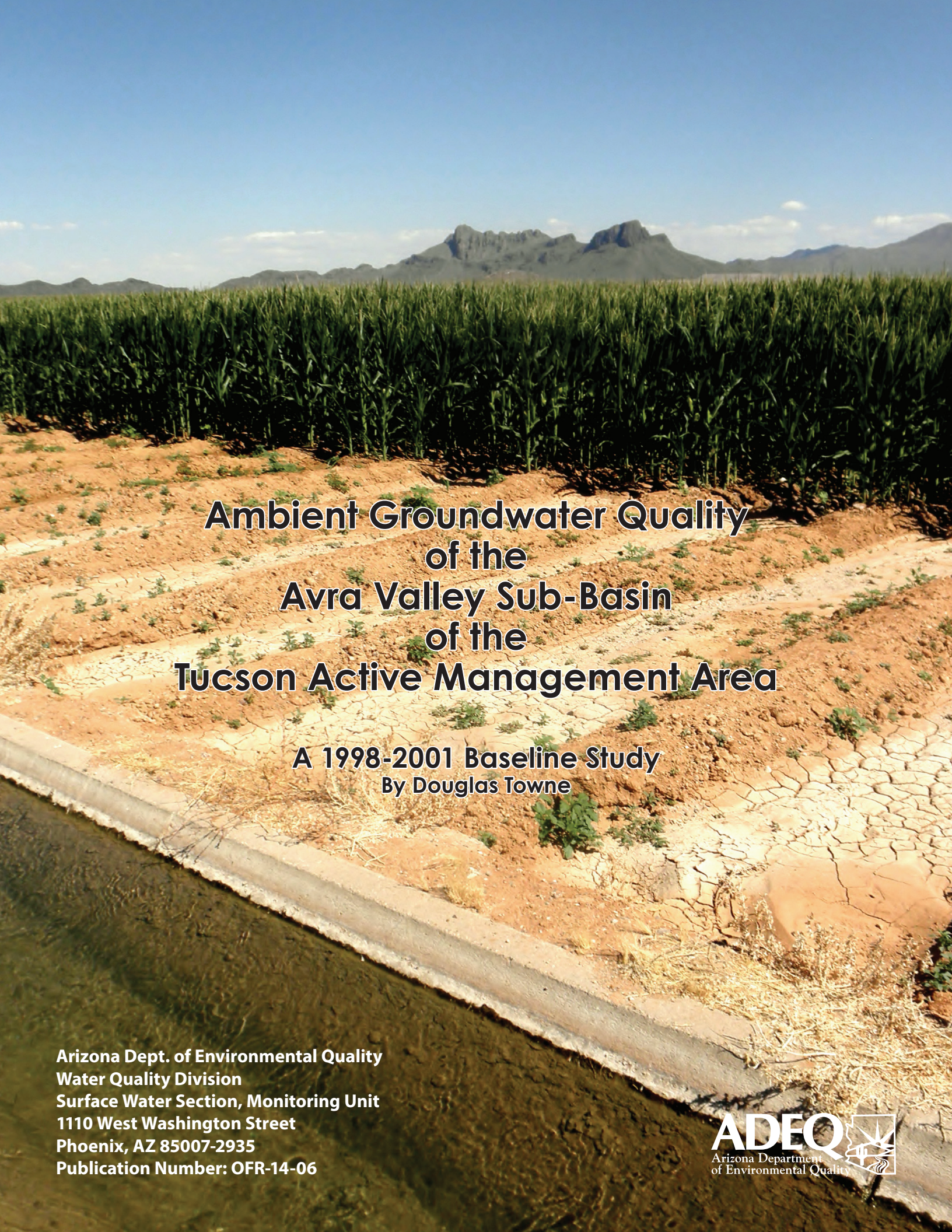

Ambient Groundwater Quality of the Avra Valley Sub-Basin of the Tucson Active Management Area

A 1998-2001 Baseline Study

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ADEQ
Arizona Department of Environmental Quality

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Open File Report 14-06

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Report Cover: An irrigated field of corn is almost ready for harvest in the late spring near the Town of Marana. Most irrigated agriculture in the Avra Valley sub-basin is located in this area, which is becoming a bedroom community of Tucson. Saguaro National Monument West and the Tucson Mountains are in the distance.

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

Harquahala Basin	OFR 14-04, 62 p.	FS 14-09, 5 p.
Tonto Creek Basin	OFR 13-04, 50 p.	FS 13-04, 4 p.
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Groundwater Quality in Arizona	OFR 11-04, 26 p.	-
McMullen Valley Basin	OFR 11-02, 94 p.	FS 11-03, 6 p.
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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.

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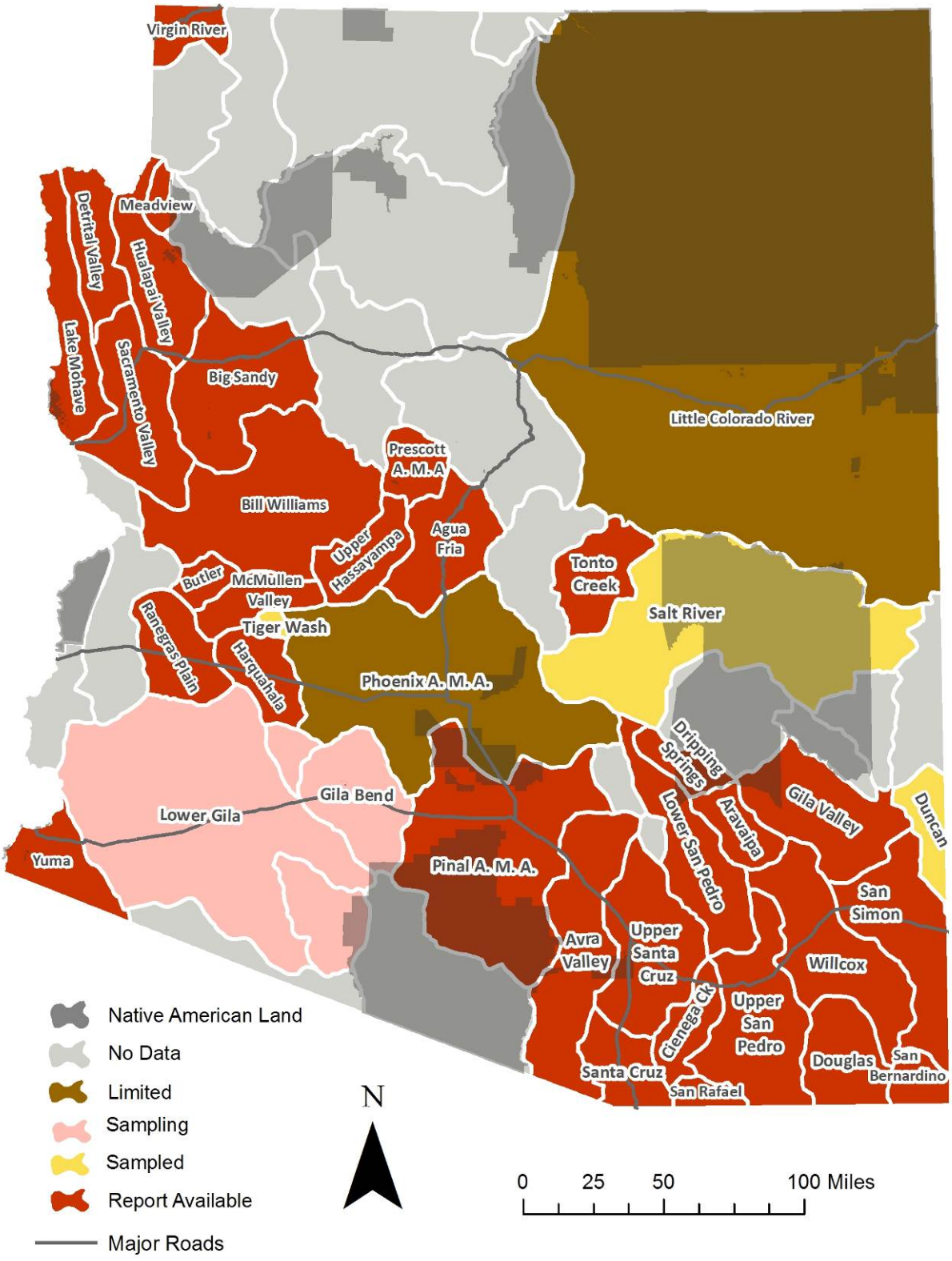
ADEQ Ambient Groundwater Reports



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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
AVB	Avra Valley Sub-basin
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
^{o}C	degrees Celsius
$CI_{0.95}$	95 percent Confidence Interval
Cl	chloride
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
gpm	gallons per minute
GWPL	Groundwater Protection List active ingredient
HCl	hydrochloric acid
LLD	Lower Limit of Detection
Mn	manganese
MCL	Maximum Contaminant Level
ml	milliliter
msl	mean sea level
ug/L	micrograms per liter
um	micron
uS/cm	microsiemens per centimeter at 25° Celsius
mg/L	milligrams per liter
MRL	Minimum Reporting Level
ns	not significant
ntu	nephelometric turbidity unit
pCi/L	picocuries per liter
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
SAR	Sodium Adsorption Ratio
SDW	Safe Drinking Water
SC	Specific Conductivity
su	standard pH units
SO_4	sulfate
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
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 Avra Valley Sub-basin of the Tucson Active Management Area: A 1998-2001 Baseline Study

Abstract - The Tucson Active Management Area (AMA) consists of two parallel sub-basins: the Upper Santa Cruz Valley sub-basin in the east and the Avra Valley sub-basin in the west. The Upper Santa Cruz Valley sub-basin and the adjacent Santa Cruz AMA were the subject of a joint Arizona Department of Environmental Quality (ADEQ)-U.S. Geological Survey ambient groundwater quality study in 1998.[13] ADEQ subsequently conducted a study of the Avra Valley sub-basin from 1998-2001 to complete the groundwater quality characterization of the Tucson AMA.

The Avra Valley sub-basin comprises 2,167 square miles within Pima, Pinal, and Santa Cruz counties. The long, thin basin is located west of Tucson and includes Altar and Avra valleys, which are divided by State Route 86. Population centers include exurban areas of Tucson, most of Town of Marana, and unincorporated communities including Arivaca, Three Points, Red Rock, and Sasabe. Most (87 percent) of the sub-basin is rangeland.[36] The sub-basin is drained by Altar Wash, which name changes to Brawley Wash north of State Route 86. Downgradient, the wash eventually empties into the Santa Cruz River, which has nine miles of perennial flow as the result of effluent discharge from wastewater treatment plants.[5] All other washes in the sub-basin are ephemeral.[22] Groundwater was formerly the source of all irrigation, public, domestic, industrial, and stock uses. Colorado River water, conveyed through the Central Arizona Project canal, has supplemented the water supply of the Tucson AMA since 1992.[9]

Sediments in the Avra Valley sub-basin have been divided into upper and lower alluvial units, which form the regional aquifer. The upper unit is the primary water producer and is composed of streambed deposits of silt, sand, and gravel which range in thickness from approximately 100 to 1,000 feet. The lower alluvial unit is thousands of feet thick and consists of gravel and conglomerates located near the edges of the sub-basin. These deposits transition into clayey silts and mudstones along the sub-basin's central axis.[5] Limited amounts of groundwater are also found in the surrounding mountains in thin alluvial deposits and in fractured or faulted bedrock.[22]

ADEQ collected samples from 42 wells used for domestic, stock, irrigation, and public water supply purposes. Sampled wells generally did not have driller's logs, but most were thought to tap the upper alluvial unit.[7] Inorganic samples were collected at each site while radionuclide (24), volatile organic compounds or VOCs (22), and radon (19) samples were collected at selected sites. Based on these water quality results, groundwater in the sub-basin is generally suitable for drinking water uses. Of the 42 sites sampled, 36 sites met all health-based and aesthetics-based water quality standards, excluding the proposed radon standard.

Health-based, Primary Maximum Contaminant Levels (MCLs) were exceeded at six of 42 sites (14 percent). These enforceable standards define the maximum constituent concentrations allowed in water supplied for drinking water purposes by a public water system.[29] Constituents exceeding Primary MCLs include arsenic (two sites), gross alpha (five sites), uranium (two sites), and one site each for nitrate and radium-226+228. Aesthetics-based, Secondary MCLs were exceeded at 11 of 42 sites (26 percent). These are unenforceable guidelines that define the maximum constituent concentration that can be present in drinking water without an unpleasant taste, color, or odor but is not considered a health concern.[29] Constituents above Secondary MCLs include total dissolved solids or TDS (seven sites), fluoride (five sites), manganese (two sites), iron and sulfate (one site apiece). Of the 19 sites sampled for radon, one exceeded the proposed 4,000 picocuries per liter (pCi/L) standard while 16 sites (84 percent) exceeded the proposed 300 pCi/L standard.[30] Of the 32 compounds sampled for, there were no VOC detections.

Groundwater in the basin typically has calcium or mixed-bicarbonate chemistry and is *slightly alkaline*, *fresh*, and *moderately hard* to *hard*, based on pH levels along with TDS and hardness concentrations.[15, 17] Groundwater constituent concentrations significantly differed between valleys and geology.[4,32] Constituents such as temperature, specific conductivity (SC), TDS, sodium, potassium, chloride, sulfate, nitrate, and fluoride had significantly higher constituent concentrations at sites in Avra Valley than at sites in Altar Valley (Kruskal-Wallis test, $p \leq 0.05$). Constituents such as hardness, turbidity, magnesium, bicarbonate, and radon had significantly greater concentrations in sites located in consolidated rock than in unconsolidated sediment; temperature and nitrate exhibited the opposite pattern (Kruskal-Wallis test, $p \leq 0.05$).

Groundwater quality does not appear to be impacted by anthropomorphic sources, especially in Altar Valley. Concentrations of many constituents naturally increase downgradient in Avra Valley. Near Marana, however, irrigation recharge appears to have increased nitrate and TDS concentrations in groundwater.[14]

INTRODUCTION

Purpose and Scope

The Tucson Active Management Area (AMA) comprises two parallel sub-basins: the Upper Santa Cruz Valley sub-basin in the east and the Avra Valley sub-basin in the west. The groundwater quality of the Upper Santa Cruz sub-basin was characterized in 1998 in a joint Arizona Department of Environmental Quality (ADEQ) – U.S. Geological Survey water investigations report that also included the Santa Cruz AMA.[13] The ADEQ ambient monitoring program subsequently sampled the Avra Valley sub-basin to complete the groundwater quality characterization of the Tucson AMA.

