmium (0.011 mg/L), iron (0.068 mg/L), and thallium (0.013 mg/L) in the 2011 sample (TON-28) that were all non-detect in the 2002 sample (TON-2/2S). Subsequent investigation indicated these trace elements may have been the result of a recent concrete upgrade of the spring box. A subsequent resampling in 2012 (TON-32) had non-detections for cadmium, iron, and thallium.

Statistical Considerations

Various statistical analyses were used to examine the groundwater quality data of the study. All statistical tests were conducted using SYSTAT software.[28]

Data Normality: Data associated with 24 constituents were tested for non-transformed normality using the Kolmogorov-Smirnov one-sample test with the Lilliefors option.[7] Results of this test revealed that 11 of the 24 constituents examined were not normally distributed including turbidity, sodium, potassium, chloride, sulfate, nitrate, barium, fluoride, gross alpha, gross beta, and deuterium.

Spatial Relationships: The non-parametric Kruskal-Wallis test using untransformed data was applied to investigate the hypothesis that constituent concentrations from groundwater sites having different aquifers were the same.

The Kruskal-Wallis test uses the differences, but also incorporates information about the magnitude of each difference.[28] The null hypothesis of identical mean values for all data sets within each test was rejected if the probability of obtaining identical means by chance was less than or equal to 0.05. The Kruskal-Wallis test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.[14]

Correlation Between Constituents: In order to assess the strength of association between constituents, their concentrations were compared to each other using the non-parametric Kendall's tau-b test. Kendall's 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 Kendall's tau-b test were then subjected to a probability test to determine which of the individual pair wise correlations were significant.[28] The Kendall's tau-b test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.[14]

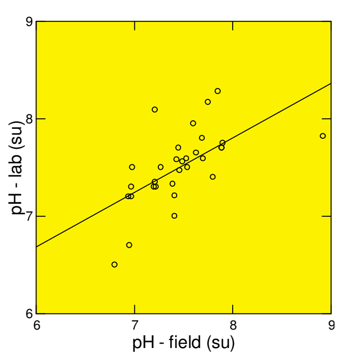


Diagram 1 – The graph illustrates a positive correlation between two parameters; as pH-field levels increase, pH-lab levels also increase. This relationship is described by the regression equation: y = 0.66x + 2.47 (r = 0.61). The pH value is closely related to the environment of the water and is likely to be altered by sampling and storage.[15]

GROUNDWATER SAMPLING RESULTS

Water Quality Standards/Guidelines

The ADEQ ambient groundwater program characterizes regional groundwater quality. An important determination ADEQ makes concerning the collected samples is how the analytical results compare to various drinking water quality standards.

ADEQ used three sets of drinking water standards that reflect the best current scientific and technical judgment available to evaluate the suitability of groundwater in the basin for drinking water use:

- Federal Safe Drinking Water (SDW) Primary Maximum Contaminant Levels (MCLs). These enforceable health-based standards establish the maximum concentration of a constituent allowed in water supplied by public systems.[26]

- State of Arizona Aquifer Water Quality Standards. These apply to aquifers that are classified for drinking water protected use. All aquifers within Arizona are currently classified and protected for drinking water use. These enforceable State standards are identical to the federal Primary MCLs except for arsenic which is at 0.05 mg/L compared with the federal Primary MCL of 0.01 mg/L.[2]

- Federal SDW Secondary MCLs. These non-enforceable aesthetics-based guidelines define the maximum concentration of a constituent that can be present without imparting unpleasant taste, color, odor, or other aesthetic effects on the water.[26]

Health-based drinking water quality standards (such as Primary MCLs) are based on the lifetime consumption (70 years) of two liters of water per day and, as such, are chronic not acute standards.[26] Exceedances of specific constituents for each groundwater site is found in Appendix B.

Overall Results – Of the 31 sites sampled in the Tonto Basin study, 22 sites met all health-based and aesthetics-based, water quality standards (excluding the proposed radon standard discussed below).

Of the 31 sites sampled in the Tonto Basin study, health-based water quality standards were exceeded at 8 sites (26 percent). Constituents above Primary MCLs include arsenic (6 sites), gross alpha (2 sites), and 1 site each for nitrate, radium-226+228, and uranium.

Inorganic Constituent Results - Of the 31 sites sampled for the full suite of inorganic constituents (excluding radionuclide sample results) in the Tonto Creek study, 23 sites (74 percent) met all health-based and aesthetics-based, water quality standards.

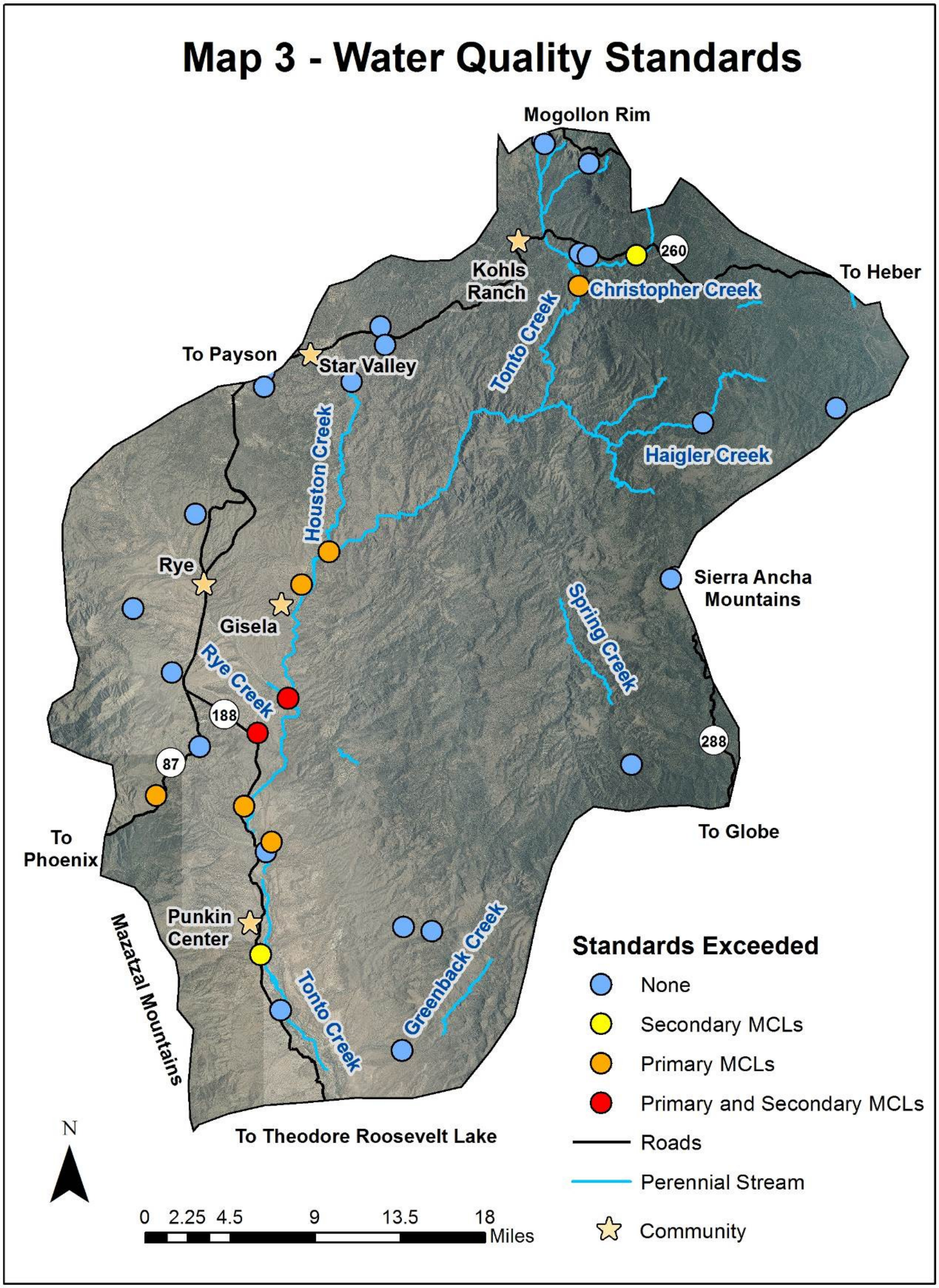
Health-based Primary MCL water quality standards and State aquifer water quality standards were exceeded at 6 sites (19 percent) of the 31 sites (Map 3; Table 5). Constituents above Primary MCLs include arsenic (6 sites) and nitrate (1 site). Potential impacts of these Primary MCL exceedances are given in Table 5.

Aesthetics-based Secondary MCL water quality guidelines were exceeded at 4 of 31 sites (13 percent; Map 3; Table 6). Constituents above Secondary MCLs include fluoride (1 site), manganese (1 site), and TDS (3 sites). Potential impacts of these Secondary MCL exceedances are given in Table 6.

Radon Results - Of the five 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. All five sites exceeded the proposed 300 pCi/L standard (Table 4) that would apply if Arizona doesn't develop a multimedia program.[26]

Analytical Results

Analytical inorganic and radiochemistry results of the Tonto Basin sample sites are summarized (Table 7) using the following indices: 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.[28] Specific constituent information for each sampled groundwater site is in Appendix B.



Map 3 - Water Quality Standards
Mogollon Rim
260
To Heber
Kohls Ranch
Christopher Creek
Tonto Creek
To Payson
Star Valley
Haigler Creek
Houston Creek
Rye
Gisela
Sierra Ancha Mountains
Spring Creek
Rye Creek
188
87
288
To Phoenix
To Globe
Punkin Center
Mazatzal Mountains
Tonto Creek
Greenback Creek
Standards Exceeded
None
Secondary MCLs
Primary MCLs
Primary and Secondary MCLs
Roads
Perennial Stream
Community
To Theodore Roosevelt Lake
N
0 2.25 4.5 9 13.5 18
Miles

Table 5. Sampled Sites Exceeding Health-based Water Quality Standards or Primary MCLs

Constituent	Primary MCL	Number of Sites Exceeding Primary MCL	Highest Concentration	Potential Health Effects of MCL Exceedances *
Nutrients				
Nitrite (NO_2-N)	1.0	0	-	-
Nitrate (NO_3-N)	10.0	**1**	28.5	methemoglobinemia
Trace Elements				
Antimony (Sb)	0.006	0	-	-
Arsenic (As)	0.01	**6**	0.20	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**	210	cancer
Ra-226+Ra-228	5	**1**	10	-
Radon ***	300	**5**	906	cancer
Radon ***	4,000	0	-	-
Uranium	30	**1**	220	cancer and kidney toxicity

All units are mg/L except gross alpha, radium-226+228 and radon (pCi/L), and uranium (ug/L).
* Health-based drinking water quality standards are based on a lifetime consumption of two liters of water per day over a 70-year life span.[26]
** One sample exceeded this Primary MCL was likely from contamination.
*** Proposed EPA Safe Drinking Water Act standards for radon in drinking water. [26]

Table 6. Sampled 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	**3**	825	hardness; deposits; colored water; staining; salty taste
Major Ions				
Chloride (Cl)	250	0	-	salty taste
Sulfate (SO_4)	250	0	-	salty taste
Trace Elements				
Fluoride (F)	2.0	**1**	3.5	tooth discoloration
Iron (Fe)	0.3	0	-	-
Manganese (Mn)	0.05	**1**	0.15	black staining; bitter metallic taste
Silver (Ag)	0.1	0	**-**	**-**
Zinc (Zn)	5.0	0	**-**	**-**

All units mg/L except pH is in standard units (su). Source: [26]