The Avra Valley sub-basin consists of approximately 2,167 square miles in the south-central portion of the state (Map 1).[4] The basin is located west of Tucson within Pima, Pinal, and Santa Cruz counties, and includes the Altar and Avra valleys. Population centers include exurban areas of the Tucson metropolitan area, most of the Town of Marana, and the unincorporated communities of Arivaca, Three Points, Red Rock, Sasabe, and Silver Bell. Most of the sub-basin (87 percent) consists of rangeland. [36] Groundwater was formerly used for all irrigation, public, domestic, industrial, and stock uses. Since 1992, Colorado River water conveyed through the Central Arizona Project (CAP) has also been used in the Tucson AMA. [9] The land in the sub-basin is primarily used for livestock grazing, recreation, wildlife, and residential use along with some irrigated agriculture near Marana.

Sampling by the 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."* [3]

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 Avra Valley sub-basin identifying water quality variations between groundwater originating from different valleys and geology.
- 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

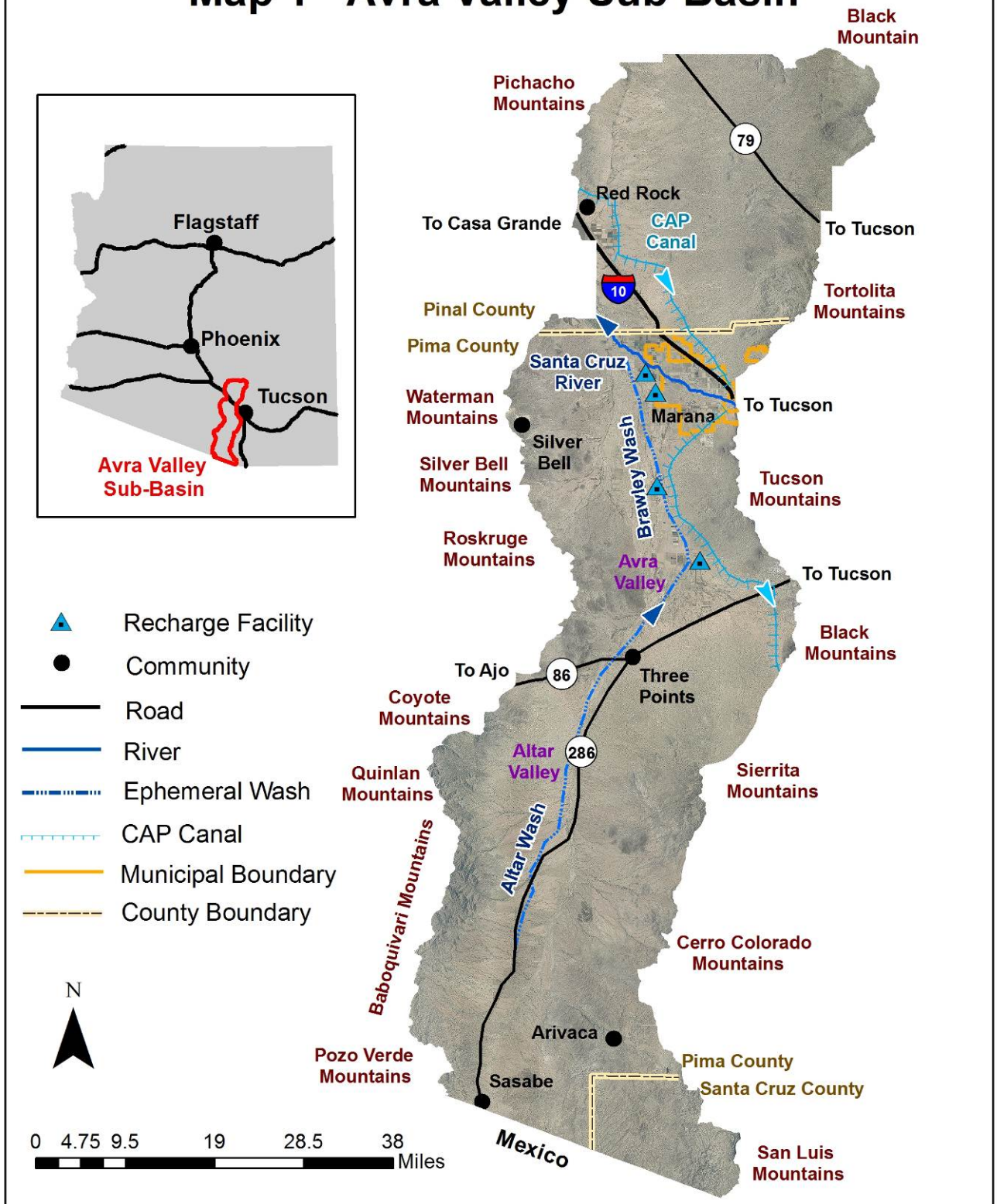
Geography – The Avra Valley sub-basin has a maximum width of about 25 miles east to west, and a maximum length of about 65 miles north to south. The sub-basin is located within the Basin and Range physiographic province of central Arizona.[5] The basin consists of relatively deep alluvial basins filled with sediments within the Altar and Avra Valleys that are bordered by mountains. Vegetation classification is composed of four types ranging with elevation from Middle Sonoran desert (1,200 – 2000 feet), Upper Sonoran desert (2,000 – 3,200 feet) Chihuahuan-Sonoran semi-desert grasslands (3,200-5,000 feet), and Mexican oak-pine woodland (5,000 – 7,000 feet).[6]

The basin, which extends southward into Mexico, for the purposes of this report is bounded on the south by the International Border, on the west by the Pozo Verde, Baboquivari, Quinlan, Coyote, Roskruge, Silver Bell, Waterman, and Picacho Mountains, on the east by the San Luis, Cerro Colorado, Sierrita, Black, Tucson, Tortolita Mountains and on the north by Black Mountain. Elevations in the basin range from a high of approximately 7,257 feet above mean sea level (amsl) atop Baboquivari Peak to a low of 1,847 feet amsl where the Santa Cruz River exits the sub-basin.

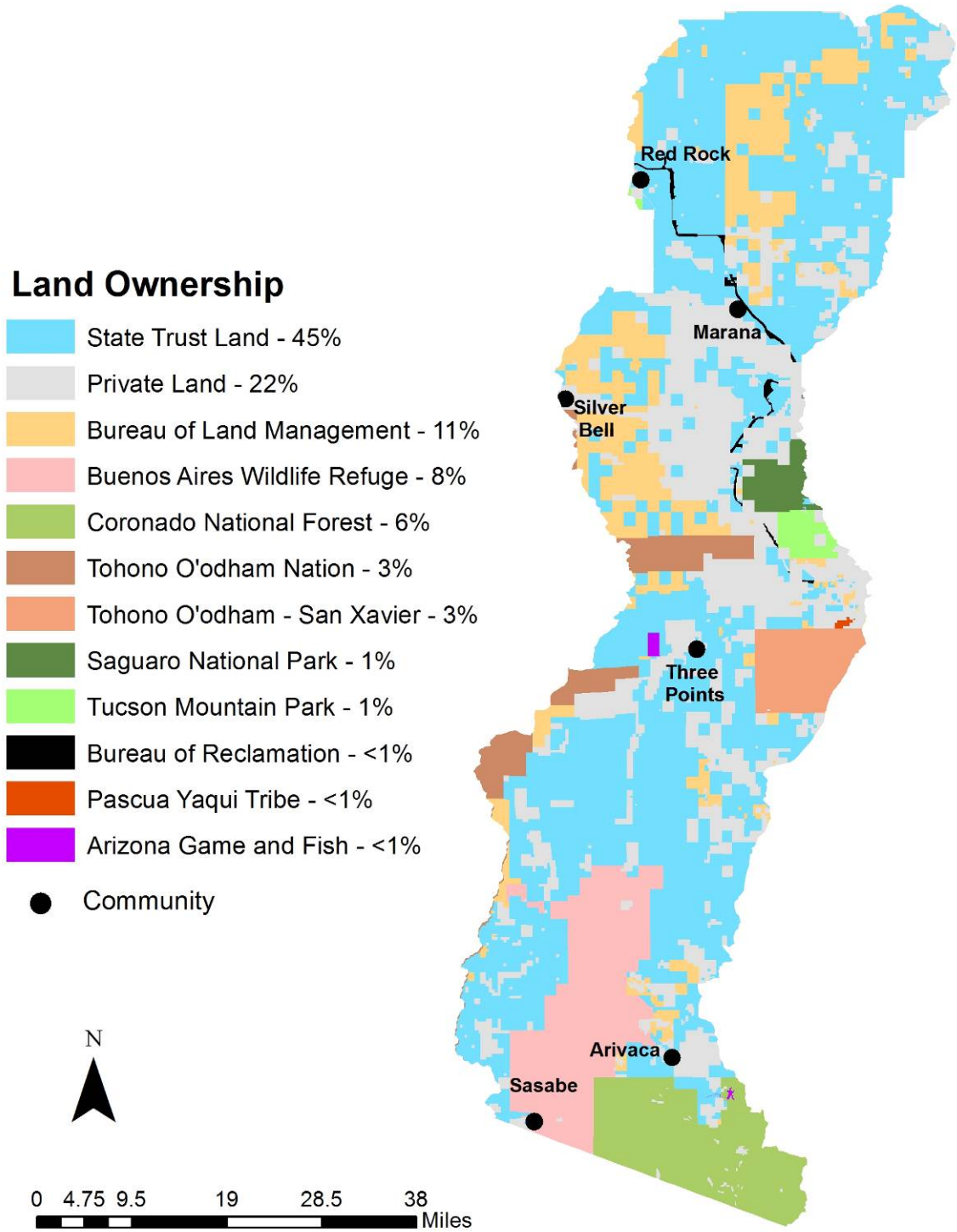
Land Ownership - The Avra Valley sub-basin consists of State Trust (45 percent) and federal lands (26 percent managed by the Bureau of Land Management (11 percent), the U.S. Fish and Wildlife Service (eight percent), the U.S. Forest Service (six percent), the National Park Service (one percent), and the Bureau of Reclamation (one percent). The remainder is private land (22 percent), Tohono O'odham Nation (six percent), and Tucson Mountain Park, the Pascua Yaqui Tribe, and Arizona Fish and Game holdings (Map 2). [4]

Climate – The Avra Valley sub-basin has a semiarid climate characterized by hot, dry summers and mild winters. There is wide variation in precipitation amounts which range annually from 30 inches atop Baboquivari Peak to 10 inches near Marana.[6] Precipitation occurs predominantly as rain in either late summer, localized thunderstorms or, less often, as widespread, low intensity winter rain that occasionally includes snow at higher elevations. [22]

Map 1 - Avra Valley Sub-Basin



Map 2 - Land Ownership



Surface Water – The sub-basin is drained by a watercourse that is named Altar Wash within Altar Valley and called Brawley Wash downgradient in Avra Valley. Arivaca Creek is the largest tributary to Altar Wash. Mountain runoff usually recharges along the pediments or evaporates before reaching the main drainages. As a result, the numerous stream channels which originate in the mountains surrounding Avra Valley become less distinct and may disappear altogether as the channels approach the valley floor.[14]

Brawley Wash drains north eventually discharging into Los Robles Wash, a short distance before its confluence with the Santa Cruz River.[5] The latter has a nine-mile effluent dependent perennial reach due to discharges from Tucson wastewater treatment plants, which have occurred since 1969.[14] The Santa Cruz River flows northwesterly across the northern reaches of Avra Valley and exits the sub-basin into the Pinal AMA.

Agriculture – Historically, agriculture has been the largest user of groundwater in the Avra Valley sub-basin. The first irrigation wells were drilled in 1937 near Marana and, by 1954, more than 100 wells produced 90,000 acre-feet (af) of water to irrigate 30,000 acres of farmland. Declining groundwater levels led to the state declaring most of Avra Valley a critical groundwater area in 1954. This designation banned the drilling of new irrigation wells but failed to restrict how much water existing wells could pump. By the early 1960's, annual pumping had increased to 150,000 af with water level declines in some wells of up to 140 feet by 1979.[14]

To stabilize groundwater levels and obtain the associated water rights, the City of Tucson has purchased and retired more than 14,000 acres of farmland since the early 1970s.[14] About 10,000 acres of irrigated crops, mostly alfalfa and cotton, continue to be farmed. Much of this acreage will likely be converted to urban use in the future.

Central Arizona Project - The Central Arizona Project (CAP) canal enters the Avra Valley sub-basin from the north near the Picacho Mountains, continues south, and exits the sub-basin to the east, south of State Route 86. The CAP canal eventually terminates at Pima Mine Road just south of the San Xavier District of the Tohono O'odham Nation in the Upper Santa Cruz Valley sub-basin of the Tucson AMA. [9]

Colorado River water has been conveyed through the CAP to the Tucson AMA since 1992. Tucson's Water Department, which previously supplied only groundwater to its customers, provided CAP water directly to its customers for two years. The different chemistry resulted in discolored water, broken water lines, and damaged water heaters and evaporative coolers. The Tucson City Council ordered the city to cease directly using CAP water in 1994. The direct delivery of CAP water unless its quality was equal to that of groundwater was prohibited by Proposition 200 in 1995. [9]

CAP water is currently recharged in five facilities in the Tucson AMA, four of which are located in the Avra Valley sub-basin. Two recharge facilities are located near the Santa Cruz River northwest of Marana: the Avra Valley facility operated by Metro Water, and the Lower Santa Cruz facility operated by the Central Arizona Water Conservation District.[11]

Two facilities are located south of Marana in Avra Valley: the Central Avra Valley Storage and Recovery Project (CAVSARP) and the Southern Avra Valley Storage and Recovery Project (SAVSARP) operated by the Tucson Water Department. The CAVSARP and SAVSARP are part of the city's Clearwater Renewable Resource Facility and are capable of recharging up to 140,000 af of Colorado River water, nearly all of Tucson Water's current annual allocation.[12]

The CAP water is recharged, blended with groundwater in the aquifer, and pumped out for public water use. The supplied water originally consisted of 95 percent groundwater and will transition into equal parts groundwater and CAP water.[12]

CAP water is also used directly for irrigation in the Avra Valley sub-basin. Tucson Water partners with farms within the Tucson AMA which irrigate their crops with CAP water rather than groundwater. The farmers purchase a portion of the City of Tucson's CAP allotment at a cost that is competitive with their cost for pumping groundwater. In exchange, Tucson Water receives the right to the groundwater that would otherwise have been used for irrigation. [12]

This ADEQ study was conducted before there were considered to be any potential impacts from CAP recharge in the groundwater quality of the Avra Valley sub-basin.