Table 7. Summary Statistics for Groundwater Quality Data

Constituent	Minimum Reporting Limit (MRL)*	# of Samples / Samples Over MRL	Median	Lower 95% Confidence Interval	Mean	Upper 95% Confidence Interval
Physical Parameters						
Temperature (^oC)	0.1	31 / 31	17.2	15.1	17.1	19.0
pH-field (su)	0.01	31 / 31	7.45	7.31	7.47	7.62
pH-lab (su)	0.01	31 / 31	7.50	7.37	7.51	7.65
Turbidity (ntu)	0.01 / 0.20	31 / 28	0.3	0.3	1.2	2.0
General Mineral Characteristics						
T. Alkalinity	2.0 / 6.0	31 / 31	240	206	244	282
Phenol. Alk.	2.0 / 6.0	31 / 0	> 50% of data below MRL			
SC-field (µS/cm)	N/A	31 / 31	536	470	576	682
SC-lab (µS/cm)	N/A / 2.0	31 / 31	560	596	576	703
Hardness-lab	10 / 6	31 / 31	250	201	242	285
TDS	10 / 20	31 / 31	330	284	349	415
Major Ions						
Calcium	5 / 2	31 / 31	65	54	65	76
Magnesium	1.0 / 0.25	31 / 31	17	15	20	24
Sodium	5 / 2	31 / 31	17	15	35	55
Potassium	0.5 / 2.0	31 / 26	2.1	1.9	2.6	3.2
Bicarbonate	2.0 / 6.0	31 / 31	290	252	298	344
Carbonate	2.0 / 6.0	31 / 0	> 50% of data below MRL			
Chloride	1 / 20	31 / 30	12	17	29	41
Sulfate	10 / 20	31 / 30	13	10	24	37
Nutrients						
Nitrate (as N)	0.02 / 0.20	31 / 20	0.1	-0.7	1.2	3.0
Nitrite (as N)	0.02 / 0.20	31 / 0	> 50% of data below MRL			
TKN	0.05 / 1.0	31 / 11	> 50% of data below MRL			
Ammonia	0.02 / 0.05	31 / 3	> 50% of data below MRL			
T. Phosphorus	0.02 / 0.10	31 / 11	> 50% of data below MRL			

Table 7. Summary Statistics for Groundwater Quality Data—Continued

Constituent	Minimum Reporting Limit (MRL)*	# of Samples / Samples Over MRL	Median	Lower 95% Confidence Interval	Mean	Upper 95% Confidence Interval
Trace Elements						
Aluminum	0.5 / 0.2	22 / 0	> 50% of data below MRL			
Antimony	0.005 / 0.003	31 / 0	> 50% of data below MRL			
Arsenic	0.01 / 0.001	31 / 11	> 50% of data below MRL			
Barium	0.1 / 0.001	31 / 20	0.09	0.08	0.11	0.13
Beryllium	0.0005 / 0.001	31 / 0	> 50% of data below MRL			
Boron	0.1 / 0.2	31 / 3	> 50% of data below MRL			
Cadmium	0.001	31 / 0	> 50% of data below MRL			
Chromium	0.01 / 0.001	31 / 1	> 50% of data below MRL			
Copper	0.01 / 0.001	31 / 9	> 50% of data below MRL			
Fluoride	0.2 / 0.4	31 / 22	0.3	0.3	0.6	0.8
Iron	0.1 / 0.05	31 / 2	> 50% of data below MRL			
Lead	0.005 / 0.001	31 / 1	> 50% of data below MRL			
Manganese	0.05 / 0.01	31 / 1	> 50% of data below MRL			
Mercury	0.0005 / 0.0002	31 / 0	> 50% of data below MRL			
Nickel	0.1 / 0.01	31 / 0	> 50% of data below MRL			
Selenium	0.005 / 0.002	31 / 1	>50% of data below MRL			
Silver	0.001	31 / 0	> 50% of data below MRL			
Strontium	0.10	10 / 8	0.24	0.11	0.30	0.49
Thallium	0.002 / 0.001	31 / 0	> 50% of data below MRL			
Zinc	0.05	31 / 8	> 50% of data below MRL			
Radiochemical						
Gross Alpha**	Varies	20 / 14	2	-7	16	39
Gross Beta**	Varies	20 / 17	3	0	6	11
Radon **	Varies	5 / 5	689	674	441	908
Isotopes						
Oxygen-18 ***	Varies	10 / 10	-10.4	-10.9	-10.2	-9.4
Deuterium ***	Varies	10 / 10	-71.5	-75.1	-70.8	-66.5

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

GROUNDWATER COMPOSITION

General Summary

The water chemistry of the 31 sample sites in the Tonto Basin (in decreasing frequency) include calcium-bicarbonate (16 sites), mixed-bicarbonate (12 sites), sodium-bicarbonate, magnesium-bicarbonate, and mixed-mixed (1 site apiece) (Diagram 2 – middle figure) (Map 4).

The dominant cation was calcium at 16 sites and sodium and magnesium at 1 site apiece. At 13 sites the composition was mixed as there was no dominant cation (Diagram 2 – left figure).

The dominant anion was bicarbonate at 30 sites. The composition was mixed as there was no dominant anion at one site (Diagram 2 – right figure).

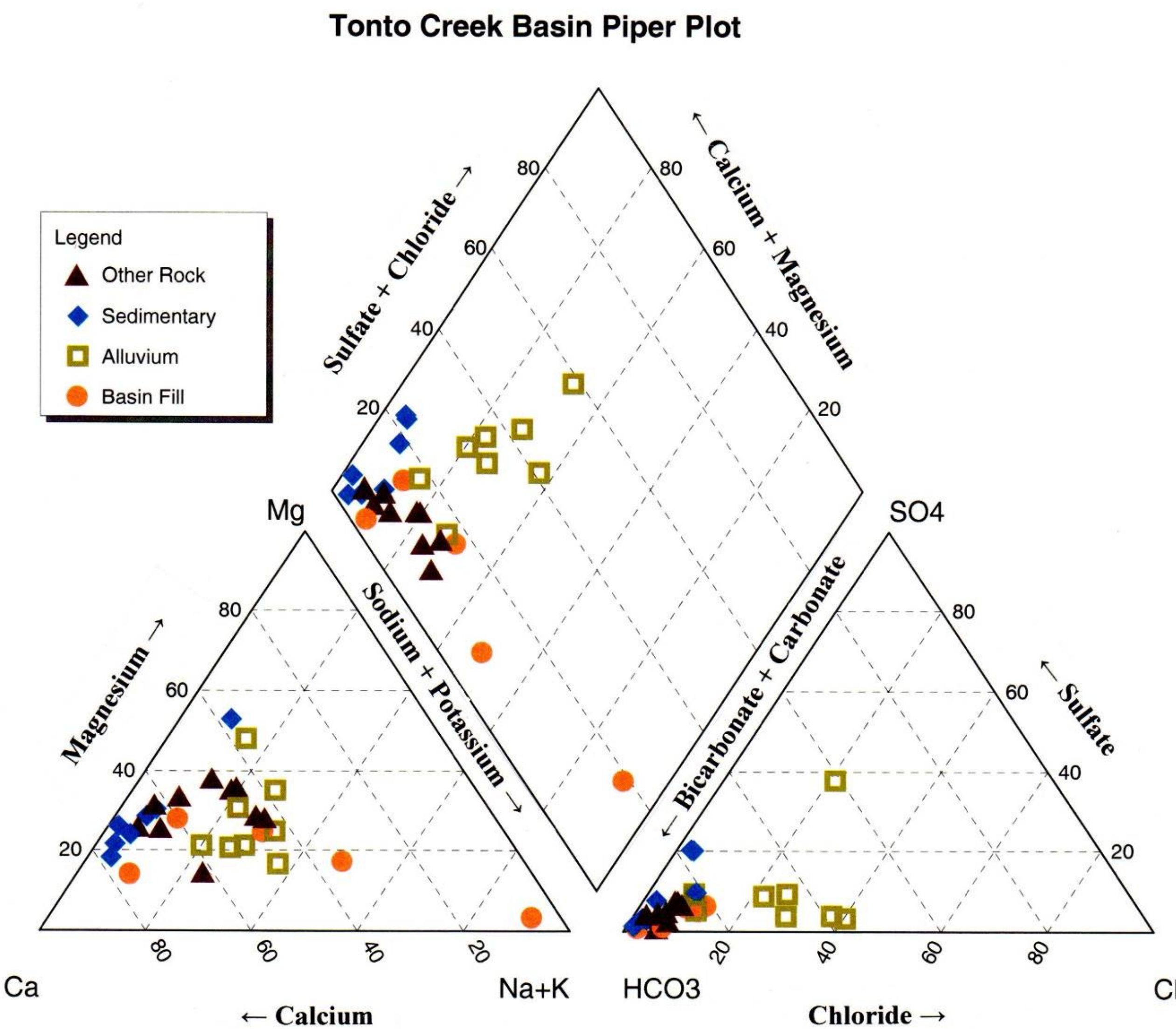
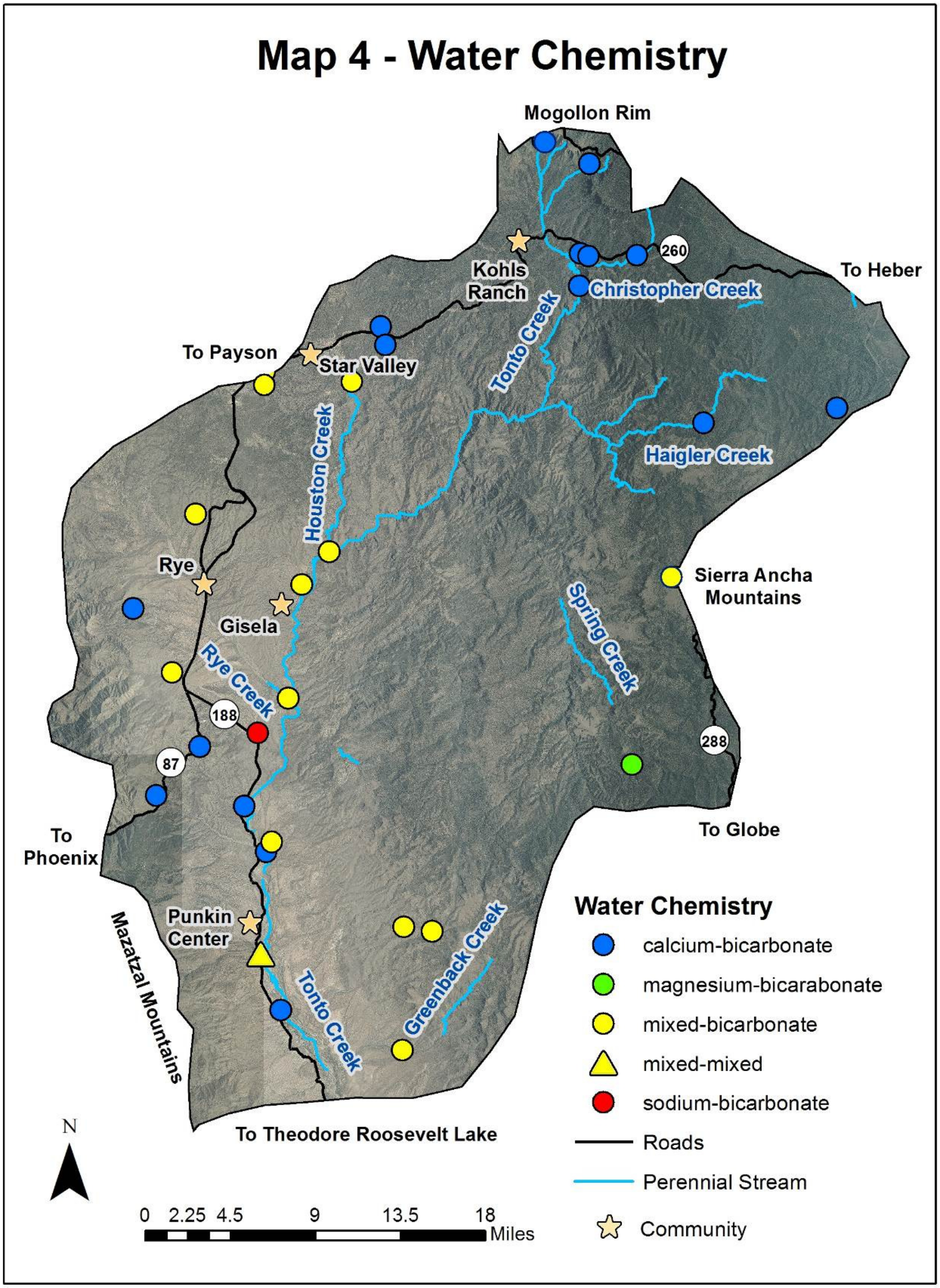


Diagram 2 – Groundwater samples collected in the Tonto Creek basin are predominantly a calcium-bicarbonate or mixed-bicarbonate chemistry which is reflective of young groundwater that has been recently recharged.[20] Samples collected from shallow wells drilled in the stream alluvium of Tonto Creek and its major tributaries form a seperate cluster exhibiting higher concentrations of chloride and sulfate than samples collected from other geologic units. The greatest water chemistry variability was exhibited by samples collected from wells and springs located in the basin-fill sediments. Two basin-fill samples were water chemistry outliers trending towards a sodium-bicarbonate chemistry, one slightly (TON-27) and one strongly (TON-13/14).