Groundwater Characteristics

Aquifers – Sediments in the Avra Valley sub-basin have been divided into upper and lower alluvial units. The units are hydrologically connected and form the regional aquifer. [5]

The upper unit is the primary water producer. The unit is composed of streambed deposits of silt, sand, and

gravel along Altar and Brawley washes and their major tributaries. The upper alluvial unit ranges in thickness from less than 100 feet to more than 1,000 feet. [22]

The lower alluvial unit is thousands of feet thick and consists of gravel and conglomerates located near the edges of the sub-basin. These deposits transition into clayey silts and mudstones along the sub-basin's central axis. These deposits are thickest in the northern part of the sub-basin, reaching an estimated depth of 9,600 feet in Avra Valley. The lower alluvial unit thins to the south, with sediments in the Altar Valley ranging from 4,800 feet thick in the northern part to 400 feet thick near the border with Mexico. [5]

Limited amounts of groundwater are also found in the surrounding mountains in thin alluvial deposits and in fractured or faulted bedrock.

Groundwater Conditions – Groundwater flow follows surface-water drainage, moving north and northwest from the border with Mexico. Groundwater is found in unconfined conditions though wells deeper than 1,000 feet below land surface (bls) may encounter confining conditions caused by less permeable clay layers. Perched groundwater exists in northeast Avra Valley, created by fine-grained beds impeding recharging irrigation water.[5]

Precipitation is the main source of natural recharge in the Avra Valley sub-basin. Most storm runoff recharge occurs along the contact zone between the mountains and valley sediments.[14] Minor amounts of recharge also occur during flow events along Altar and Brawley washes and their major tributaries.[32] Natural recharge in the Avra Valley sub-basin constitutes only about 16 percent of the Tucson AMA's total.[6]

A small amount of groundwater underflow also recharges the basin from gaps in the mountains that separate it from the Upper Santa Cruz Valley sub-basin. An estimated 29,000 af per year of groundwater exits the Avra Valley sub-basin to the northwest into the Pinal AMA near the Picacho Mountains.[5]

Minimal groundwater development has occurred in the Altar Valley, where depth-to-water ranges from 14 to 720 feet bls.[5] The shallowest water levels are along the Altar and Brawley washes while the deepest water levels are found on alluvial fans along the mountain fronts.[5] There has been no significant change in groundwater levels as most wells are shallow, low-yielding, and used for stock watering. Numerous domestic wells do exist, however, near the community of Arivaca.[6]

Most groundwater development in the sub-basin has occurred within Avra Valley, where water levels range from 140 to 600 feet bls.[5] Irrigation wells located near the center of Avra Valley are very productive, capable of more than 3,000 gallons per minute (gpm). Well yields decline towards the basin's margins as the basin-fill sediments decrease in thickness.[5]

Irrigation pumping in Avra Valley had caused water level declines of more than 200 feet near the community of Red Rock by 1985. These declining groundwater levels have resulted in aquifer compaction and land subsidence of up to 1.1 feet in this area. Groundwater pumping was significantly reduced in Avra Valley between 1975 and 1984 as the result of the City of Tucson purchasing and retiring agricultural lands.[36] After 1985, groundwater levels have increased near Marana as the result of the retirement of agricultural lands, the use of CAP water instead of groundwater, and groundwater recharge projects. [6]

INVESTIGATION METHODS

ADEQ collected samples from 42 sites to characterize regional groundwater quality in the Avra Valley sub-basin (Map 3). Specifically, the following types of samples were collected:

- inorganic suites at 42 sites
- radionuclides at 24 sites
- volatile organic compounds (VOCs) at 22 sites
- radon at 19 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. [16]

Wells pumping groundwater for domestic, stock, irrigation, and public water supply 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.[2, 8]

For this study, ADEQ personnel sampled 42 wells served by 30 submersible pumps, 10 windmills, and two turbine pumps. Additional information on groundwater sample sites is compiled from the Arizona Department of Water Resources (ADWR) well registry in Appendix A. [7]

Map 3 - Sample Sites

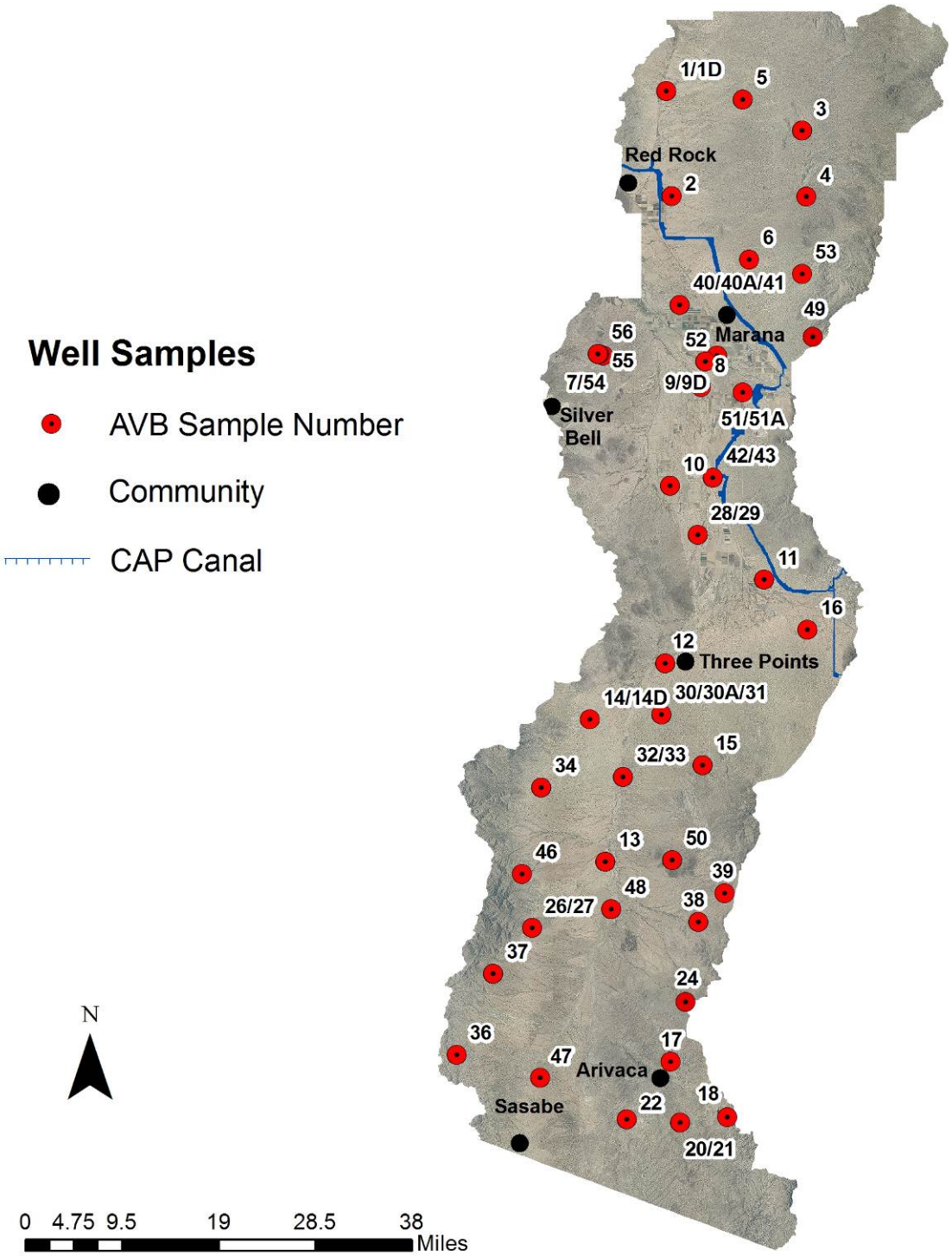


Figure 1 – The Avra Valley sub-basin extends for a short distance past the Sasabe Customs Inspection Station shown above, south into Mexico. Sasabe is a small, unincorporated community that has one of the least-used crossings along the international border.

Figure 2 – The Buenos Aires National Wildlife Refuge is located in southern Altar Valley, just north of the Mexican border. The wildlife refuge provides 117,107 acres of grassland habitat for threatened and endangered species, most notably for the reintroduction of masked bobwhite quail and pronghorn. [4]

Figure 3 – In the Altar Valley, the majority of lands are State Trust lands leased for grazing. Baboquivari Mountain is in the distance to the west. [4]

Figure 4 – Most groundwater development in Altar Valley is for livestock use such as at the Santa Margarita Ranch, owned for many years by the famed Ronstadt family. Baboquivari Mountain is framed by the gateway entrance to the ranch.

Figure 5 – An Arizona Water Company well used for public water supply is located south of the community of Three Points (also known as Robles Junction), at the intersection of State Routes 86 and 286.

Figure 6 – Water from Lane Windmill pours into a storage tank for use by livestock and wildlife. A duplicate sample (AVB-26/27) was collected at the site.

Figure 7 – Former ADEQ employee Joe Harmon collects a sample (AVB-50) from the Cinco de Mayo stock well located near the Sierrita Mountains in Altar Valley.

Figure 8 – A sample (AVB-4) was collected from this windmill on State Trust land located north of Interstate 10 near the Tortilita Mountains.

Figure 9 – Former ADEQ employee Wang Yu poses by Kai Farm Well #1, a 650-foot-deep irrigation well in Marana. The sample (AVB-8) collected from the well met both health and aesthetics water quality standards.

Figure 10 – Duplicate samples (AVB-9/9D) were collected from Heatley Well, used for irrigation in Marana. The duplicate samples exceeded water quality standards for both nitrate and TDS.

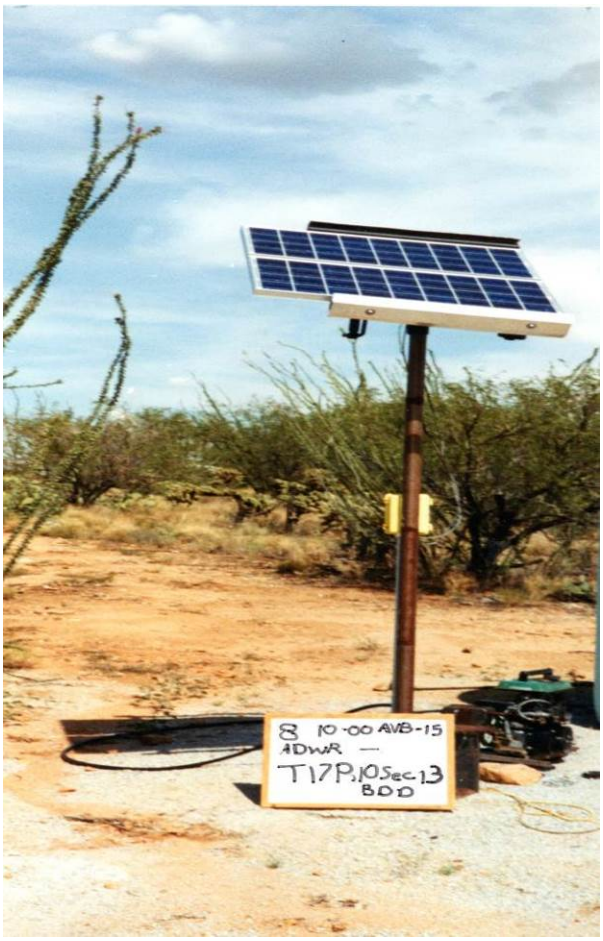


Figure 11 – This well used for domestic purposes is located in granitic geology near the Sierrita Mountains in Altar Valley. The sample (AVB-15) exceeded water quality standards for radionuclides and had the highest radon concentration (83,620 piC/L) ever collected by the ADEQ ambient groundwater monitoring program.

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Figure 12 – A sample (AVB-36) was collected from Agua del Oro Well that is located in the remote southern part of the Baboquivari Mountains. No water quality standards were exceeded at this stock well, which is powered by a pump jack.

Figure 13 – The sample (AVB-51/51D) obtained at the Avra Valley Air Park well was collected before any treatment by the water system. The well, one of the few in the study that had a driller's log, tapped the upper alluvial unit of the regional aquifer. [7]

Figure 14 – A duplicate sample (AVB-42/43) was collected from this domestic well located in Avra Valley just west of the Tucson Mountains. The samples met all water quality standards.

Figure 15 – The 740-foot-deep Bringhurst Well, located north of Interstate 10 is used for domestic and stock purposes. The sample (AVB-6) collected from the well had the highest field pH value of the study (8.19 su) and exceeded standards for arsenic, fluoride, and gross alpha.

Figure 16 – The sample (AVB-52) collected from Kai Farm Well #2 met all water quality standards except for the aesthetic standard for TDS. Water produced by the well is used for irrigation in Marana.

Sample Collection

The sample collection methods for this study conformed to the *Quality Assurance Project Plan* (QAPP) [2] and the *Field Manual for Water Quality Sampling*.[8] While these sources should be consulted as references to specific sampling questions, a brief synopsis of the procedures involved in collecting a groundwater sample is provided.

After obtaining permission from the well owner, the volume of water needed to purge the well three bore-hole volumes was calculated from well log and on-site information. Physical parameters—temperature, pH, and specific conductivity—were monitored every five minutes using a 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

Radon, a naturally occurring, intermediate breakdown from the radioactive decay of uranium-238 to lead-206, was collected in two unpreserved, 40 milliliter (ml) clear glass vials. Radon samples were filled to minimize volatilization and sealed so that no headspace remained.[8, 26]

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 subsequently checked to make sure there were no air bubbles in the vials. [24]

The inorganic constituents were collected in three, one-liter polyethylene bottles: samples to be analyzed for dissolved metals were filtered into bottles using a positive pressure filtering apparatus with a 0.45 micron (µm) pore size groundwater capsule filter and preserved with 5 ml nitric acid (70 percent). Samples AVB-4 through AVB-16 were delivered unpreserved and not acidified to the laboratory and analyzed for total recoverable metals instead of dissolved metals. 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.[24, 26]

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. [8]

All samples were kept at 4ºC with ice in an insulated cooler. [24] Chain of custody procedures were followed in sample handling. Samples for this study were collected during 12 field trips conducted between 1998 and 2002.

Laboratory Methods

VOC samples and the inorganic analyses were conducted by the Arizona Department of Health Services (ADHS) Laboratory in Phoenix, Arizona. The inorganic analyses for the four split samples (AVB-19, AVB-26, AVB-33, and AVB-41) were conducted by Test America Laboratory in Phoenix, Arizona. A complete listing of inorganic parameters, including laboratory method and Minimum Reporting Level (MRL) for each laboratory is provided in Table 1. The VOCs analyte list is provided in Table 2.

Radionuclide analyses were conducted by the Arizona Radiation Agency Laboratory in Phoenix. The following EPA Safe Drinking Water Act (SDWA) 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.

Radon samples were submitted to Test America Laboratory and analyzed by Radiation Safety Engineering, Inc. Laboratory in Chandler, 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 Avra Valley basin study. The design of the QA/QC plan was based on recommendations included in the *Quality Assurance Project Plan* (*QAPP*) and *the Field Manual for Water Quality Sampling*. [2, 8]

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 / 0.50
Total Phosphorus	Colorimetric	EPA 365.4 / M 4500-PB	0.02 / 0.1

All units are mg/L except as noted
Source [24, 26]

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
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
Gross alpha beta	Gas flow proportional counter	EPA 900.0	varies
Co-Precipitation	Gas flow proportional counter	EPA 00.02	varies
Radium 226	Gas flow proportional counter	EPA 903.0	varies
Radium 228	Gas flow proportional counter	EPA 904.0	varies
Uranium	Kinetic phosphorimeter	EPA Laser Phosphorimetry	varies

All units are mg/L Source [24, 26]

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	

Types and numbers of QC inorganic samples collected for this study include four blanks, seven duplicates, four partial duplicates, and three splits.

Blanks – Four equipment blanks 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.[8] 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 50 percent or more of the equipment blank samples contained measurable quantities of a particular groundwater quality constituent. The equipment blanks contained boron, turbidity and specific conductivity (SC-lab) at levels that could be explained by impurities in the source water used for the samples.

Three of four equipment blanks tested had detections of SC with a mean value of 2.9 micro-Siemens per cm (uS/cm) which was less than one 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, which 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.[24]

Three of four equipment blanks tested had detections of turbidity with a mean level of 0.04 nephelometric turbidity units (ntu), less than one percent of the turbidity mean level for the study. This was not considered to significantly affect 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.[24]

Two of four equipment blanks tested had detections of boron with a mean value of 0.115 mg/L. These levels were not considered to significantly affect the sample results. The boron detections may have occurred with detergent residue left when the de-ionized water bottles were cleaned.[24] Boron detections in equipment blanks have been found in previous ADEQ ambient groundwater studies.[27]

Zinc was also detected at a concentration of 0.17 mg/L in one equipment blank. The cause of this detection was unknown.

The eight 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.[8] 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.

Seven complete duplicate samples and four partial duplicate samples were collected and submitted to the ADHS laboratory for this study. Analytical results indicate that of the 40 constituents examined, 24 had concentrations above the MRL. The duplicate samples had an excellent correlation as the maximum variation between constituents was less than 10 percent except for nitrate (14 percent), sulfate (15 percent), turbidity (41 percent), and TKN (63 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.[8] Four 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, 16 had concentrations above MRLs for both ADHS and Test America laboratories. The maximum variation between constituent values was 10 percent or below except for TDS (11 percent), zinc (12 percent), fluoride (14 percent), sulfate and nitrate (18 percent), and turbidity (61 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.[33] 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. [19]

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.[19]

Overall, cation/anion meq/L balances of Avra Valley samples were significantly correlated (regression analysis, $p \leq 0.01$). Of the 42 samples, all were within +/-5 percent and 29 samples were within +/- 2 percent. Twenty-seven samples had low cation/high anion sums and 15 samples had high cation/low anion sums.

SC/TDS – The SC and TDS concentrations measured by contract laboratories were significantly correlated as were SC-field and TDS concentrations (regression analysis, $r = 0.98$, $p \leq 0.01$). The TDS concentration in mg/L should be from 0.55 to 0.75 times greater than the SC in µS/cm for groundwater up to several thousand TDS mg/L.[19] 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.[19]

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

Hardness – Concentrations of laboratory-measured and calculated values of hardness were significantly correlated (regression analysis, $r = 0.99$, $p \leq 0.01$) (Diagram 1). Hardness concentrations were calculated using the following formula: [(calcium x 2.497) + (magnesium x 4.118)]. [17]

pH – The pH value is related to the environment of the water and is likely to be altered by sampling and storage.[20] Still, the pH values measured in the field using a YSI meter at the time of sampling were not significantly correlated with laboratory pH values (regression analysis, $r = 0.37$, $p \leq 0.05$).

Statistical Considerations

Various statistical analyses were used to examine the groundwater quality data of the study. All statistical tests were conducted using SYSTAT software.[33]

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	7	0 %	3 %	0 %	0	10	0
SC (µS/cm)	4	0 %	1 %	0 %	0	10	5
Hardness	7	0 %	2 %	0 %	0	10	0
pH (su)	7	0 %	5 %	1 %	0	0.7	0.1
TDS	7	0 %	2 %	1 %	0	20	10
Turb. (ntu)	5	0 %	41 %	4 %	0	1.8	0.02
Major Ions							
Calcium	11	0 %	8 %	0 %	0	5	0
Magnesium	11	0 %	5 %	0 %	0	0.8	0
Sodium	11	0 %	5 %	0 %	0	3.6	0
Potassium	11	0 %	5 %	0 %	0	0.2	0.1
Bicarbonate	7	0 %	2 %	0 %	0	10	0
Chloride	7	0 %	2 %	0 %	0	1	0
Sulfate	7	0 %	15 %	0 %	0	40	0
Nutrients							
Nitrate (as N)	7	0 %	14 %	1 %	0	0.2	0.027
Phosphorus, T.	1	-	-	11 %	-	-	0.014
TKN *	4	3 %	63 %	12 %	0.004	0.08	0.015
Trace Elements							
Barium	3	0 %	3 %	0 %	0	0.01	0
Boron	3	0 %	5 %	3 %	0	0.1	0.1
Fluoride	7	0 %	9 %	1 %	0	0.06	0.01
Iron	1	-	-	1 %	-	-	0.01
Manganese	1	-	-	0 %	-	-	0
Zinc**	8	0 %	8 %	0 %	0	0.12	0

All concentration units are mg/L except as noted with certain physical parameters.
* = TKN was detected in one sample (AVB-14D) at a concentration of 0.087 mg/L and not detected in the duplicate (AVB-14)
** = Zinc was detected in one sample (AVB-27) at a concentration of 0.2 mg/L and not detected in the duplicate (AVB-26)
Silver was detected in one sample (AVB-1D) at a concentration of 0.0056 mg/L and not detected in the duplicate (AVB-1)

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	4	0 %	8 %	0	20	ns
SC (µS/cm)	4	0 %	8 %	0	70	ns
Hardness	4	0 %	0 %	0	0	ns
pH (su)	4	1 %	3 %	0.11	0.47	ns
TDS	4	2 %	11 %	20	40	ns
Turbidity (ntu)	2	22 %	61 %	3.1	21.9	ns
Major Ions						
Calcium	4	0 %	3 %	0	2	ns
Magnesium	4	0 %	3 %	0	0.4	ns
Sodium	4	3 %	7 %	1	7	ns
Potassium	4	2 %	10 %	0.1	0.5	ns
Chloride	4	5 %	8 %	1	5	ns
Sulfate	4	0 %	18 %	0	15	ns
Nutrients						
Nitrate as N	3	1 %	18 %	0.3	1.5	ns
Trace Elements						
Barium	1	0 %	0 %	0	0	ns
Fluoride	4	2 %	14 %	0.12	0.63	ns
Zinc	3	4 %	12 %	0.008	0.4	ns

ns = No significant ($p \leq 0.05$) difference
All units are mg/L except as noted
TKN was detected by Test America in (AVB-29) at 0.56 mg/L and not detected in the ADHS split sample (AVB-25)
TKN was detected by Test America in (AVB-41) at 1.7 mg/L and not detected in the ADHS split sample (AVB-40)
Turbidity was detected by Test America in (AVB-41) at 0.011 mg/L and not detected in the ADHS split sample (AVB-40)

Data Normality: Data associated with 24 constituents were tested for non-transformed normality using the Kolmogorov-Smirnov one-sample test with the Lilliefors option.[10] Results of this test revealed that two of the 24 constituents examined were normally distributed including temperature and pH-field.

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 valleys and geology were the same. With the four-way valley/geology demarcation, the Tukey test was also used to examine for significant differences between groups. [18]

The Kruskal-Wallis test uses the differences, but also incorporates information about the magnitude of each difference.[33] 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.[18]

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.[33] The Kendall's tau-b test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.[18]

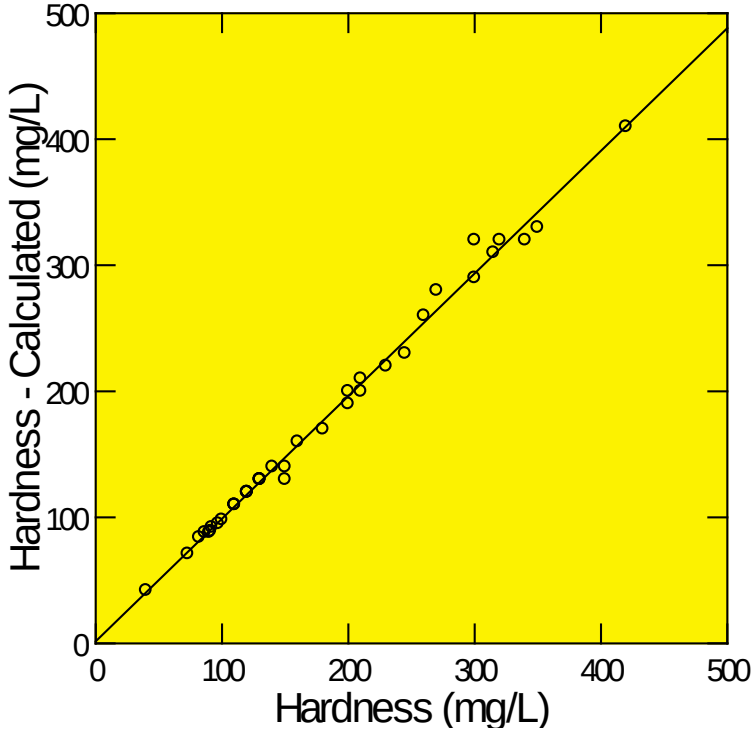


Diagram 1 – The graph illustrates a positive correlation between two constituents; as hardness concentrations increase, calculated hardness concentrations also increase. This strong relationship is described by the regression equation: $y = 1.02x + 0.5$ ($r = 0.40$). This relationship is one of the QA/QC correlations conducted to validate the laboratory results. [19] Hardness concentrations were calculated using the following formula: [(calcium x 2.497) + (magnesium x 4.118)].

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.[29]

- 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 and uranium with a federal Primary MCL of 30 ug/L. [3]

- 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.[29]

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

Overall Results – Of the 42 sites sampled in the Avra Valley study, 36 sites met all health-based and aesthetics-based, water quality standards (excluding the proposed radon standard discussed below).

Of the 42 sites sampled in the Avra Valley study, health-based water quality standards were exceeded at six sites (14 percent). Constituents above Primary MCLs include arsenic (two sites), gross alpha (five sites), uranium (two sites), and one site each for nitrate and radium-226+228.

Inorganic Constituent Results - Of the 42 sites sampled for the full suite of inorganic constituents (excluding radionuclide sample results) in the Avra Valley study, 29 sites (69 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 three of the 42 sites (seven percent) (Map 4). Constituents above Primary MCLs include arsenic (two sites) and nitrate (one site). Potential impacts of these Primary MCL exceedances are given in Table 5.

Aesthetics-based Secondary MCL water quality guidelines were exceeded at 11 of 42 sites (26 percent) (Map 4). Constituents above Secondary MCLs include TDS (seven sites), fluoride (five sites), manganese (two sites), iron and sulfate (one site apiece). Potential impacts of these Secondary MCL exceedances are given in Table 6.

Radionuclide Results - Of the 24 sites sampled for radionuclides, health-based water quality standards were exceeded at five sites (21 percent). Constituents above Primary MCLs include gross alpha (five sites), uranium (two sites), and radium-226+228 (one site).

VOC Results - Of the 22 sites sampled for VOCs, there were no detections of any of the 32 compounds.

Radon Results - Of the 19 sites sampled for radon, one exceeded the proposed 4,000 picocuries per liter (pCi/L) standard that would apply if Arizona establishes an enhanced multimedia program to address the health risks from radon in indoor air. Sixteen sites exceeded the proposed 300 pCi/L standard (Table 5; Map 5) that would apply if Arizona doesn't develop a multimedia program. [30]

Analytical Results

Analytical inorganic and radiochemistry results of the Avra Valley sub-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.[33] Specific constituent information for each sampled groundwater site is in Appendix B.