Map 4 - Water Chemistry
Mogollon Rim
Kohls Ranch
260
To Heber
Christopher Creek
Tonto Creek
To Payson
Star Valley
Houston Creek
Haigler Creek
Rye
Gisela
Sierra Ancha Mountains
Spring Creek
Rye Creek
188
288
87
To Phoenix
To Globe
Punkin Center
Mazatzal Mountains
Tonto Creek
Greenback Creek
To Theodore Roosevelt Lake
N
0 2.25 4.5 9 13.5 18 Miles
Water Chemistry
calcium-bicarbonate
magnesium-bicarabonate
mixed-bicarbonate
mixed-mixed
sodium-bicarbonate
Roads
Perennial Stream
Community

At 25 sites, levels of pH-field were *slightly alkaline* (above 7 su) and 1 site was above 8 su. At 6 sites, pH-field levels were *slightly acidic* (below 7 su) [13]

TDS concentrations were considered *fresh* (below 999 mg/L) at all 31 sites (Map 5).[13]

Hardness concentrations were *soft* (below 75 mg/L) at 1 site, *moderately hard* (75 – 150 mg/L) at 6 sites, *hard* (150 – 300 mg/L) at 17 sites, and *very hard* (300 - 600 mg/L) at 7 sites (Map 6).[9]

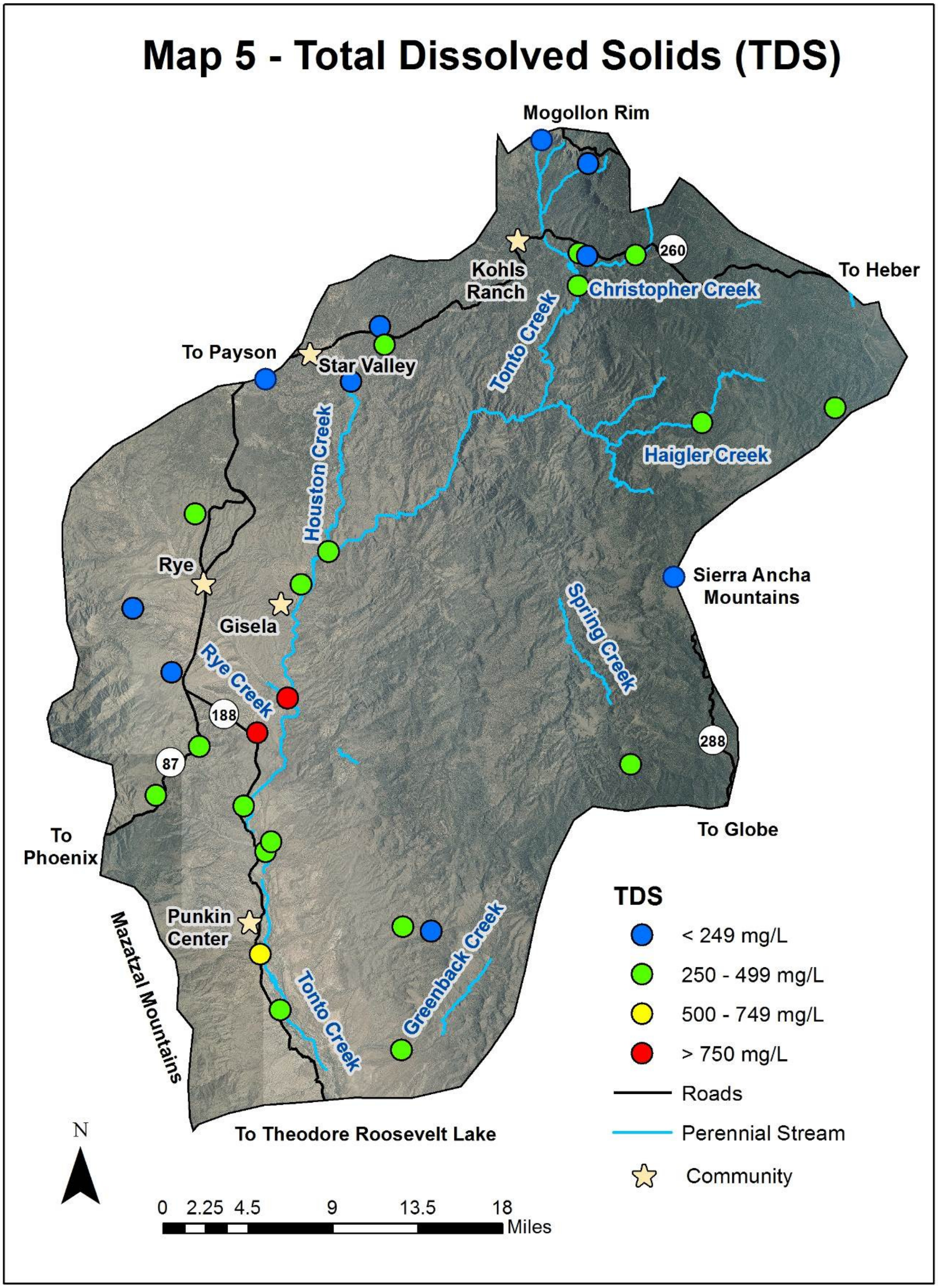
Nitrate (as nitrogen) concentrations at most sites may have been influenced by human activities. Nitrate concentrations were divided into natural background (19 sites at < 0.2 mg/L), may or may not indicate human influence (11 sites at 0.2 – 3.0 mg/L), may result from human activities (0 sites at 3.0 – 10 mg/L), and probably result from human activities (1 site > 10 mg/L).[16]

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

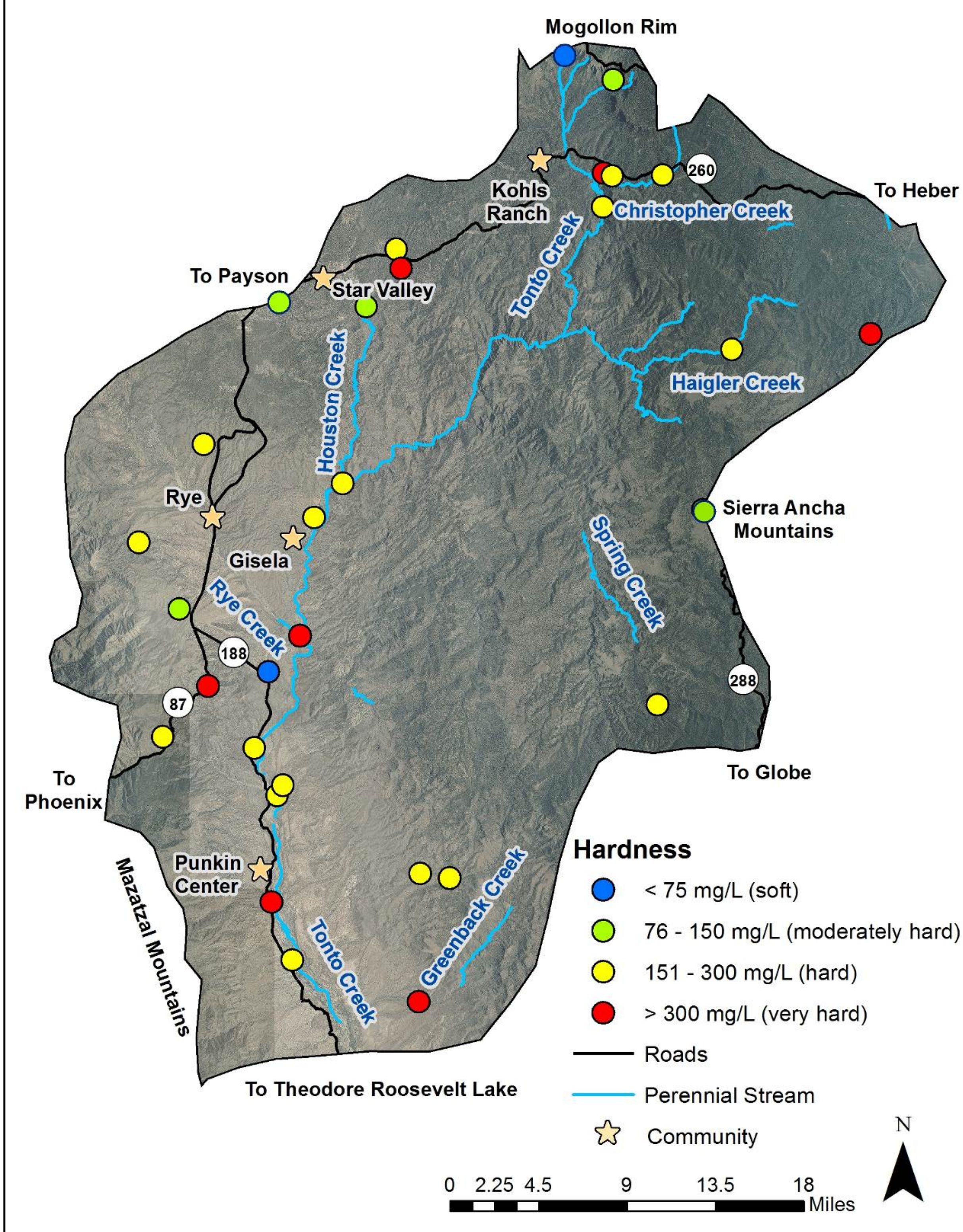
The groundwater at each sample site was assessed as to its suitability for irrigation use based on salinity and sodium hazards. Excessive levels of sodium are known to cause physical deterioration of the soil and vegetation. Irrigation water may be classified using SC and the Sodium Adsorption Ratio (SAR) in conjunction with one another.[28] Groundwater sites in the Tonto Basin display a narrow range of irrigation water classifications. Samples predominantly had a "low" sodium hazard and a "medium" salinity hazard (Table 8).

Table 8. Sodium and Salinity Hazards for Sampled Sites

Hazard	Total Sites	Low	Medium	High	Very High
			Sodium Hazard		
Sodium Adsorption Ratio (SAR)		0 - 10	10- 18	18 - 26	> 26
Sample Sites	31	30	0	1	0
			Salinity Hazard		
Specific Conductivity (µS/cm)		100–250	250 – 750	750-2250	>2250
Sample Sites	31	4	20	7	0


Map 5 - Total Dissolved Solids (TDS)
Mogollon Rim
260
Kohls Ranch
Christopher Creek
To Heber
Tonto Creek
To Payson
Star Valley
Houston Creek
Haigler Creek
Rye
Gisela
Sierra Ancha Mountains
Spring Creek
Rye Creek
188
288
87
To Phoenix
To Globe
Punkin Center
Mazatzal Mountains
Tonto Creek
Greenback Creek
To Theodore Roosevelt Lake
TDS
< 249 mg/L
250 - 499 mg/L
500 - 749 mg/L
> 750 mg/L
Roads
Perennial Stream
Community
N
0 2.25 4.5 9 13.5 18
Miles

Map 6 - Hardness



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.[28]

Several significant correlations occurred among the 31 sample sites (Table 8, Kendall's tau-b test, $p \leq 0.05$). Three groups of correlations were identified:

- There were positive correlations with TDS and SC, hardness, calcium, magnesium, sodium, potassium, bicarbonate (Diagram 3), chloride, and sulfate.
- Fluoride had a strong positive correlation with sodium, potassium, and chloride, though these relationships were influenced by an outlier.
- Nitrate was positively correlated with magnesium, and chloride, though these relationships were influenced by an outlier.