Map 4 - Water Quality

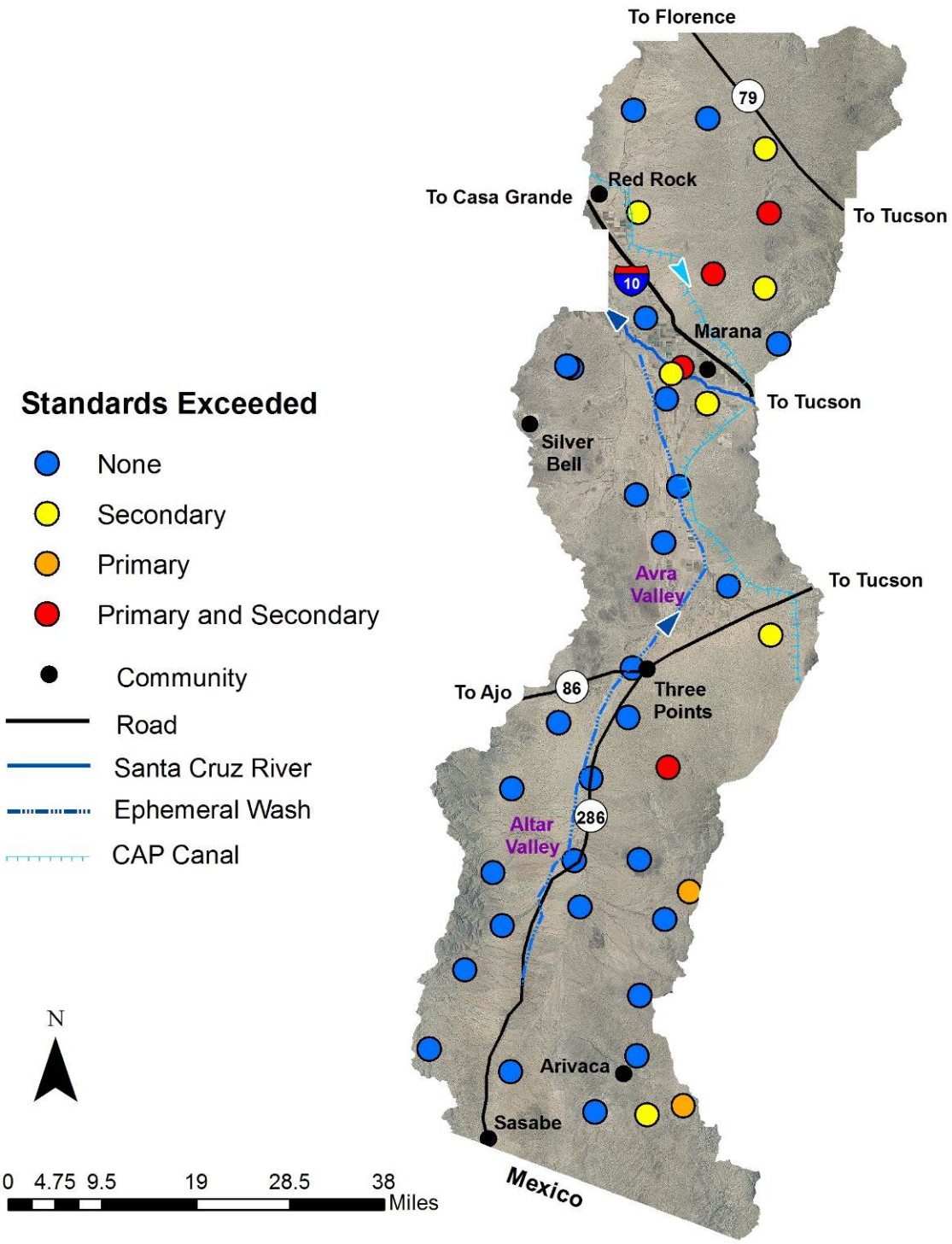


Table 5. Sampled Sites Exceeding Health-based Water Quality Standards or Primary MCLs

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**	12.5	methemoglobinemia
Trace Elements				
Antimony (Sb)	0.006	0	-	-
Arsenic (As)	0.01	**2**	0.038	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	**5**	170	cancer
Ra-226+Ra-228	5	**1**	30.8	bone cancer
Radon **	300	**16**	906	cancer
Radon **	4,000	**1**	83,620	cancer
Uranium	30	**2**	140	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.[29]
** Proposed EPA Safe Drinking Water Act standards for radon in drinking water. [30]

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	**7**	720	hardness; deposits; colored water; staining; salty taste
Major Ions				
Chloride (Cl)	250	0	-	-
Sulfate (SO_4)	250	1	290	salty taste
Trace Elements				
Fluoride (F)	2.0	**5**	2.8	tooth discoloration
Iron (Fe)	0.3	**1**	0.475	rusty color, reddish stains, and metallic tastes
Manganese (Mn)	0.05	**2**	0.052	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: [29]

Map 5 - Radon

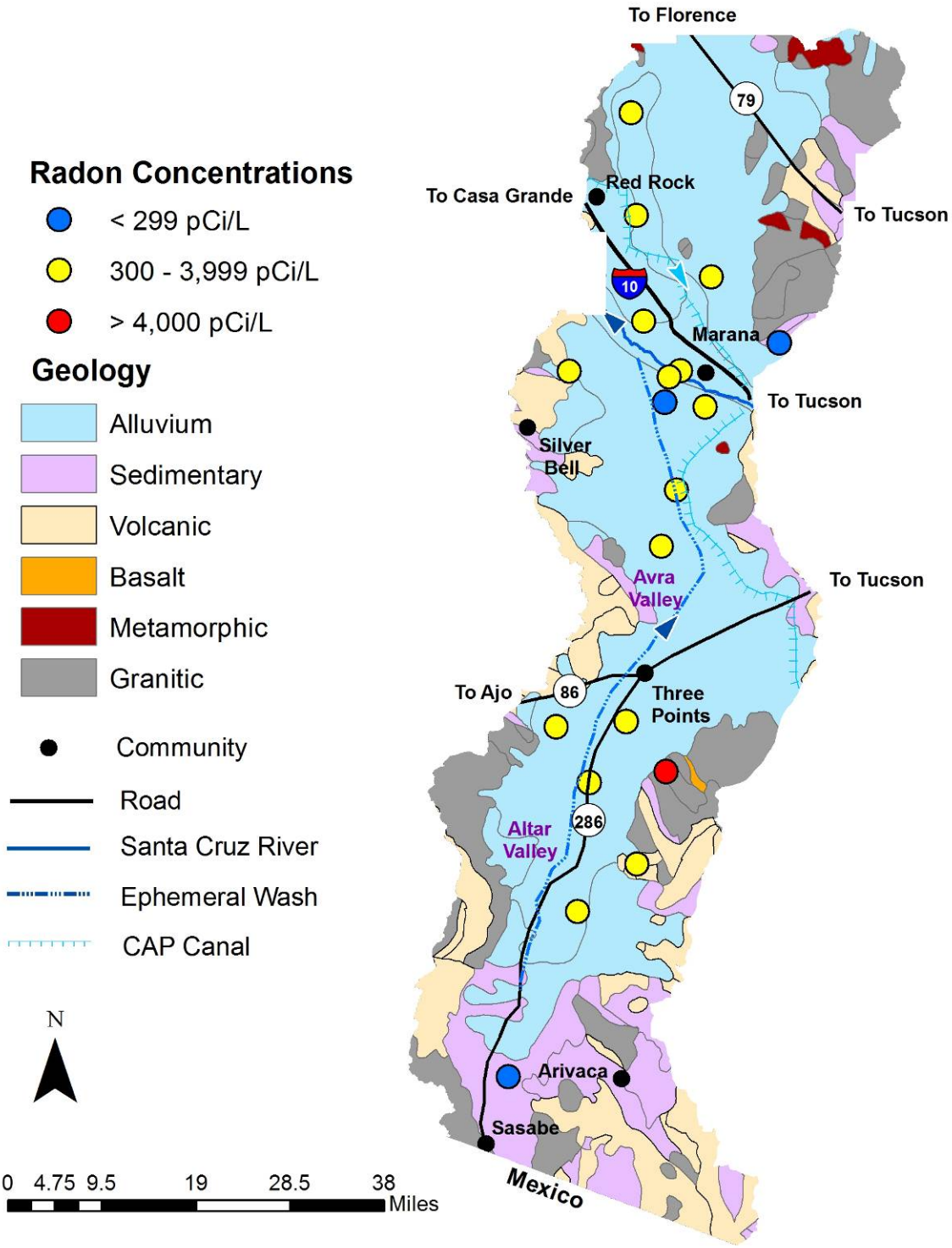

Radon Concentrations
< 299 pCi/L
300 - 3,999 pCi/L
> 4,000 pCi/L
Geology
Alluvium
Sedimentary
Volcanic
Basalt
Metamorphic
Granitic
Community
Road
Santa Cruz River
Ephemeral Wash
CAP Canal
N
0 4.75 9.5 19 28.5 38
Miles
To Florence
79
To Casa Grande
Red Rock
To Tucson
10
Marana
To Tucson
Silver Bell
Avra Valley
To Tucson
To Ajo
86
Three Points
286
Altar Valley
Arivaca
Sasabe
Mexico

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	42 / 42	26.6	25.0	26.3	27.6
pH-field (su)	0.01	42 / 42	7.57	7.46	7.56	7.66
pH-lab (su)	0.01	42 / 42	7.82	7.67	7.79	7.91
Turbidity (ntu)	0.01 / 1.0	42 / 39	0.4	-0.2	4.3	8.8
General Mineral Characteristics						
T. Alkalinity	2.0 / 5.0	42 / 42	163	169	189	209
Phenol. Alk.	2.0 / 5.0	42 / 0	> 50% of data below MRL			
SC-field (µS/cm)	N/A	42 / 42	477	480	551	623
SC-lab (µS/cm)	N/A / 2.0	42 / 42	468	485	559	633
Hardness-lab	10 / 1	42 / 42	130	144	173	202
TDS	10 / 20	42 / 42	280	303	349	394
Major Ions						
Calcium	5 / 2	42 / 42	39	43	51	59
Magnesium	1.0 / 0.5	42 / 42	10	10	13	15
Sodium	5	42 / 42	42	43	52	60
Potassium	0.5 / 1.0	42 / 42	2.4	2.1	2.5	2.9
Bicarbonate	2.0 / 5.0	42 / 42	203	206	231	255
Carbonate	2.0 / 5.0	42 / 0	> 50% of data below MRL			
Chloride	1 / 5	42 / 42	24	26	37	48
Sulfate	10	42 / 41	17	23	41	59
Nutrients						
Nitrate (as N)	0.05	42 / 41	1.7	2.0	2.9	3.7
Nitrite (as N)	0.02 / 0.20	29 / 0	> 50% of data below MRL			
TKN	0.05 / 0.5	34 / 18	> 50% of data below MRL			
Ammonia	0.02 / 0.5	31 / 1	> 50% of data below MRL			
T. Phosphorus	0.02 / 0.05	31 / 7	> 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	29 / 0		> 50% of data below MRL		
Antimony	0.005 / 0.004	42 / 0		> 50% of data below MRL		
Arsenic	0.01 / 0.003	42 / 40		> 50% of data below MRL		
Barium	0.1 / 0.01	42 / 14		> 50% of data below MRL		
Beryllium	0.0005	42 / 0		> 50% of data below MRL		
Boron	0.1 / 0.5	42 / 18		> 50% of data below MRL		
Cadmium	0.001 / 0.005	42 / 0		> 50% of data below MRL		
Chromium	0.01 / 0.004	42 / 1		> 50% of data below MRL		
Copper	0.01 / 0.004	42 / 1		> 50% of data below MRL		
Fluoride	0.05 / 0.1	42 / 42	0.5	0.5	0.8	1.0
Iron	0.1 / 0.2	42 / 3		> 50% of data below MRL		
Lead	0.005 / 0.002	42 / 0		> 50% of data below MRL		
Manganese	0.05 / 0.02	42 / 2		> 50% of data below MRL		
Mercury	0.0005 / 0.0002	42 / 0		> 50% of data below MRL		
Nickel	0.1 / 0.05	42 / 0		> 50% of data below MRL		
Selenium	0.005 / 0.004	42 / 0		>50% of data below MRL		
Silver	0.001 / 0.005	42 / 0		> 50% of data below MRL		
Thallium	0.002	42 / 0		> 50% of data below MRL		
Zinc	0.05	42 / 29	0.07	0.06	0.25	0.45
Radiochemical						
Gross Alpha**	Varies	24 / 22	7	2	16	31
Gross Beta**	Varies	24 / 24	4	0	7	16
Radon **	Varies	19 / 19	587	-3883	5276	14436

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

GROUNDWATER COMPOSITION

General Summary

The water chemistry at the 42 sample sites in the Avra Valley include mixed-bicarbonate (21 sites), calcium-bicarbonate (11 sites), sodium-bicarbonate (three sites), calcium-mixed and mixed-mixed (two sites apiece), and sodium mixed and mixed-sulfate (one site apiece) (Diagram 2 – middle figure) (Map 6).

The dominant cation was calcium at 13 sites and sodium at five sites. At 24 sites the composition was mixed as there was no dominant cation (Diagram 2 – left figure).

The dominant anion was bicarbonate at 35 sites. Chloride and sulfate were the dominant anion at one site apiece. The composition was mixed at five sites as there was no dominant anion (Diagram 2 – right figure).