TDS concentrations are best predicted among major ions by sodium concentrations (standard coefficient = 0.51), among cations by sodium concentrations (standard coefficient = 0.76) and among anions, by bicarbonate concentrations (standard coefficient = 0.62) (multiple regression analysis, $p \leq 0.01$).

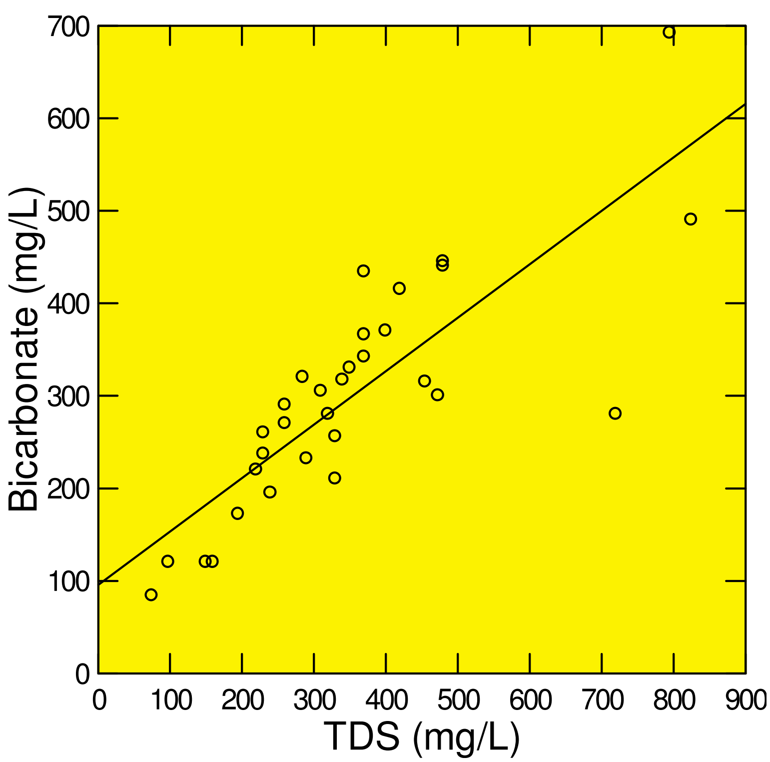


Diagram 3 – The graph illustrates a positive correlation between two constituents; as TDS concentrations increase, bicarbonate concentrations also increase. This relationship is described by the regression equation: $y = 0.30x + 231$ ($r = 0.60$). Both TDS and bicarbonate commonly occur in recharge areas and this relationship has been found in other Arizona groundwater basins.[18]

Table 8. Correlation Among Groundwater Quality Constituent Concentrations

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

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

Oxygen and Hydrogen Isotopes

Isotope samples were only collected from the 10 sites sampled in 2011-2012. The limited data for the Tonto basin roughly conforms to what would be expected in an arid environment, having a slope of 5.5, with the Local Meteoric Water Line (LMWL) described by the linear equation: $\delta D = 5.5\delta\,^{18}O - 14.7$ (Diagram 4). The LMWL for the Tonto basin (5.5) is similar to other basins in Arizona such as Aravaipa Canyon (4.1), Dripping Springs Wash (4.4), Upper Hassayampa (5.0), Detrital Valley (5.2), Agua Fria (5.3), Bill Williams (5.3), Sacramento Valley (5.5), Big Sandy (6.1), Butler Valley (6.4), Pinal Active Management Area (6.4), Gila Valley (6.4), San Simon (6.5), San Bernardino Valley (6.8), McMullen Valley (7.4), Lake Mohave (7.8), and Ranegras Plain (8.3). [24]

Isotope samples generally have values that reflect the elevation at which the sites were located. The two sample sites (TON-35 and TON-36) that are highest along the LMWL have the heaviest signatures from undergoing the most evaporation prior to sampling. These were collected from shallow wells along the lower reach of Tonto Creek (Map 7). Below these enriched samples are depleted samples that appear to consist of recharge from higher-elevation precipitation that has undergone less evaporation prior to sampling (Diagram 4).

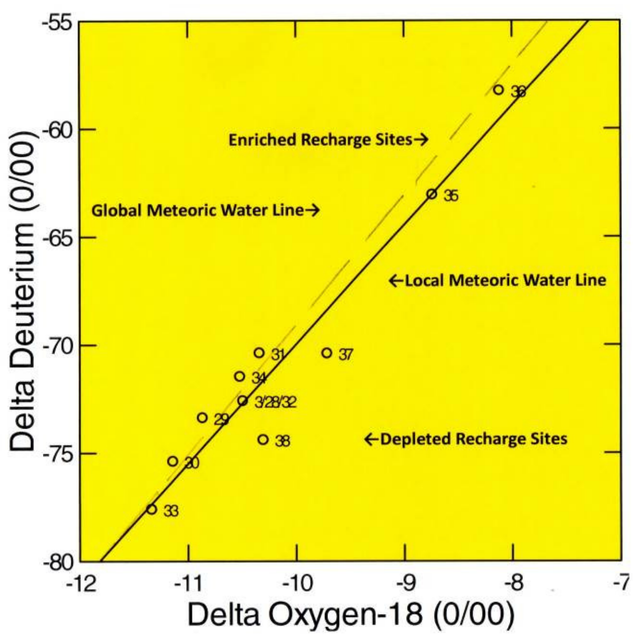


Diagram 4 – The 10 isotope samples are plotted according to their oxygen-18 and deuterium values and form the Local Meteoric Water Line.

Oxygen and Hydrogen Isotopes

Groundwater characterizations using oxygen and hydrogen isotope data may be made with respect to the climate and/or elevation where the water originated, residence within the aquifer, and whether or not the water was exposed to extensive evaporation prior to collection.[7] This is accomplished by comparing oxygen-18 isotopes ($\delta\,^{18}O$) and deuterium (δD), an isotope of hydrogen, data to the Global Meteoric Water Line (GMWL). The GMWL is described by the linear equation:

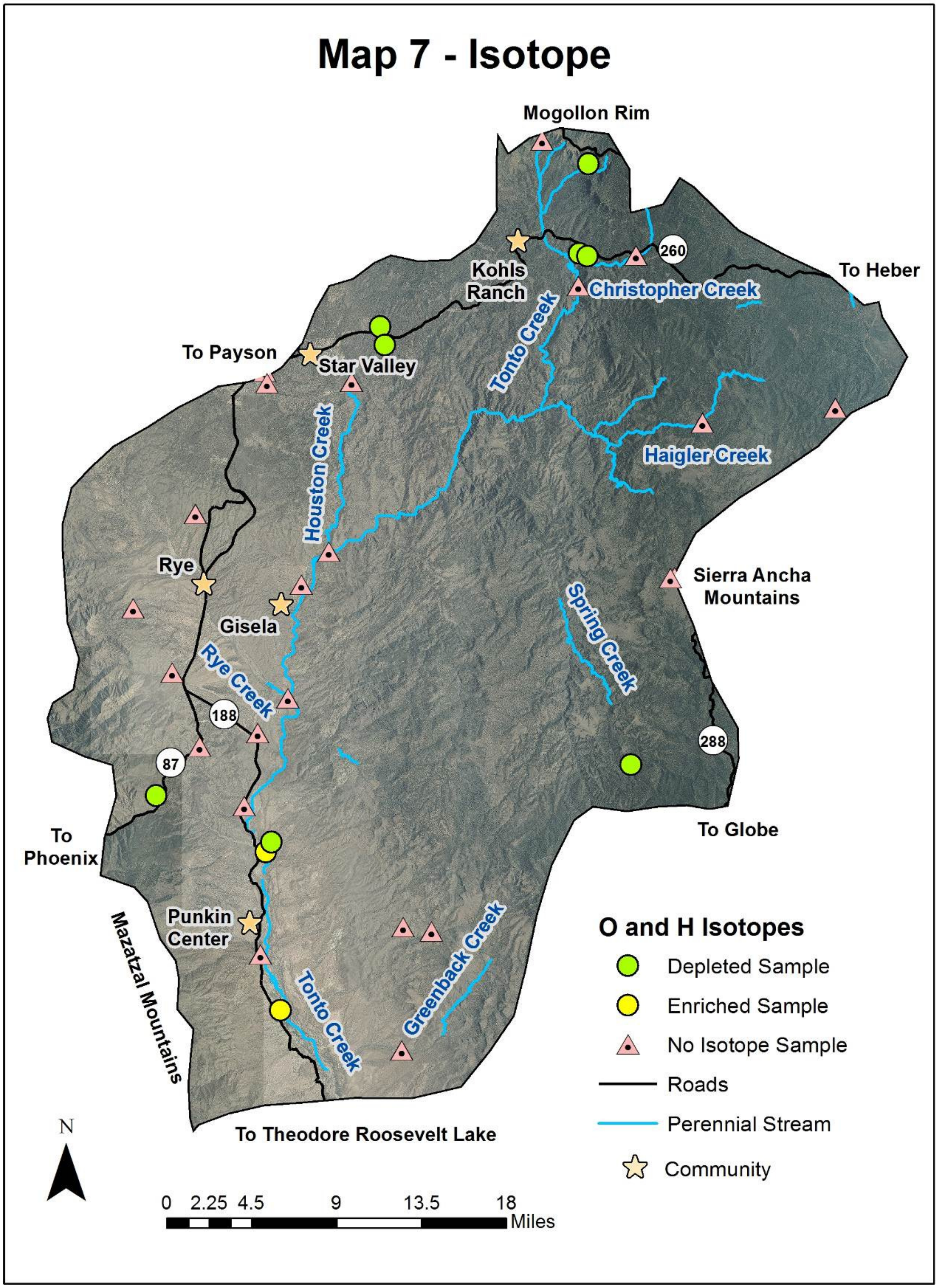
$$\delta D = 8\,\delta\,^{18}O + 10$$

where δD is deuterium in parts per thousand (per mil, $^0/_{00}$), 8 is the slope of the line, $\delta\,^{18}O$ is oxygen-18 $^0/_{00}$, and 10 is the y-intercept.[9] 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.[9] The LMWL created by $\delta\,^{18}O$ and δD values for samples collected at sites in the Tonto basin plot mostly to the right of the GMWL.

Meteoric waters exposed to evaporation are enriched and characteristically plot increasingly below and to the right of the GMWL. Evaporation tends to preferentially contain a higher percentage of lighter isotopes in the vapor phase and causes the water that remains behind to be isotopically heavier. In contrast, meteoric waters that experience little evaporation are depleted and tend to plot increasing to the left of the GMWL and are isotopically lighter. [7]

Groundwater from arid environments is typically subject to evaporation, which enriches δD and $\delta\,^{18}O$, resulting in a lower slope value (usually between 3 and 6) as compared to the slope of 8 associated with the GMWL.[7]



Map 7 - Isotope
Mogollon Rim
Kohls Ranch
260
To Heber
Christopher Creek
Tonto Creek
To Payson
Star Valley
Houston Creek
Haigler Creek
Rye
Gisela
Sierra Ancha Mountains
Spring Creek
Rye Creek
188
288
87
To Phoenix
To Globe
Punkin Center
Mazatzal Mountains
Tonto Creek
Greenback Creek
O and H Isotopes
Depleted Sample
Enriched Sample
No Isotope Sample
Roads
Perennial Stream
Community
To Theodore Roosevelt Lake
N
0 2.25 4.5 9 13.5 18
Miles

Groundwater Quality Variation

Between Two Geologic Groups – Twenty-four (24) groundwater quality constituents were compared between two broad geologic groups which included samples collected from sites predominantly in consolidated rock (17 sites) and samples collected from sites predominantly in unconsolidated sediment (14 sites). Some constituents had fewer samples collected (Table 9).

Significant concentration differences were found with ten constituents: temperature, SC-field, SC-lab, TDS (Diagram 5), sodium, potassium, chloride, strontium, oxygen-18 (Diagram 6), and deuterium (Kruskal-Wallis test, $p \leq 0.05$). In all these instances, sites located in unconsolidated sediment had significantly higher constituent concentrations than sites located in consolidated rock.

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

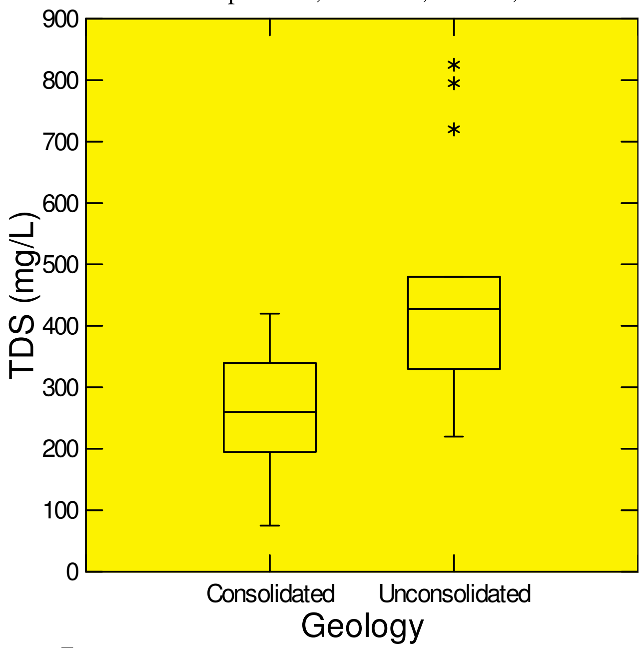


Diagram 5 – Samples collected from sites in unconsolidated sediment have significantly higher TDS concentrations than samples collected from sites in consolidated rock (Kruskal-Wallis, $p \leq 0.05$). Factors such as low rock solubility, a poor supply of carbon dioxide, and the few significant impacts from human activities influence the low TDS concentrations in upgradient sample sites located in consolidated rock. In downgradient areas of unconsolidated sediment, TDS concentrations often increase. [20]

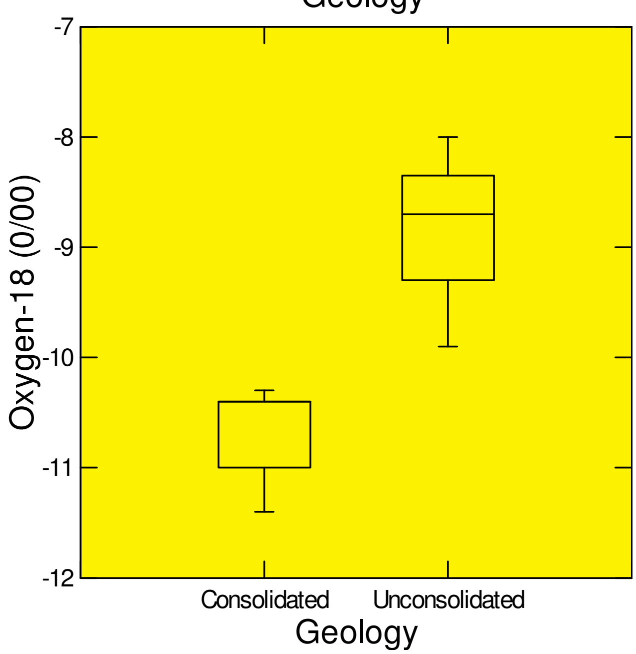


Diagram 6 – Samples collected from sites in unconsolidated sediment have significantly higher oxygen-18 levels than samples collected from sites in consolidated rock (Kruskal-Wallis, $p \leq 0.05$). Sample sites in unconsolidated sediment were generally located along the lower reach of Tonto Creek and became enriched through undergoing more evaporation prior to sampling. In contrast, sample sites from consolidated rock were collected at higher elevations in the basin. These depleted samples had undergone less evaporation prior to sampling. [9]

Table 9. Variation in Groundwater Quality Constituent Concentrations between Two Geologic Groups

Constituent	Sites Sampled	Significance	Significant Differences Between Two Geologic Groups
Temperature - field	31	**	Unconsolidated > Consolidated
pH – field	31	ns	-
pH – lab	31	ns	-
SC - field	31	**	Unconsolidated > Consolidated
SC - lab	31	**	Unconsolidated > Consolidated
TDS	31	**	Unconsolidated > Consolidated
Turbidity	31	ns	-
Hardness	31	ns	-
Calcium	31	ns	-
Magnesium	31	ns	-
Sodium	31	**	Unconsolidated > Consolidated
Potassium	31	**	Unconsolidated > Consolidated
Bicarbonate	31	ns	-
Chloride	31	**	Unconsolidated > Consolidated
Sulfate	31	ns	-
Nitrate (as N)	31	ns	-
Barium	31	ns	-
Fluoride	31	ns	-
Strontium	10	*	Unconsolidated > Consolidated
Gross alpha	19	ns	-
Gross beta	19	ns	-
Radon	5	ns	-
Oxygen	10	**	Unconsolidated > Consolidated
Deuterium	10	**	Unconsolidated > Consolidated

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

Table 10. Summary Statistics for Two Geologic Groups with Significant Constituent Differences

Constituent	Significance	Unconsolidated	Consolidated
Temperature – field (°C)	**	18.8 to 23.3	11.6 to 16.0
pH – field (su)	ns	-	-
pH – lab (su)	ns	-	-
SC – field (µS/cm)	**	585 to 933	339 to 512
SC – lab (µS/cm)	**	605 to 957	355 to 532
TDS	**	344 to 570	210 to 312
Turbidity (ntu)	ns	-	-
Hardness	ns	-	-
Calcium	ns	-	-
Magnesium	ns	-	-
Sodium	**	23 to 104	7 to 16
Potassium	**	1.9 to 3.9	1.0 to 1.9
Bicarbonate	ns	-	-
Chloride	**	34 to 75	5 to 11
Sulfate	ns	-	-
Nitrate (as N)	ns	-	-
Barium	ns	-	-
Fluoride	ns	-	-
Strontium	*	0.1 to 1.4	0.1 to 0.3
Gross alpha (pCi/L)	ns		
Gross beta (pCi/L)	ns		
Radon (pCi/L)	ns		
Oxygen (0/00)	**	-11.3 to -6.5	-11.1 to -10.3
Deuterium (0/00)	**	-80.3 to -47.7	-76.1 to -71.3

ns = not significant
* = significant at $p \leq 0.05$ or 95% confidence level
** = significant at $p \leq 0.01$ or 99% confidence level
All units are mg/L except where indicated.

Between Four Geologic Groups – Twenty-four groundwater quality constituents were compared between four geologic types: alluvium (nine sites), basin fill (five sites), consolidated sedimentary rocks (seven sites), and igneous and metamorphic (or "other rock") rocks (ten sites).[4, 10, 18]

Significant concentration differences were found with seven constituents: temperature, SC-field, SC-lab, TDS, sodium (Diagram 7), potassium, chloride (Diagram 8 and Map 8), strontium, oxygen-18, and gross alpha (Kruskal-Wallis test, $p \leq 0.05$).

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

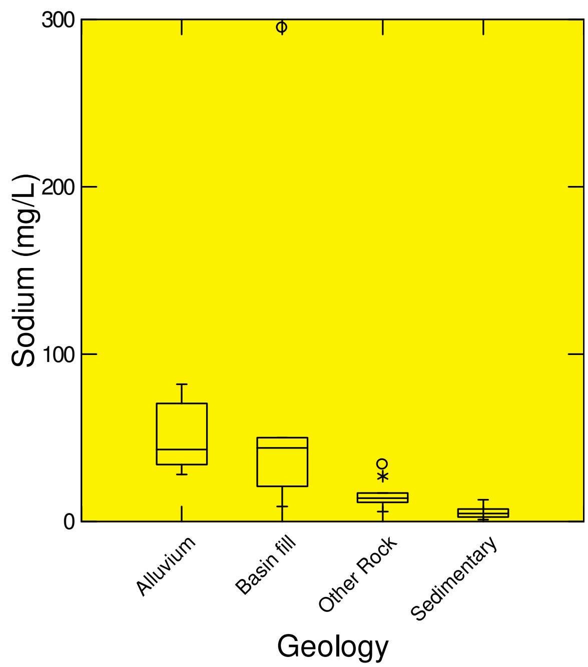


Diagram 7 – Samples collected from sites in basin fill sediments have significantly higher sodium concentrations than sample sites collected from sedimentary or other consolidated rock. Samples collected from sites in alluvium did not have significantly differences in sodium concentrations (Kruskal-Wallis, $p \leq 0.05$). Low concentrations of sodium typically occur in recharge areas and increase downgradient as the result of silicate weathering and halite dissolution along with ion exchange. [20]

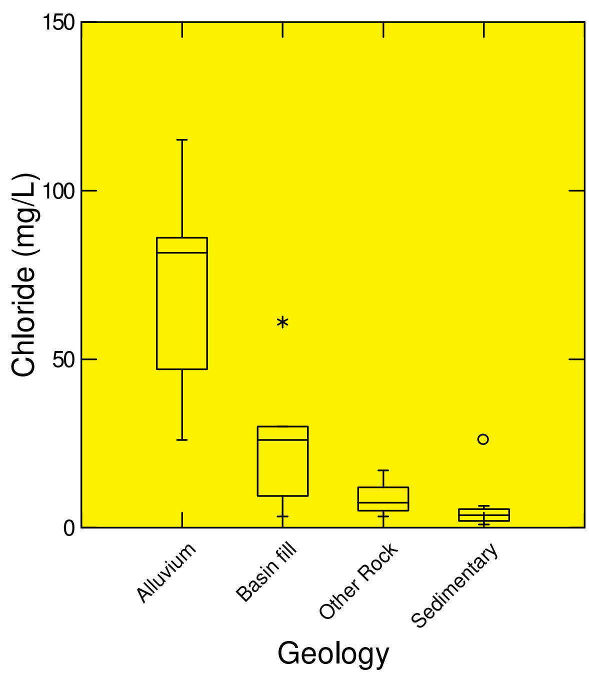


Diagram 8 – Samples collected from sites in stream alluvium have significantly higher chloride concentrations than sample sites collected from basin-fill sediments, sedimentary or other consolidated rock (Kruskal-Wallis, $p \leq 0.05$). Downgradient areas often evolve into sodium-chloride chemistry as TDS concentrations increase. [20]

Table 11. Variation in Groundwater Quality Constituent Concentrations Among Four Geologic Groups