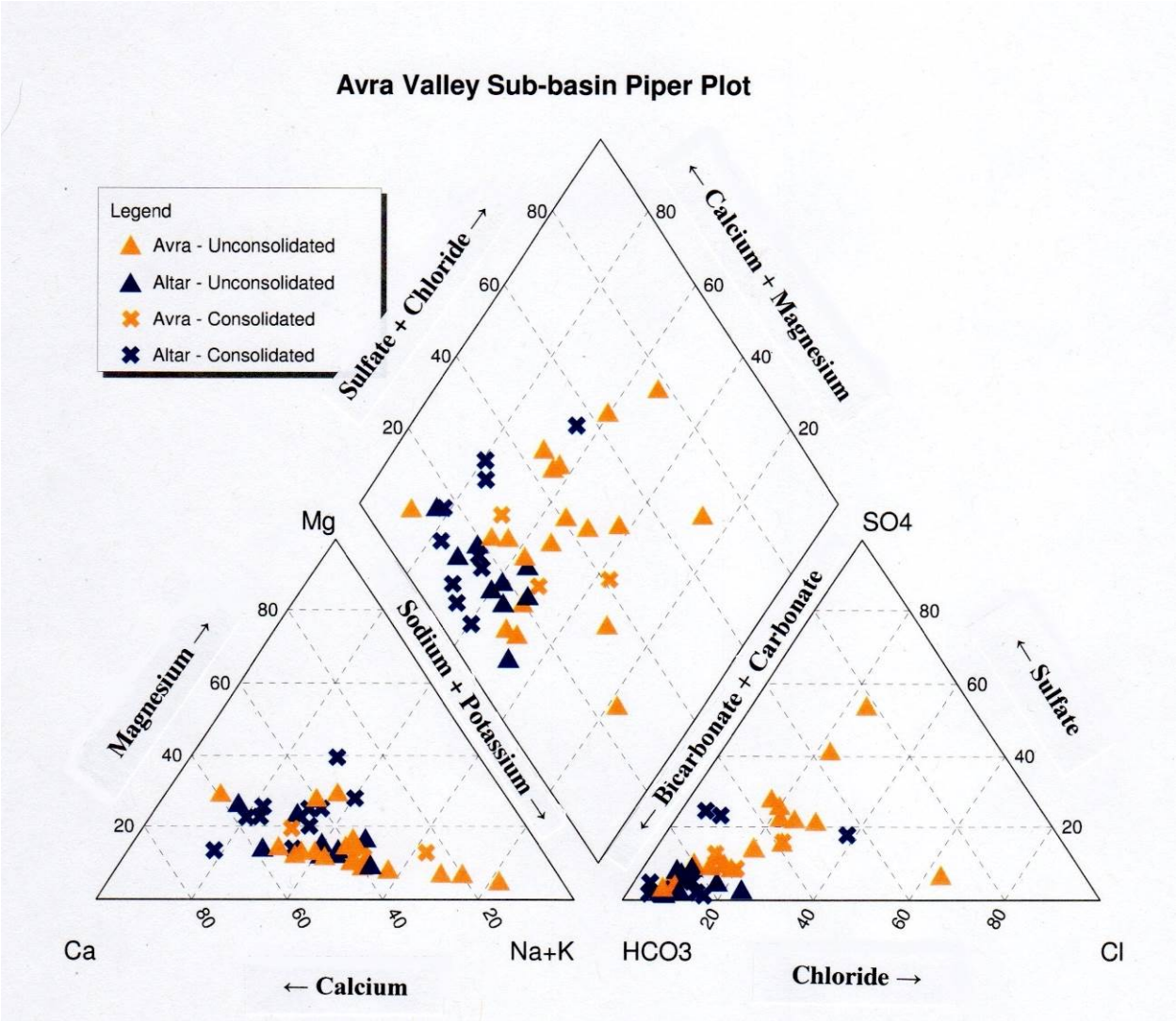
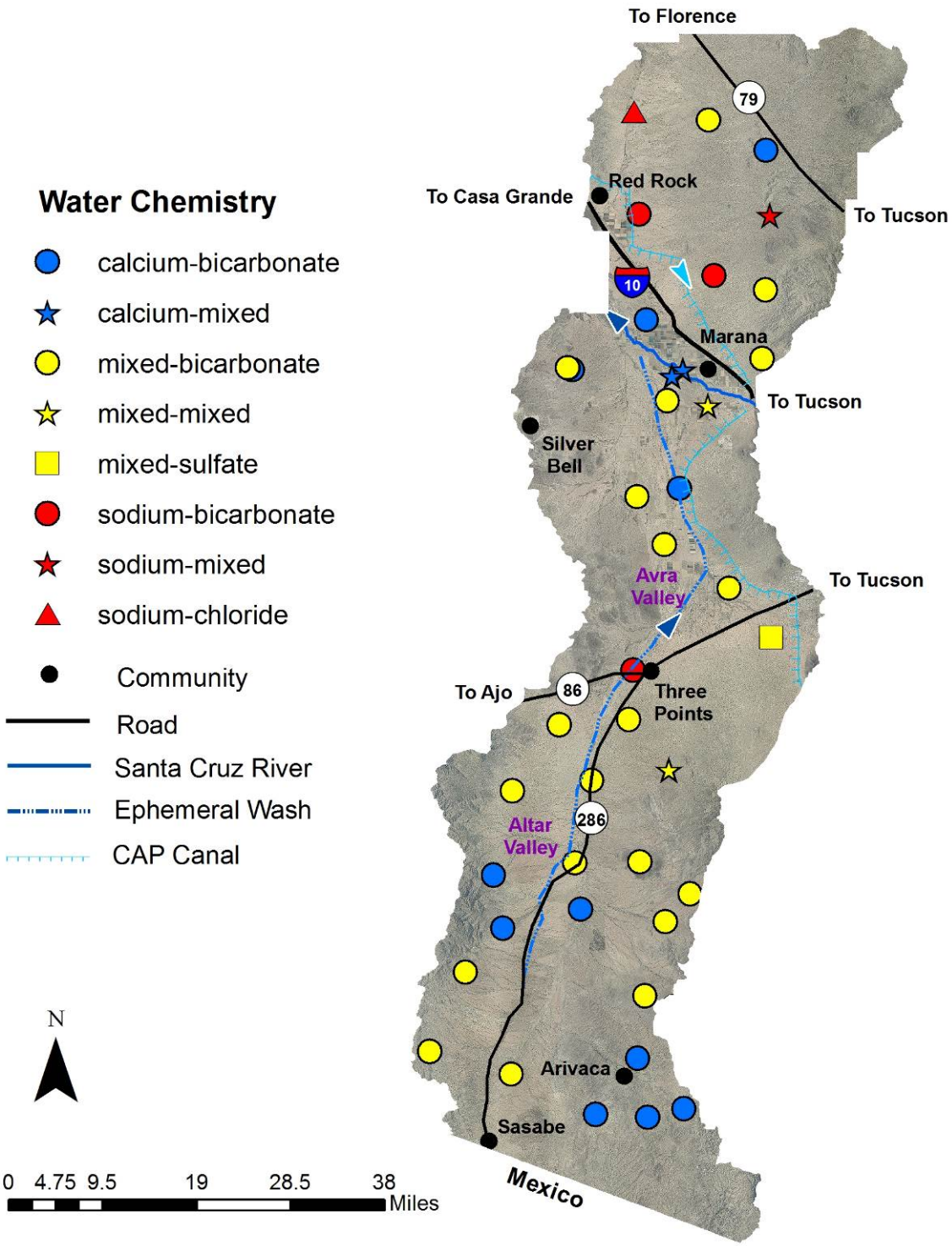


Diagram 2 – Samples collected in the Avra Valley sub-basin predominantly have a calcium-bicarbonate or mixed-bicarbonate chemistry which is reflective of younger groundwater that has been recently recharged.[25] Each sample was classified by valley location (Avra vs Altar), designated by triangles and geologic substrate (consolidated rock vs unconsolidated sediments), designated by "x's". Samples collected from wells producing water from unconsolidated sediments in Avra Valley had the most variable chemistry, probably as a result of having the most development, particularly irrigation, in that portion of the sub-basin.

Map 6 - Water Chemistry



At 42 sites, levels of pH-field were *slightly alkaline* (above 7 su) and three sites were above 8 su. No sites had pH-field levels that were *slightly acidic* (below 7 su).[17]

TDS concentrations were considered *fresh* (below 999 mg/L) at 42 sites (Map 7).[17]

Hardness concentrations were *soft* (below 75 mg/L) at two sites, *moderately hard* (75 – 150 mg/L) at 21 sites, *hard* (150 – 300 mg/L) at 13 sites, *very hard* (301 - 600 mg/L) at five sites, and *extremely hard* at one site (Map 8).[15]

Nitrate (as nitrogen) concentrations at most sites may have been influenced by human activities (Map 9). Nitrate concentrations were divided into natural background (four sites at < 0.2 mg/L), may or may not indicate human influence (23 sites at 0.2 – 3.0 mg/L), may result from human activities (14 sites at 3.0 – 10 mg/L), and probably result from human activities (one site > 10 mg/L).[21]

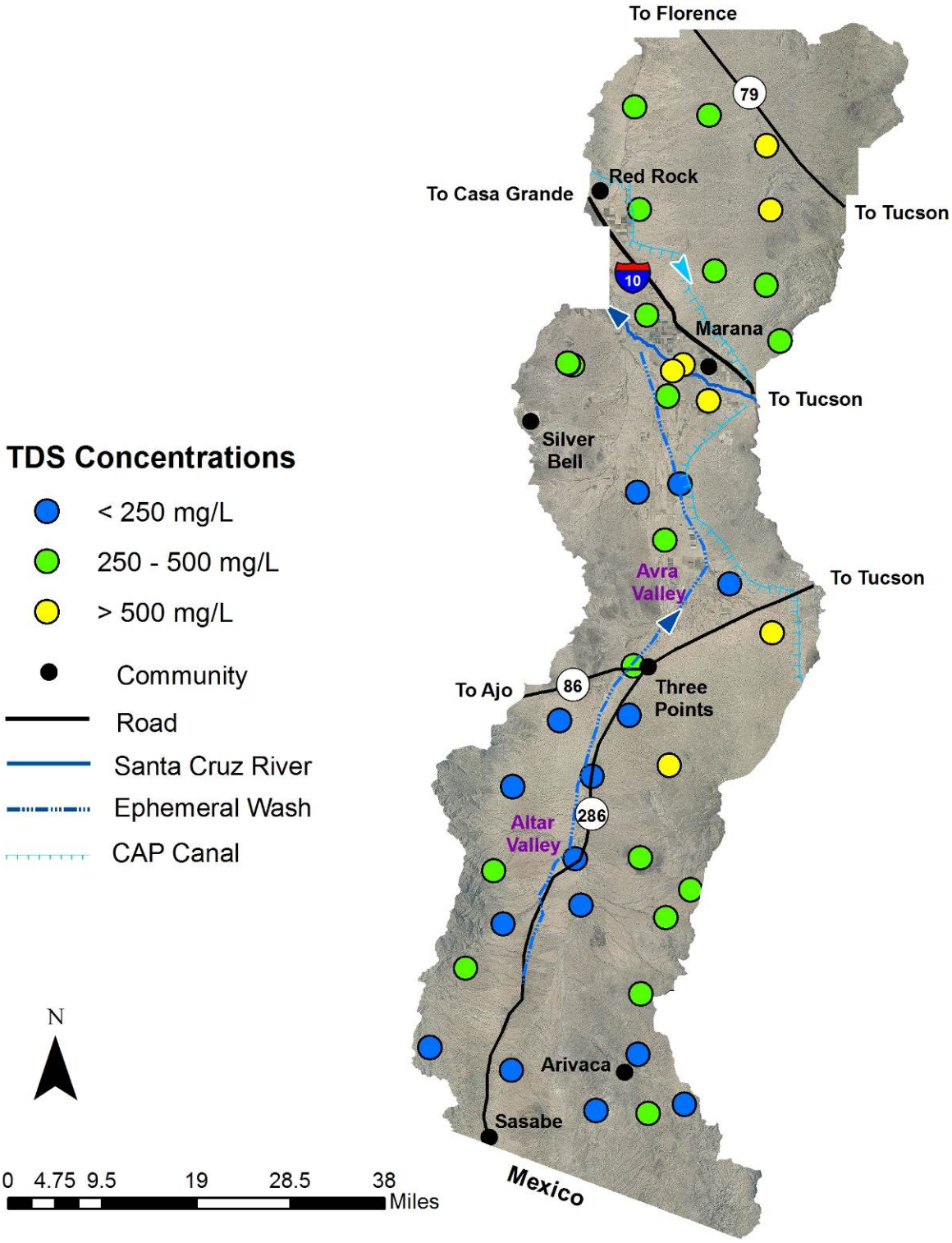
Most trace elements such as aluminum, antimony, arsenic, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, and thallium were rarely – if ever - detected. Only barium, boron, fluoride, and zinc were detected at more than 25 percent of the sites.

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.[31] Groundwater sites in the Avra Valley display a narrow range of irrigation water classifications. Samples predominantly had a "low" sodium hazard and a "medium-to-high" salinity hazard (Table 8).

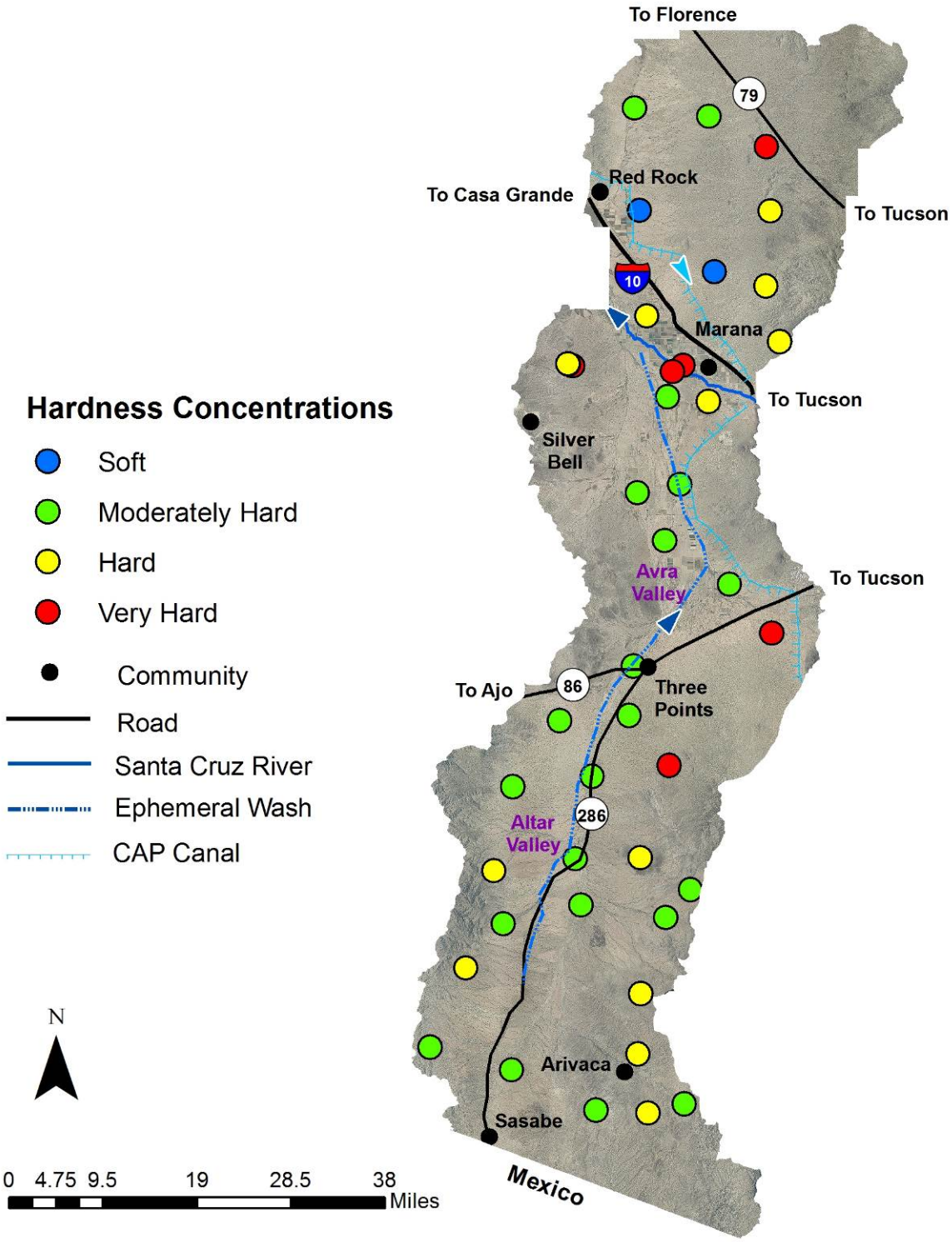
Table 8. Sodium and Salinity Hazards for Sampled Sites

Hazard	Total Sites	Low	Medium	High	Very High
		Sodium Hazard			
Sodium Adsorption Ratio (SAR)		0 - 10	10- 18	18 - 26	> 26
Sample Sites	42	42	0	0	0
		Salinity Hazard			
Specific Conductivity (µS/cm)		100–250	250 – 750	750-2250	>2250
Sample Sites	42	0	33	9	0