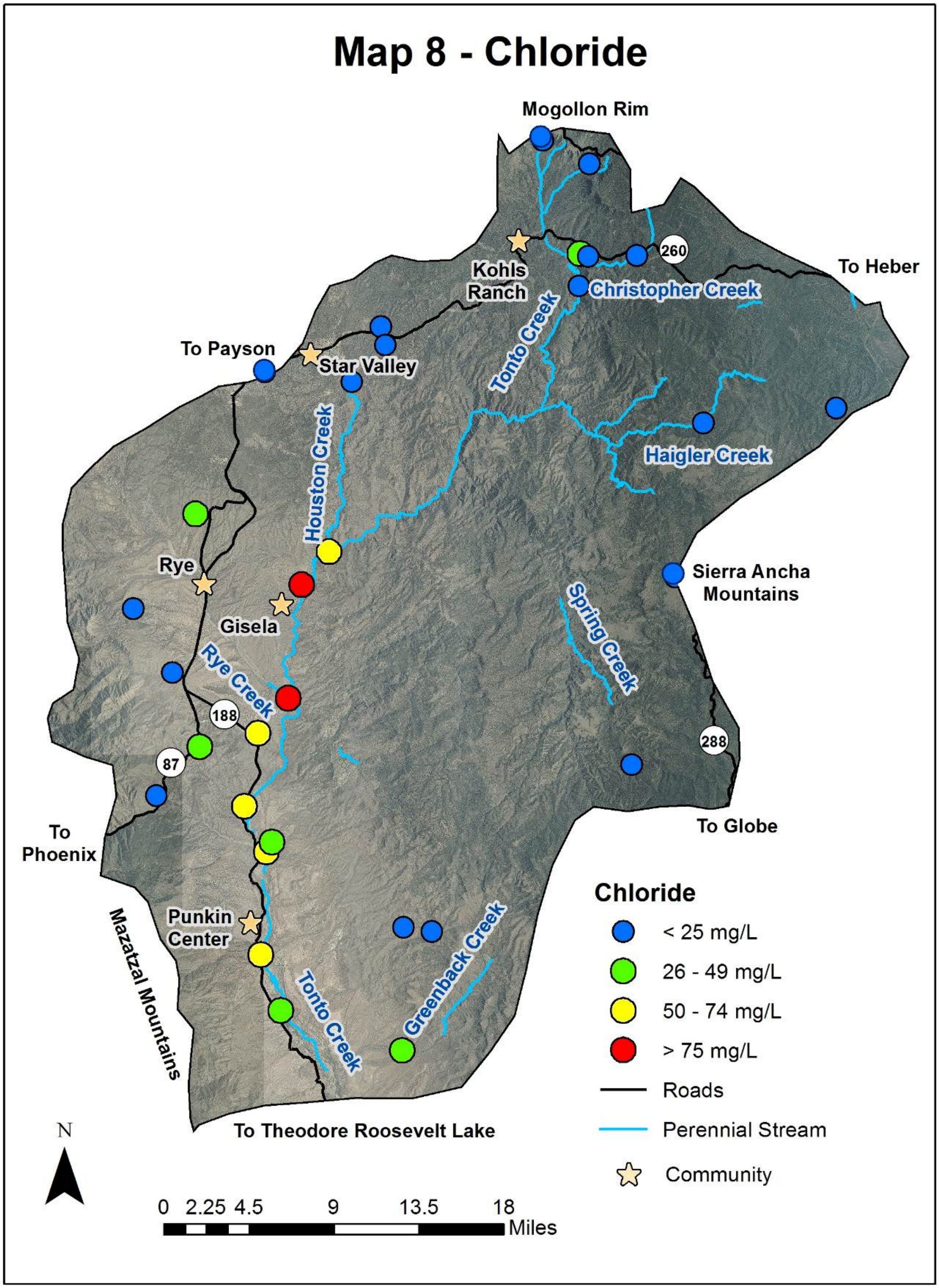
Constituent	Sites Sampled	Significance	Significant Differences Between Four Geologic Groups
Temperature - field	31	**	Alluvium > Sedimentary & Other Rock
pH – field	31	ns	-
pH – lab	31	ns	-
SC - field	31	**	Alluvium > Sedimentary & Other Rock
SC - lab	31	**	Alluvium > Sedimentary & Other Rock
TDS	31	*	Alluvium > Sedimentary & Other Rock
Turbidity	31	ns	-
Hardness	31	ns	-
Calcium	31	ns	-
Magnesium	31	ns	-
Sodium	31	**	Basin fill > Sedimentary & Other Rock
Potassium	31	**	-
Bicarbonate	31	ns	-
Chloride	31	**	Alluvium > Basin fill, Sedimentary & Other Rock
Sulfate	31	ns	-
Nitrate (as N)	31	ns	-
Barium	31	ns	-
Fluoride	31	ns	-
Strontium	10	*	Alluvium > Other Rock
Gross alpha	19	*	-
Gross beta	19	ns	-
Radon	5	ns	-
Oxygen	10	*	Alluvium > Other Rock
Deuterium	10	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. Summary Statistics for Four Geologic Groups with Significant Constituent Differences

Constituent	Significance	Alluvium	Basin Fill	Other Rock	Sedimentary
Temperature - field	**	18.6 to 25.0	-	13.8 to 17.8	6.9 to 15.0
pH – field	ns	-	-	-	-
pH – lab	ns	-	-	-	-
SC - field	**	584 to 1002	-	326 to 521	226 to 631
SC - lab	**	603 to 1033	-	343 to 538	239 to 657
TDS	*	334 to 616	-	205 to 316	140 to 384
Turbidity	ns	-	-	-	-
Hardness	ns	-	-	-	-
Calcium	ns	-	-	-	-
Magnesium	ns	-	-	-	-
Sodium	**	-	-64 to 232	9 to 22	2 to 10
Potassium	**	-	-	-	-
Bicarbonate	ns	-	-	-	-
Chloride	**	45 to 95	-2 to 54	6 to 12	-1 to 15
Sulfate	ns	-	-	-	-
Nitrate (as N)	ns	-	-	-	-
Barium	ns	-	-	-	-
Fluoride	ns	-	-	-	-
Strontium	*	0.1 to 1.4	-	0.0 to 0.5	-
Gross alpha	*	-	-	-	-
Gross beta	ns	-	-	-	-
Radon	ns	-	-	-	-
Oxygen	*	-11.3 to -6.5	-	-11.0 to -9.7	-
Deuterium	ns	-	-	-	-

ns = not significant
* = significant at $p \leq 0.05$ or 95% confidence level
** = significant at $p \leq 0.01$ or 99% confidence level
All units are mg/L except where indicated.


Map 8 - Chloride
Mogollon Rim
260
To Heber
Kohls Ranch
Christopher Creek
Tonto Creek
To Payson
Star Valley
Haigler Creek
Houston Creek
Rye
Gisela
Sierra Ancha Mountains
Spring Creek
Rye Creek
188
288
87
To Globe
To Phoenix
Mazatzal Mountains
Punkin Center
Greenback Creek
Tonto Creek
To Theodore Roosevelt Lake
Chloride
< 25 mg/L
26 - 49 mg/L
50 - 74 mg/L
> 75 mg/L
Roads
Perennial Stream
Community
N
0 2.25 4.5 9 13.5 18
Miles

DISCUSSION

Groundwater in the Tonto Creek basin is generally suitable for drinking water uses based on the water quality results from sampling conducted for the ADEQ ambient study. Most samples collected in the basin are of calcium or mixed-bicarbonate chemistry, which is characteristic of recently recharged groundwater.[20] These samples have low TDS concentrations. Nutrients and trace elements are usually not detected. When they are detected, they are typically below water quality standards. Some parts of the basin, such as the limestone aquifer along the Mogollon Rim recharged from precipitation on southern edge of the Colorado Plateau produce some of the purist water in Arizona.[10] Major springs discharging from this aquifer, such as Tonto and Horton, have TDS concentrations less than 100 mg/L. The general acceptability of groundwater for drinking water uses is supported by earlier studies conducted by the U.S. Geological Survey.[10, 21]

Samples from 22 of the 31 sites (71 percent) met all water quality standards.[26] Of the remaining nine sample sites, the constituents that most commonly impacted the acceptability of water for drinking purposes was arsenic with lesser occurrences of elevated concentrations of radionuclides and nitrate. These are three of the four constituents that most commonly exceed health-based water quality standards in Arizona.[23]

Arsenic exceedances in the Tonto Creek basin all occurred in samples collected from six sites located in unconsolidated sediment (basin fill or stream alluvium) downgradient from Gisela. Arsenic exceedances ranged from just over the 0.01 mg/L limit to a high of 0.0665 mg/L. Not all of the samples collected in the southern portion of Tonto Creek basin however, had arsenic concentrations exceeding water quality standards.

Unlike in some other Arizona basins, these sites did not have elevated pH levels so that reactions with hydroxyl ions do not appear to be the main cause of elevated arsenic concentrations.[20] An oxidizing environment and lithology appear to have been important factors in the five Primary MCL exceedances that were narrowly over the 0.01 mg/L standard in the Tonto Creek basin.

Aquifer residence time appears to be an important contribution to the highest arsenic concentration collected from the split sample (TON-13/14) collected from the deepest well (260 feet) sampled in the study that was located near Punkin Center. The groundwater sodium-bicarbonate chemistry from this well was very dissimilar to all the other samples collected in the basin. The sample was also the only one in the basin that had a fluoride concentration exceeding the 2.0 mg/L aesthetics water quality standard and one of three that exceeded the TDS Secondary MCL of 500 mg/L. Although no isotope sample was collected from the site, the well is likely producing water that has had a long aquifer residence time as evidenced by the unique water chemistry and elevated concentrations of trace elements. Another well that appears to be pumping water from the same formation was sampled in 1979 for the U.S. Geological Survey study. The 207-foot well (A-6-10-10) also exceeded water quality standards for arsenic, fluoride, and TDS.[10] Groundwater from wells such as these tapping the fine-grained facies of the upper part of the basin fill should be avoided as a drinking water source.[10, 21]

Gross alpha exceeded health-based, water quality standards in radionuclide samples collected from two of 19 sites. Sample sites were located in (TON-2/2S) or near granitic geology (TON-10/11) which is associated with elevated radionuclide concentrations in groundwater.[16] However, other samples (TON-1/1D, TON-38, and TON-7) collected from wells and/or springs in granitic geology from which radionuclide samples were collected did not exceed water quality standards.

Nitrate exceeded health-based, water quality standards (28.5 mg/L) in duplicate samples (TON-25/26) collected from a 175-foot well located at a remote ranch homestead surrounded by Forest Service lands located north of Punkin Center along Tonto Creek. The sample also had the study's highest TDS concentration (825 mg/L) and chloride concentration (115 mg/L). Elevated nitrate concentrations are likely due to discharges from a septic system as both of TDS and chloride are also indicators of septic system discharge.[6]

In the basin, there is a tendency for constituent concentrations to be significantly higher in groundwater sites collected in unconsolidated sediment and especially stream alluvium. These trends however, generally do not impact the acceptability of these sites for use as a drinking water source.