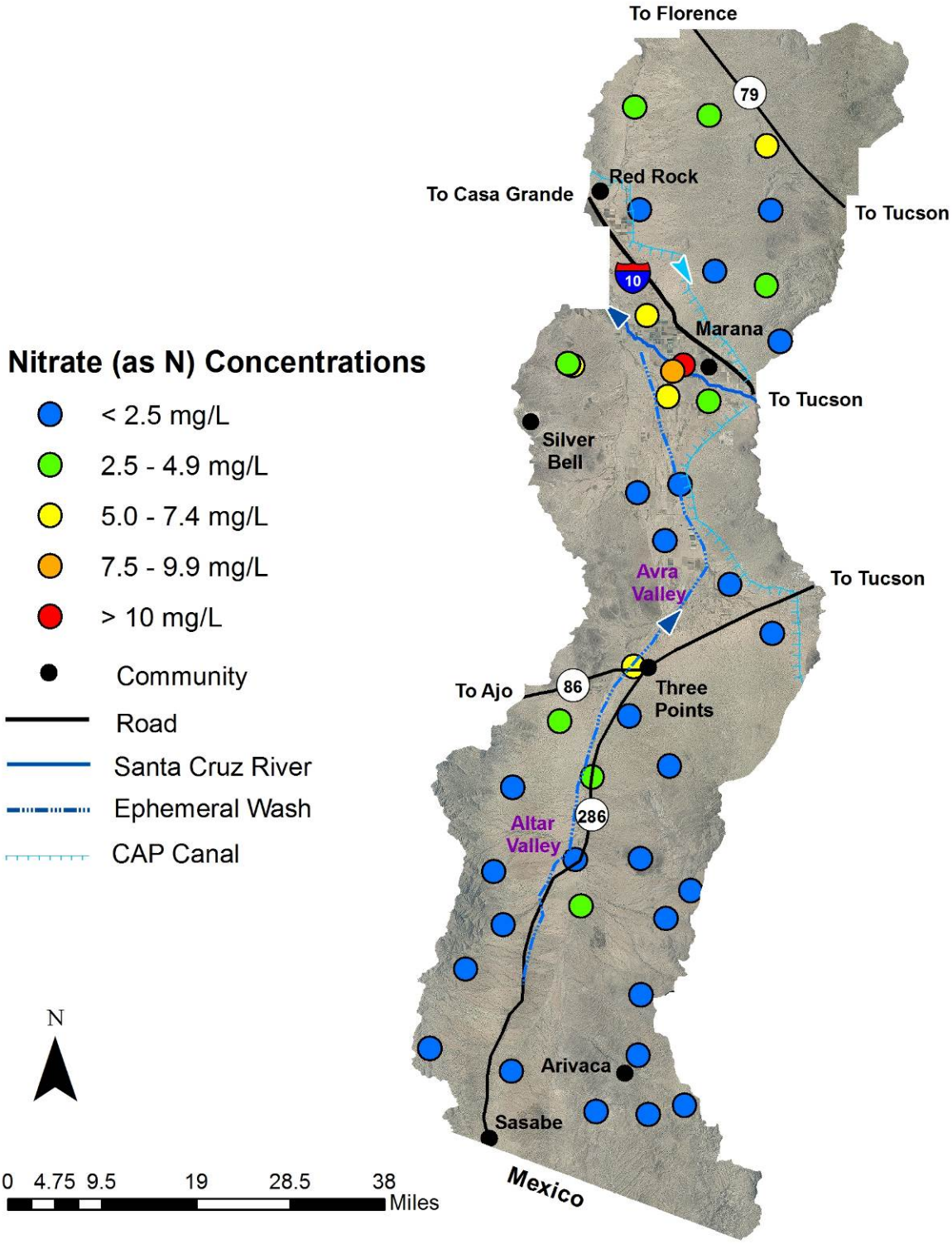
Map 7 - Total Dissolved Solids (TDS)



Map 8 - Hardness



Map 9 - Nitrate



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.[33]

Several significant correlations occurred among the 42 sample sites (Table 9, 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 pH-field, sodium, potassium, chloride, and sulfate though these relationships were influenced by an outlier.

- Nitrate was negatively correlated with pH-field, SC, TDS, hardness, calcium, magnesium, sodium, bicarbonate, chloride, sulfate, fluoride, and gross alpha though these relationships were influenced by an outlier.

TDS concentrations are best predicted among major ions by calcium concentrations (standard coefficient = 0.51), among cations by calcium concentrations (standard coefficient = 0.58) and among anions, by sulfate concentrations (standard coefficient = 0.60) (multiple regression analysis, $p \leq 0.01$).

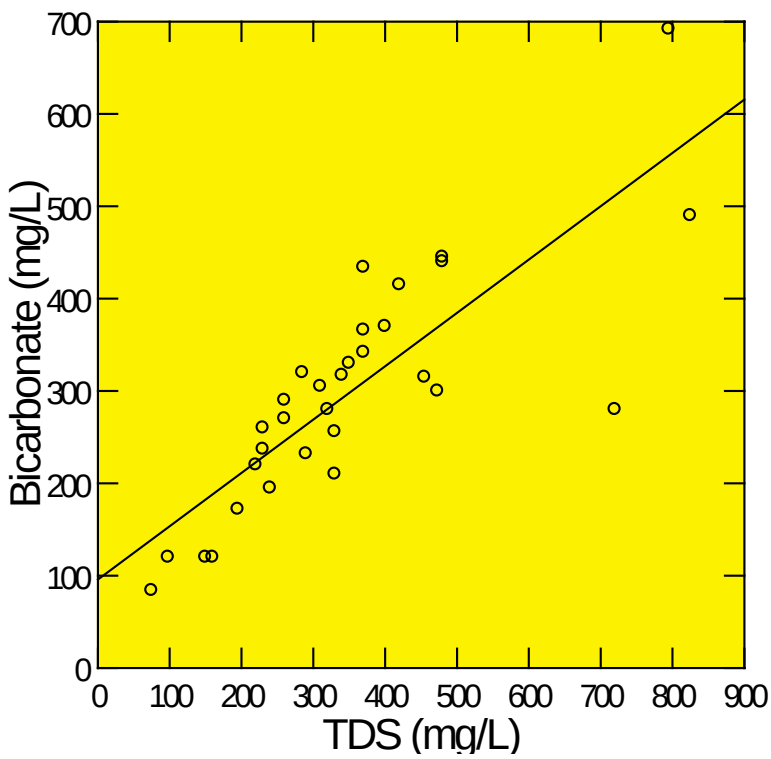


Diagram 3 – The graph illustrates a positive correlation between two constituents; as TDS concentrations increase, bicarbonate concentrations also increase. This relationship is described by the regression equation: $y = 0.26x + 141$ ($r = 0.42$). Elevated bicarbonate in groundwater is often associated with recently recharged water. Water infiltrating the sub-surface readily dissolves carbon dioxide gas (CO_2) in soil zones, where the partial pressure of CO_2 is much greater than that in the atmosphere. The CO_2 combines with water to form carbonic acid. The resultant higher acidity of recharging water increases dissolution and weathering of minerals in the sub-surface, resulting in higher TDS concentrations.[14]

Table 9. 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	Radon
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																		**
Radon																		

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

Groundwater Quality Variation

Between Two Valley Groups – Twenty-one groundwater quality constituents were compared between two groups: samples collected from sites in Altar Valley (20 sites) and Avra Valley (22 sites).

Significant concentration differences were found with 10 constituents: temperature (Diagram 4), SC-field, SC-lab, TDS (Diagram 5), sodium (Diagram 6), potassium, chloride, sulfate, nitrate (Diagram 7), and fluoride (Map 10) (Kruskal-Wallis test, $p \leq 0.05$). In all these instances, sites located in Avra Valley had significantly higher constituent concentrations than sites located in Altar Valley.

Complete statistical results are contained in Table 10. For valley groups with significantly different concentrations, 95 percent confidence intervals are contained in Table 11.

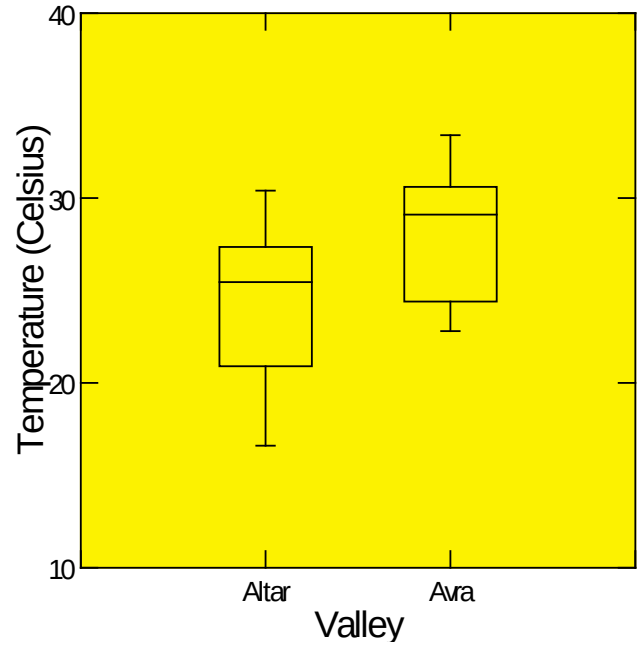


Diagram 4 – Samples collected from sites in Avra Valley have significantly higher temperatures values than samples collected from sites in Altar Valley (Kruskal-Wallis, $p \leq 0.01$). This phenomenon might be explained by the generally deeper groundwater levels in Avra Valley wells. Groundwater temperatures increase with depth, approximately 3 degrees Celsius with every 100 meters or 328 feet in depth.[34]

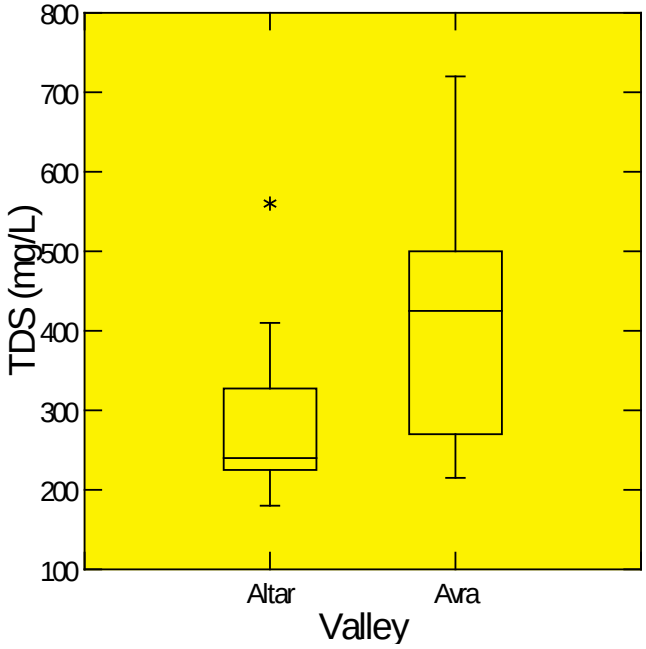


Diagram 5 – Samples collected from sites in Avra Valley have significantly higher TDS concentrations than samples collected from sites in Altar Valley (Kruskal-Wallis, $p \leq 0.01$). Possible explanations for this TDS difference include low rock solubility, a poor supply of carbon dioxide which increases acidity to aid in the weathering of sub-surface minerals, influence of CAP recharge, and the few significant impacts from human activities in the Altar Valley.[25]

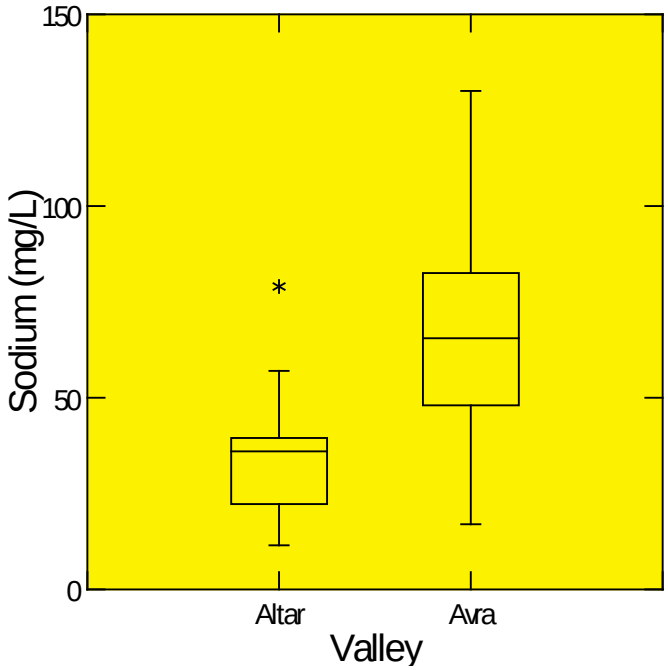


Diagram 6 – Samples collected from sites in Avra Valley have significantly higher sodium concentrations than samples collected from sites in Altar Valley (Kruskal-Wallis, $p \leq 0.01$). Low concentrations of sodium typically occur in recharge areas and increase downgradient as the result of silicate weathering and halite dissolution along with ion exchange.[25] Sodium concentrations in the Avra Valley could also be elevated by CAP recharge.

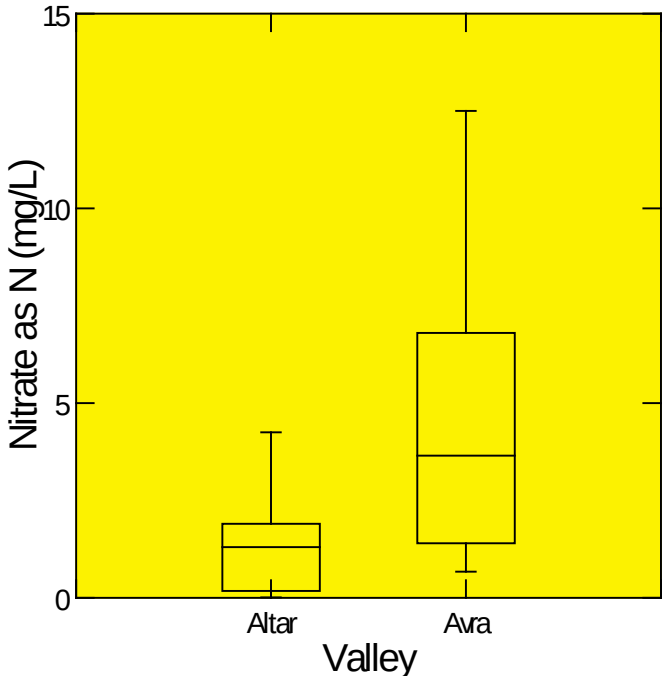


Diagram 7 – Samples collected from sites in Avra Valley have significantly higher nitrate concentrations than samples collected from sites in Altar Valley (Kruskal-Wallis, $p \leq 0.01$). Development in Altar Valley is limited to isolated ranches and some residential use in its northern reaches. Avra Valley, in contrast, has much more urban development along with expanses of irrigated cropland near Marana. Nitrate loading to the groundwater from irrigation recharge and septic tank leaching probably accounts for the difference in nitrate concentrations between the two valleys.