REFERENCES

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Appendix A. Data for Sample Sites, Tonto Creek Basin, 2002 – 2012

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Geology
1st Field Trip, January 22-24, 2002 – Harmon & Lucci									
TON-1/1D duplicate	A(11-11)27cba submersible	34°16'04.940" 111°13'07.019"	648682	59459	Davis Well	Inorganic Radiochem	160’	75’	Other Rock
TON-2/2S split	A(11-12)34dda submersible	34°17'37.290" 111°03'59.880"	636650	59481	Collins Well	Inorganic, VOCs Radiochem	210’	25’	Other Rock
TON-3/28/32	A(12-12)33bac spring	34°23'09.68" 111°05'42.791"	-	59476	Tonto Crk Hatchry Sp	Inorganic	-	-	Sedimentary
TON-5	A(10-14)13bba spring	34°12'59.290" 111°52'10.272"	-	59460	Clay Spring	Inorganic Radiochem	-	-	Sedimentary
TON-6	A(10-13)13aba submersible	34°12'25.476" 111°58'18.273"	582238	59461	Nye Well	Inorganic, VOCs Radiochem	140’	90’	Other Rock
TON-7	A(10-11)05ddc submersible	34°13'59.743" 111°14'26.523"	539489	59462	Korner Well	Inorganic Radiochem	200’	30’	Other Rock
TON-8	A(10-10)02bbc submersible	34°14'22.923" 111°18'26.053"	600871	12292	FS Ranger Well	Inorganic Radiochem	-	-	Other Rock
TON-9	A(11-13)30bad submersible	34°18'47.121" 111°01'21973"	542599	59463	Cheney Well	Inorganic Radiochem	120’	20’	Sedimentary
2nd Field Trip, March 18-20, 2002 – Towne & Harmon (Equipment Blank, TON-19)									
TON-10/11 duplicate	A(9-11)18dca submersible	34°00'06.455" 111°21'26.534"	623457	59754	Bassett Well	Inorganic Radiochem	50’	-	Alluvium
TON-12	A(9-10)24cda turbine	34°06'16.124" 111°16'45.025"	513641	59596	Siebert Well	Inorganic, Radon VOCs	45’	25’	Alluvium
TON-13/14 split	A(8-10)27adb submersible	34°00'37.636" 111°18'45.445"	576386	59597	Whatley Well	Inorganic Radiochem	260’	4’	Basin Fill
TON-15	A(7-10)10dbb submersible	33°57'50.060" 111°19'22.770"	505978	59598	Mitchell Well	Inorganic, Radon VOCs	95’	75’	Alluvium
TON-16	A(8-10)29cdd windmill	34°00'06.455" 111°21'26.534"	601017	11864	Gold Creek Windmill	Inorganic Radiochem	-	-	Basin Fill
TON-17	A(9-10)05cbc windmill	34°08'57.406" 111°21'37.281"	-	59599	Harris Windmill	Inorganic Radiochem	130’	-	Basin Fill
TON-18	A(6-11)12aad spring	33°53'03.889" 111°10'46.380"	-	59600	Oak Ranch Spring	Inorganic	-	-	Other Rock
TON-20	A(6-11)02cdb spring	33°53'13.246" 111°12'04.353"	-	59601	Walnut Spring	Inorganic VOC	-	-	Other Rock
TON-21	A(6-10)14bba submersible	33°52'10.874" 111°18'38.728"	500197	11576	Cline Well	Inorganic Radon	40’	15’	Alluvium
TON-22	A(9-9)26cca spring	34°05'22.415" 111°24'30.309"	-	59602	Boone Moore Spr	Inorganic, Radiochem	-	-	Basin Fill
3rd Field Trip, April 9-10, 2002 – Harmon & Lucci									
TON-23/23D duplicate	A(5-11)02bac submersible	33°48'31.221" 111°12'07.920"	630180	59700	Speer Well	Inorganic, Radiochem VOCs	50’	18’	Alluvium
TON-24/24S split	A(9-13)23bcc submersible	34°06'33.144" 110°59'34.852"	648977	59701	Seeley Well	Inorganic, Radiochem VOCs	162’	40’	Other Rock
4th Field Trip, May 3, 2002 – Towne & Harmon									
TON-25/26 duplicate	A(8-10)13cdb submersible	34°01'57.197" 111°17'23.091"	622906	59811	Neal Well	Inorganic, Radiochem	175’	25’	Alluvium
TON-27	A(8-10)07cbd submersible	34°02'54.141" 111°22'41.756"	-	11856	Haught Windmill	Inorganic, Radiochem VOCs	-	-	Basin Fill

Appendix A. Data for Sample Sites, Tonto Creek Basin, 2002 - 2012

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Year Drilled
5th Field Trip, October 31, 2011 – Towne & Determann									
TON-3/28/32	A(12-12)33bac spring	34°23'09.68" 111°05'42.791"	-	59476	Tonto Crk Hatchry Sp	Inorganic Isotopes	-	-	Sedimentary
TON-29	A(11-12)27aad spring	34°18'52.4" 111°04'00.7"	-	12626	Bootleg Spring	Inorganic, Radiochem Isotopes	-	-	Sedimentary
TON-30	A(11-12)26bdb spring	34°18'45.8" 111°03'37.2"	-	12625	R-C Spring	Inorganic Isotopes	-	-	Sedimentary
6th Field Trip, November 16, 2011 – Towne & Determann									
TON-31	A(8-13)33cad spring	33°59'24.799" 111°01'37.678"	-	77361	Elephant Corral Spr	Inorganic Isotopes	-	-	Sedimentary
7th Field Trip, September 13, 2012 – Towne, Boettcher & Dickens									
TON-3/28/32	A(12-12)33bac spring	34°23'09.68" 111°05'42.791"	-	59476	Tonto Crk Hatchry Sp	Inorganic, Radiochem Isotopes	-	-	Sedimentary
TON-33	A(11-12)02bdb spring	34°22'17.438" 111°03'33.830"	-	78181	Horton Spring	Inorganic Isotopes	-	-	Sedimentary
8th Field Trip, November 7 - 8, 2012 – Towne & Rhyner									
TON-34	A(7-9)01ccc spring	33°58'14.981" 111°23'27.637"	-	78265	Cane Spring	Inorganic Isotopes	-	-	Other Rock
TON-35	A(6-10)26add submersible	33°50'02.511" 111°17'45.385"	578243	78266	Marks IR Well	Inorganic, Radon Isotopes	40’	20’	Alluvium
TON-36	A(7-10)23bdd submersible	33°56'06.175" 111°18'25.459"	623507	78267	PC&M Well #1	Inorganic Isotopes	65’	13’	Alluvium
TON-37	A(7-10)23aba spring	33°56'28.030" 111°18'09.887"	-	78268	Kayler Spring	Inorganic Isotopes	-	-	Alluvium
TON-38	A(11-11)34bdb submersible	34°15'23.577" 111°12'57.158"	525321	78269	Brunson Well	Inorganic, Radiochem Isotopes	60’	30’	Other Rock

Appendix B. Groundwater Quality Data, Tonto Creek Basin, 2002-2012---Continued

Site #	MCL Exceedances	Temp (°C)	pH-field (su)	pH-lab (su)	SC-field (µS/cm)	SC-lab (µS/cm)	TDS (mg/L)	Hard (mg/L)	Hard - cal (mg/L)	Turb (ntu)
TON-1/1D	-	12.5	7.63	*7.65*	434	460	260	220	230	*0.095*
TON-2/2S	Gross alpha Ra-226+228, U	13.7	7.53	7.59	502	530	285	255	250	1.3
TON-3/28/32	-	9.6	7.6	*7.2*	146	160	82	76	75	1.2
TON-5	-	1.7	7.69	*7.8*	634	670	370	380	350	0.40
TON-6	-	14.4	6.98	*7.5*	471	500	260	290	250	0.22
TON-7	-	13.8	6.95	*6.7*	204	220	150	78	77	0.34
TON-8	-	13.4	6.80	*6.5*	225	240	160	87	85	0.34
TON-9	Mn	11.3	6.94	7.2	536	560	320	280	280	12
TON-10/11	Gross alpha	21.1	7.27	*7.5*	808	817.5	455	240	240	5.0
TON-12	As	18.6	6.97	*7.3*	826	860	473	260	270	0.33
TON-13/14	As, F, TDS	22.8	7.60	*7.95*	1294	1300	**795**	63	62	0.06
TON-15	As	17.8	7.54	*7.5*	618	640	330	220	220	0.04
TON-16	-	19.4	6.97	*7.2*	760	780	480	380	370	0.28
TON-17	-	19.5	7.45	*7.7*	671	700	400	250	260	3.7
TON-18	-	21.8	7.41	*7.0*	403	410	230	180	190	0.80
TON-20	-	17.1	7.89	*7.7*	584	580	350	250	260	0.82
TON-21	TDS	19.2	7.20	*7.3*	1095	1100	**720**	390	390	0.21
TON-22	-	14.2	7.89	*7.7*	402	410	230	200	190	1.1
TON-23/23D	-	19.7	7.22	*7.3*	773	805	480	365	380	0.22
TON-24/24S	-	17.2	7.90	*7.75*	319	335	195	145	140	0.02
TON-25/26	As, NO_3, TDS	21.4	7.21	7.35	1343	1400	**825**	570	575	0.05
TON-27	-	21.8	7.80	*7.4*	359	380	220	100	100	0.23
TON-3/28/32	Cd, Th*	12.2	7.47	*7.88*	116	120	78	-	67	1.7
TON-29	-	16.2	7.21	*8.09*	701	720	420	-	400	0.20
TON-30	-	12.4	7.75	8.17	356	370	240	-	200	2.7
TON-31	-	11.9	7.70	*7.59*	467	490	310	-	250	2.4
TON-3/28/32	-	12.1	7.30	*7.33*	125	130	64	-	67	1.3
TON-33	-	11.8	7.49	*7.56*	177	190	98	-	98	ND

italics = constituent exceeded holding time
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level
* Cadmium and thallium were apparently introduced to the water sample from recent concrete work at the water source.

Appendix B. Groundwater Quality Data, Tonto Creek Basin, 2002-2012---Continued

Site #	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	T. Alk (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
TON-1/1D	66	15	5.8	0.945	220	270	ND	10	1.5
TON-2/2S	64.5	23	11.5	1.8	265	320	ND	5.1	10
TON-3/28/32	21	5.5	1.6	0.87	75	92	ND	1.1	2.3
TON-5	110	19	4.8	1.2	356	434	ND	3.0	4.1
TON-6	66	20	6.6	1.2	240	290	ND	4.3	10
TON-7	19	7.4	14	ND	97	120	ND	3.4	4.6
TON-8	21	8.1	14	ND	100	120	ND	6.4	7.2
TON-9	92	13	5.4	0.57	230	280	ND	6.5	57
TON-10/11	74.5	14	73.5	3.1	260	315	ND	81.5	16
TON-12	80	17	70	2.2	250	300	ND	110	15
TON-13/14	16.5	5.5	295	6.5	568.5	692	ND	61	41.5
TON-15	64	16	39	2.1	170	210	ND	86	9.0
TON-16	100	28	21	3.5	360	440	ND	26	24
TON-17	68	22	50	1.3	300	370	ND	30	17
TON-18	42	20	12	2.6	194	237	ND	7.8	6.7
TON-20	58	28	27	2.8	270	330	ND	15	22
TON-21	99	34	82	1.8	230	280	ND	82	200
TON-22	65	7.2	8.9	1.4	210	260	ND	3.4	1.4
TON-23/23D	66	51.5	28	3.6	365	445	ND	27	39
TON-24/24S	32.5	15	14	1.8	145.5	172	ND	7.1	11.5
TON-25/26	140	54.5	70.5	6.45	400	490	ND	115	54.5
TON-27	28	8.4	44	1.8	180	220	ND	9.4	ND
TON-3/28/32	19	4.7	ND	ND	66	81	ND	ND	2.2
TON-29	110	32	13	ND	340	415	ND	26	38
TON-30	59	12	4.4	ND	160	195	ND	3.7	40
TON-31	41	35	9.5	4.0	250	305	ND	4.5	20
TON-3/28/32	19	4.8	ND	ND	67	82	ND	ND	2.3
TON-33	29	6.3	ND	ND	98	120	ND	ND	2.9

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

Appendix B. Groundwater Quality Data, Tonto Creek Basin, 2002-2012---Continued

Site #	T. Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	T. Phosphorus (mg/L)	SAR (value)	Irrigation Quality	Aluminum (mg/L)	Strontium (mg/L)
TON-1/1D	0.62	ND	ND	ND	ND	0.2	C2-S1	ND	-
TON-2/2S	ND	ND	ND	ND	ND	0.3	C2-S1	ND	-
TON-3/28/32	0.10	ND	ND	ND	0.040	0.1	C1-S1	ND	-
TON-5	0.033	ND	ND	ND	0.070	0.1	C2-S1	ND	-
TON-6	0.14	ND	0.068	0.045	ND	0.2	C2-S1	ND	-
TON-7	0.16	ND	ND	ND	ND	0.7	C1-S1	ND	-
TON-8	0.25	ND	ND	ND	ND	0.7	C1-S1	ND	-
TON-9	0.44	ND	0.072	ND	0.022	0.1	C2-S1	ND	-
TON-10/11	0.14	ND	ND	ND	0.034	2.0	C3-S1	-	-
TON-12	0.45	ND	ND	ND	0.029	1.9	C3-S1	-	-
TON-13/14	ND	ND	ND*	ND	ND	16.0	C3-S3	-	-
TON-15	0.19	ND	ND	ND	0.027	1.1	C2-S1	-	-
TON-16	0.59	ND	ND	ND	ND	0.5	C3-S1	-	-
TON-17	1.1	ND	ND	ND	0.037	1.3	C2-S1	-	-
TON-18	0.31	ND	0.82	0.37	0.056	0.4	C2-S1	-	-
TON-20	0.19	ND	0.071	ND	0.028	0.7	C2-S1	-	-
TON-21	0.66	ND	ND	ND	0.023	1.8	C3-S1	ND	-
TON-22	ND	ND	ND	ND	0.034	0.3	C2-S1	ND	-
TON-23/23D	0.275	ND	ND	ND	ND	0.6	C3-S1	ND	-
TON-24/24S	0.63	ND	0.11	ND	ND	0.5	C2-S1	ND	-
TON-25/26	**28.5**	ND	0.205	ND	0.073	1.3	C3-S1	ND	-
TON-27	0.45	ND	ND	ND	ND	1.9	C2-S1	-	-
TON-3/28/32	ND	ND	ND	ND	ND	0.1	C1-S1	ND	ND
TON-29	ND	ND	ND	ND	ND	0.3	C2-S1	ND	0.28
TON-30	ND	ND	ND	ND	ND	0.1	C2-S1	ND	0.17
TON-31	ND	ND	ND	0.10	ND	0.3	C2-S1	ND	0.12
TON-3/28/32	ND	ND	0.17	ND	ND	0.1	C1-S1	ND	ND
TON-33	ND	ND	ND	ND	ND	0.0	C1-S1	ND	ND

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

Appendix B. Groundwater Quality Data, Tonto Creek Basin, 2002-2012---Continued

Site #	Antimony (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Fluoride (mg/L)
TON-1/1D	ND	ND	0.14	ND	ND	ND	ND	ND	0.21
TON-2/2S	ND	ND	0.235	ND	ND	ND	ND	0.013	0.355
TON-3/28/32	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON -5	ND	ND	ND	ND	ND	ND	ND	ND	0.28
TON -6	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON -7	ND	ND	ND	ND	ND	ND	ND	ND	1.4
TON -8	ND	ND	ND	ND	ND	ND	ND	ND	0.78
TON -9	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-10/11	ND	ND	ND	ND	ND	ND	ND	ND	1.5
TON-12	ND	**0.014**	0.14	ND	ND	ND	ND	ND	0.63
TON-13/14	ND	**0.0665**	ND	ND	0.36	ND	ND	ND	**3.5**
TON-15	ND	ND	0.11	ND	ND	ND	ND	ND	0.28
TON-16	ND	**0.020**	ND	ND	ND	ND	ND	0.23	1.2
TON-17	ND	ND	0.19	ND	ND	ND	ND	ND	0.44
TON-18	ND	ND	0.29	ND	ND	ND	ND	ND	0.39
TON-20	ND	ND	0.12	ND	ND	ND	ND	0.048	0.69
TON-21	ND	ND	0.16	ND	0.67	ND	ND	ND	0.57
TON-22	ND	ND	0.17	ND	ND	ND	ND	ND	0.19
TON-23/23D	ND	ND	ND	ND	ND	ND	ND	ND	0.405
TON-24/24S	ND	ND	ND	ND	ND	ND	ND	ND	0.20
TON-25/26	ND	**0.012**	0.25	ND	1.1	ND	ND	ND	0.28
TON-27	ND	ND	ND	ND	ND	ND	ND	0.017	ND
TON-3/28/32	ND	ND	0.093	ND	ND	**0.011**	ND	ND	ND
TON-29	ND	ND	0.11	ND	ND	ND	ND	0.013	ND
TON-30	ND	0.0013	0.066	ND	ND	ND	ND	ND	ND
TON-31	ND	ND	0.0030	ND	ND	ND	ND	ND	ND
TON-3/28/32	ND	0.0011	0.086	ND	ND	ND	ND	0.0013	ND
TON-33	ND	0.0050	0.091	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, Tonto Creek Basin, 2002-2012---Continued

Site #	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Zinc (mg/L)
TON-1/1D	ND	ND	ND	ND	ND	ND	ND	ND	0.22
TON-2/2S	ND	0.00765	ND	ND	ND	ND	ND	ND	0.85
TON-3/28/32	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-5	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-6	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-7	ND	ND	ND	ND	ND	ND	ND	ND	0.070
TON-8	ND	ND	ND	ND	ND	ND	ND	ND	2.4
TON-9	0.14	ND	0.15	ND	ND	ND	ND	ND	ND
TON-10/11	0.11	ND	ND	ND	ND	ND	ND	ND	ND
TON-12	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-13/14	ND	ND	ND	ND	ND	ND	ND	ND	0.235
TON-15	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-16	ND	ND	ND	ND	ND	ND	ND	ND	0.053
TON-17	ND	ND	ND	ND	ND	ND	ND	ND	1.1
TON-18	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-20	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-21	ND	ND	ND	ND	ND	0.0058	ND	ND	ND
TON-22	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-23/23D	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-24/24S	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-25/26	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-27	ND	ND	ND	ND	ND	ND	ND	ND	0.096
TON-3/28/32	0.068	0.013	ND	ND	ND	ND	ND	**0.013**	ND
TON-29	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-30	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-31	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-3/28/32	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-33	ND	ND	ND	ND	ND	ND	ND	ND	ND

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

Appendix B. Groundwater Quality Data, Tonto Creek Basin, 2002-2012---Continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Ra-226 + Ra-228 (pCi/L)	Uranium (µg/L)	VOCs	*^{18}O ($^{0}/_{00}$)	*D ($^{0}/_{00}$)	Type of Chemistry
TON-1/1D	-	3.3	2.5	-	-	ND	-	-	calcium-bicarbonate
TON-2/2S	-	**210**	54	**10**	**220**	-	-	-	calcium-bicarbonate
TON-3/28/32	-	ND	ND	-	-	-	-	-	calcium-bicarbonate
TON-5	-	0.79	2.8	-	-	-	-	-	calcium-bicarbonate
TON-6	-	8.9	3.2	ND	-	ND	-	-	calcium-bicarbonate
TON-7	-	2.2	2.0	-	-	-	-	-	mixed-bicarbonate
TON-8	-	1.7	ND	-	-	-	-	-	mixed-bicarbonate
TON-9	-	1.7	ND	-	-	-	-	-	calcium-bicarbonate
TON-10/11	-	**35**	5.6	ND	8.6	-	-	-	mixed-bicarbonate
TON-12	**689**	-	-	-	-	ND	-	-	mixed-bicarbonate
TON-13/14	-	12	8.0	0.32	-	-	-	-	sodium-bicarbonate
TON-15	**391**	-	-	-	-	ND	-	-	calcium-bicarbonate
TON-16	-	4.5	4.4	-	-	-	-	-	calcium-bicarbonate
TON-17	-	1.3	ND	-	-	-	-	-	mixed-bicarbonate
TON-18	-	-	-	-	-	-	-	-	mixed-bicarbonate
TON-20	-	-	-	-	-	-	-	-	mixed-bicarbonate
TON-21	**906**	-	-	-	-	-	-	-	mixed-mixed
TON-22	-	ND	2.4	-	-	-	-	-	calcium-bicarbonate
TON-23/23D	-	6.7	4.9	ND	-	ND	-	-	mixed-bicarbonate
TON-24/24S	-	1.7	3.3	-	-	ND	-	-	mixed-bicarbonate
TON-25/26	-	3.6	6.8	-	-	-	-	-	mixed-bicarbonate
TON-27	-	3.8	2.1	-	-	ND	-	-	mixed-bicarbonate
TON-3/28/32	-	-	-	-	-	-	- 10.5	- 73	calcium-bicarbonate
TON-29	-	ND	-	ND	1.5	-	- 10.8	- 74	calcium-bicarbonate
TON-30	-	-	-	-	-	-	- 11.2	- 75	calcium-bicarbonate
TON-31	-	-	-	-	-	-	- 10.4	- 71	magnesium-bicarbonate
TON-3/28/32	-	0.9	ND	ND	ND	-	- 10.3	- 71	calcium-bicarbonate

LLD = Lower Limit of Detection
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Appendix B. Groundwater Quality Data, Tonto Creek Basin, 2002-2012---Continued

Site #	MCL Exceedances	Temp (°C)	pH-field (su)	pH-lab (su)	SC-field (µS/cm)	SC-lab (µS/cm)	TDS (mg/L)	Hard (mg/L)	Hard - cal (mg/L)	Turb (ntu)
TON-34	As	17.8	8.92	*7.82*	494	530	340	240	-	*0.21*
TON-35		23.7	7.41	7.21	563	570	330	270	-	0.98
TON-36		31.6	7.43	*7.58*	528	550	290	220	-	ND
TON-37	As	23.1	7.85	*8.28*	585	620	370	270	-	ND
TON-38		16.5	7.39	*7.33*	597	600	370	340	-	0.22

italics = constituent exceeded holding time

Appendix B. Groundwater Quality Data, Tonto Creek Basin, 2002-2012---Continued

Site #	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	T. Alk (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
TON-34	78	11	34	ND	260	317	ND	12	13
TON-35	79	17	30	ND	210	256	ND	47	25
TON-36	65	15	34	2.2	190	232	ND	57	9.9
TON-37	56	31	43	3.5	280	342	ND	26	16
TON-38	96	23	17	ND	300	366	ND	17	7.7

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bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Tonto Creek Basin, 2002-2012---Continued

Site #	T. Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	T. Phosphorus (mg/L)	SAR (value)	Irrigation Quality	Aluminum (mg/L)	Strontium (mg/L)
TON-34	ND	-	0.47	ND	ND	1.0	C2-S1	ND	0.26
TON-35	ND	ND	0.13	ND	ND	0.9	C2-S1	ND	0.57
TON-36	ND	ND	0.16	ND	ND	1.0	C2-S1	ND	0.32
TON-37	ND	ND	0.26	ND	ND	1.1	C2-S1	ND	0.92
TON-38	ND	ND	0.12	ND	ND	0.4	C2-S1	ND	0.22

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bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Tonto Creek Basin, 2002-2012---Continued

Site #	Antimony (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Fluoride (mg/L)
TON-34	ND	**0.012**	0.073	ND	ND	ND	ND	0.0012	1.0
TON-35	ND	0.0013	0.11	ND	ND	ND	ND	0.0023	ND
TON-36	ND	0.0024	0.10	ND	ND	ND	ND	0.0024	ND
TON-37	ND	**0.026**	0.096	ND	ND	ND	0.0082	ND	1.1
TON-38	ND	0.0031	0.18	ND	ND	ND	ND	0.0014	ND

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

Appendix B. Groundwater Quality Data, Tonto Creek Basin, 2002-2012---Continued

Site #	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Zinc (mg/L)
TON-34	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-35	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-36	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-37	ND	ND	ND	ND	ND	ND	ND	ND	ND
TON-38	ND	ND	ND	ND	ND	ND	ND	ND	ND

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

Appendix B. Groundwater Quality Data, Tonto Creek Basin, 2002-2012---Continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Ra-226 + Ra-228 (pCi/L)	Uranium (µg/L)	VOCs	*^{18}O ($^0/_{00}$)	* D ($^0/_{00}$)	Type of Chemistry
TON-33	-	-	-	-	-	-	- 11.4	- 78	calcium-bicarbonate
TON-34	**-**	-	-	-	-	-	- 10.3	- 71	calcium-bicarbonate
TON-35	**634**	-	-	-	-	-	- 8.7	- 63	calcium-bicarbonate
TON-36	**-**	-	-	-	-	-	- 8.0	- 58	calcium-bicarbonate
TON-37	**-**	-	-	-	-	-	- 9.9	- 71	mixed-bicarbonate
TON-38	**750**	2.0	ND	ND	4.2	-	- 10.4	- 75	calcium-bicarbonate

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