Map 10 - Fluoride

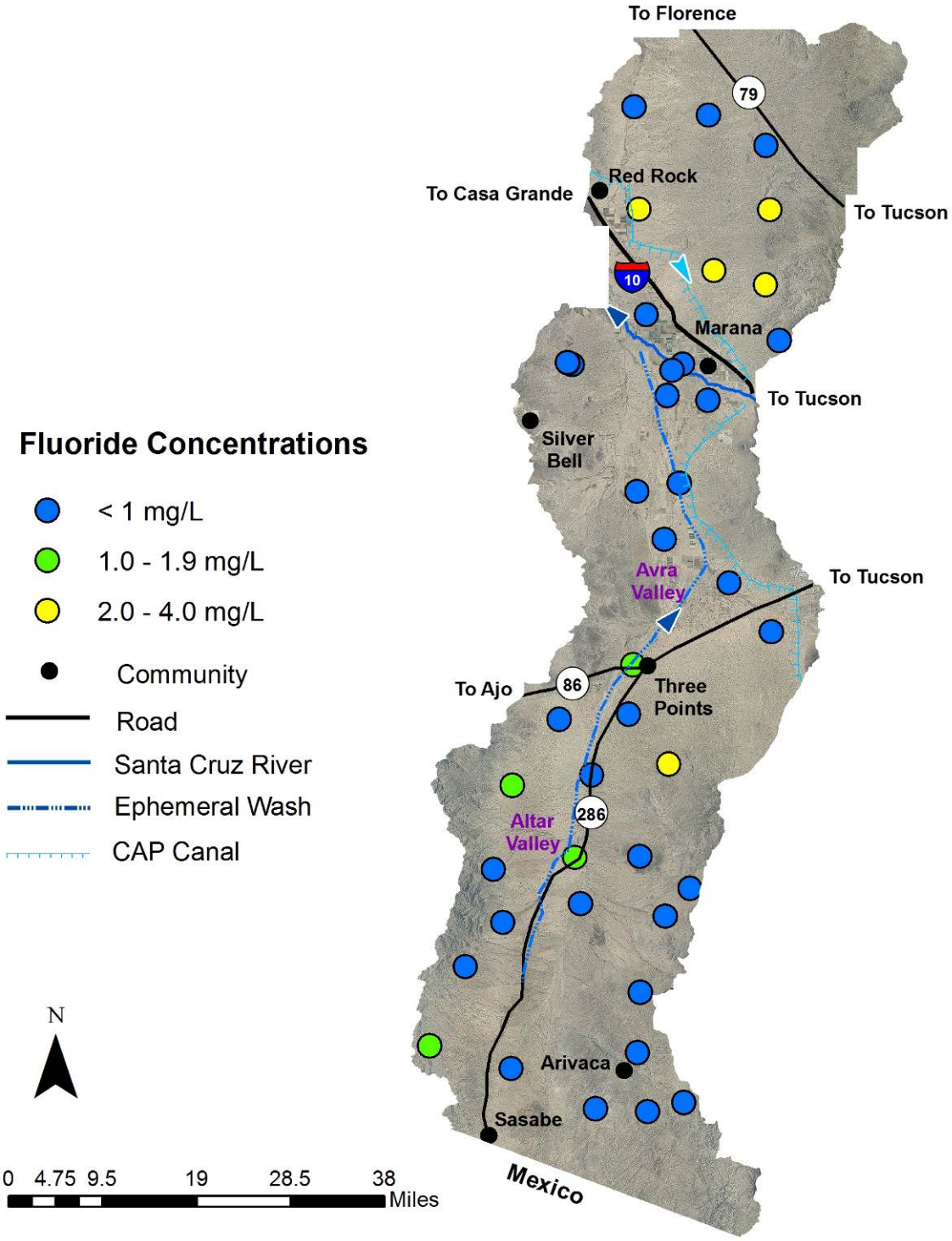


Table 10. Variation in Groundwater Quality Constituent Concentrations between Two Valley Groups

Constituent	Sites Sampled	Significance	Significant Differences Between Two Valley Groups
Temperature - field	42	**	Avra Valley > Altar Valley
pH – field	42	ns	-
pH – lab	42	ns	-
SC - field	42	**	Avra Valley > Altar Valley
SC - lab	42	**	Avra Valley > Altar Valley
TDS	42	**	Avra Valley > Altar Valley
Turbidity	42	ns	-
Hardness	42	ns	-
Calcium	42	ns	-
Magnesium	42	ns	-
Sodium	42	**	Avra Valley > Altar Valley
Potassium	42	*	Avra Valley > Altar Valley
Bicarbonate	42	ns	-
Chloride	42	**	Avra Valley > Altar Valley
Sulfate	42	**	Avra Valley > Altar Valley
Nitrate (as N)	42	**	Avra Valley > Altar Valley
Fluoride	42	*	Avra Valley > Altar Valley
Zinc	42	ns	-
Gross alpha	24	ns	-
Gross beta	24	ns	-
Radon	19	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 11. Summary Statistics for Two Valley Groups with Significant Constituent Differences

Constituent	Significance	Altar Valley	Avra Valley
Temperature – field (ºC)	**	22.3 to 26.1	26.8 to 29.7
pH – field (su)	ns	-	-
pH – lab (su)	ns	-	-
SC – field (µS/cm)	**	361 to 513	551 to 760
SC – lab (µS/cm)	**	364 to 520	557 to 775
TDS	**	234 to 319	345 to 484
Turbidity (ntu)	ns	-	-
Hardness	ns	-	-
Calcium	ns	-	-
Magnesium	ns	-	-
Sodium	**	27 to 42	55 to 80
Potassium	*	1.8 to 2.4	2.3 to 3.5
Bicarbonate	ns	-	-
Chloride	**	9 to 36	34 to 66
Sulfate	**	7 to 28	32 to 93
Nitrate (as N)	**	0.8 to 2.0	2.7 to 5.6
Fluoride	*	0.3 to 0.9	0.5 to 1.3
Zinc	ns	-	-
Gross alpha (pCi/L)	ns	-	-
Gross beta (pCi/L)	ns	-	-
Radon (pCi/L)	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.

Between Two Geologic Groups – Twenty-one (21) groundwater quality constituents were compared between two general geologic types: unconsolidated sediment (29 sites) and consolidated rock (13 sites.).[22]

Significant concentration differences were found with seven constituents: temperature, hardness (Diagram 8), turbidity, magnesium, bicarbonate (Diagram 9), nitrate, and radon (Kruskal-Wallis test, $p \leq 0.05$).

Complete statistical results are in Table 12 and 95 percent confidence intervals for significantly different groups based on recharge groups are in Table 13.

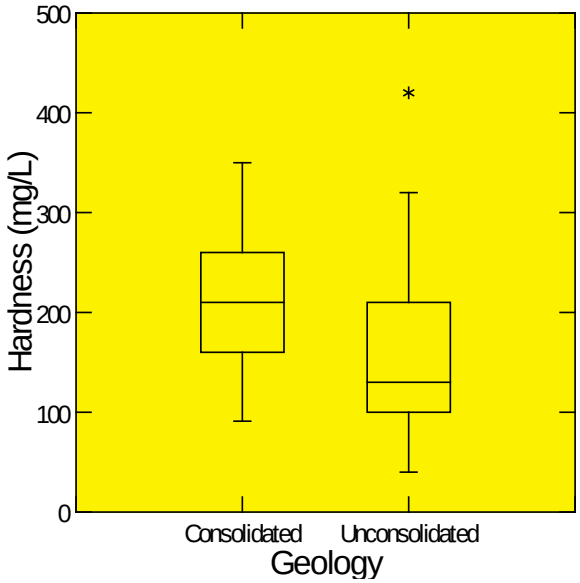


Diagram 8 – Samples collected from sites in consolidated rock have significantly higher hardness concentrations than sample sites collected from unconsolidated sediments (Kruskal-Wallis, $p \leq 0.05$). Samples collected in consolidated rock were generally "hard" while those in unconsolidated sediments were generally "moderately hard." This difference is likely due to calcium-dominated recharge occurring near mountains along with the natural softening that occurs along a groundwater flow path in downgradient areas.[25]

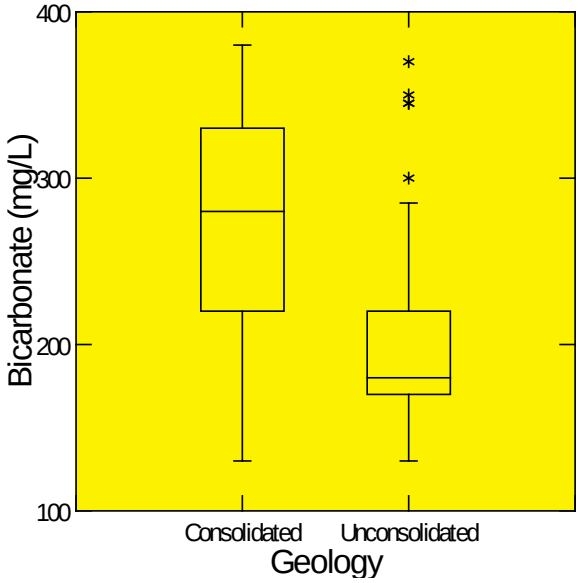


Diagram 9 – Samples collected from sites in consolidated rock have significantly higher bicarbonate concentrations than sample sites collected from unconsolidated sediments (Kruskal-Wallis, $p \leq 0.01$). Elevated bicarbonate in ground water is often associated with recently recharged water. Water infiltrating the sub-surface dissolves carbon dioxide gas (CO_2) in soil, where the partial pressure of CO_2 is much greater than that in the atmosphere. The CO_2 combines with water to form carbonic acid. The acid then dissociates to hydrogen and bicarbonate ions.[14]

Table 12. Variation in Groundwater Quality Constituent Concentrations between Two Geologic Groups

Constituent	Sites Sampled	Significance	Significant Differences between Two Geologic Groups
Temperature - field	42	*	Unconsolidated Sediment > Consolidated Rock
pH – field	42	ns	-
pH – lab	42	ns	-
SC - field	42	ns	-
SC - lab	42	ns	-
TDS	42	ns	-
Turbidity	42	*	Consolidated Rock > Unconsolidated Sediment
Hardness	42	*	Consolidated Rock > Unconsolidated Sediment
Calcium	42	ns	-
Magnesium	42	**	Consolidated Rock > Unconsolidated Sediment
Sodium	42	ns	-
Potassium	42	ns	-
Bicarbonate	42	*	Consolidated Rock > Unconsolidated Sediment
Chloride	42	ns	-
Sulfate	42	ns	-
Nitrate (as N)	42	**	Unconsolidated Sediment > Consolidated Rock
Fluoride	42	ns	-
Zinc	42	ns	-
Gross alpha	24	ns	-
Gross beta	24	ns	-
Radon	19	*	Consolidated Rock > Unconsolidated Sediment

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

Table 13. Summary Statistics for Two Geologic Groups with Significant Constituent Differences

Constituent	Significance	Consolidated Rock	Unconsolidated Sediment
Temperature – field (ºC)	*	21.5 to 26.9	25.9 to 28.7
pH – field (su)	ns	-	-
pH – lab (su)	ns	-	-
SC – field (µS/cm)	ns	-	-
SC – lab (µS/cm)	ns	-	-
TDS	ns	-	-
Turbidity (ntu)	*	-3.9 to 26.1	0 to 2.6
Hardness	*	166 to 263	129 to 202
Calcium	ns	-	-
Magnesium	**	12 to 21	8 to 14
Sodium	ns	-	-
Potassium	ns	-	-
Bicarbonate	*	225 to 325	185 to 237
Chloride	ns	-	-
Sulfate	ns	-	-
Nitrate (as N)	**	0.3 to 2.7	2.3 to 4.6
Fluoride	ns	-	-
Zinc	ns	-	-
Gross alpha (pCi/L)	ns	-	-
Gross beta (pCi/L)	ns	-	-
Radon (pCi/L)	*	-	-

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.

Among Four Valley/Geologic Groups – Twenty-one groundwater quality constituents were compared between four valley-geologic groups: Altar Valley unconsolidated sediment (eight sites), Altar Valley consolidated rock (nine sites), Avra Valley unconsolidated sediment (21 sites), and Avra Valley consolidated rock (four sites).[22]

Significant concentration differences were found with 10 constituents: temperature, SC-field, SC-lab, TDS, turbidity (Diagram 10), sodium, chloride, sulfate, nitrate (Diagram 11), and radon (Kruskal-Wallis with Tukey test, $p \leq 0.05$). Complete statistical results are in Table 14 and 95 percent confidence intervals for significantly different groups based on valley/geology groups are in Table 15.

Between Geologic Fault Groups – Twenty-one groundwater quality constituents were compared between wells located less than 2 kilometers from major fault lines (13 sites) and other wells (26 sites).[22]

A U.S. Geologic Survey report had found significantly higher concentrations on some constituents in close proximity to faults.[13] No significant concentration differences were found among the 21 constituents except for radon which had significantly higher concentrations at the four sites located near major fault lines compared with the other 15 sites (Kruskal-Wallis test, $p \leq 0.05$).

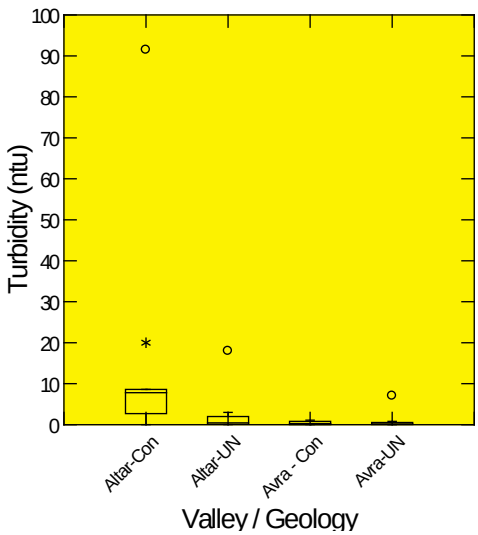


Diagram 10 – Samples collected from sites in consolidated rock in Altar Valley have significantly higher turbidity values than sample sites collected from unconsolidated sediments in Avra Valley (Kruskal-Wallis, $p \leq 0.05$). Turbidity in ground water generally is less than 5 ntu and is more reflective of well production. Although turbidity is not a direct indicator of health risk, it is aesthetically unappealing, and can provide food and shelter for pathogens.[29]

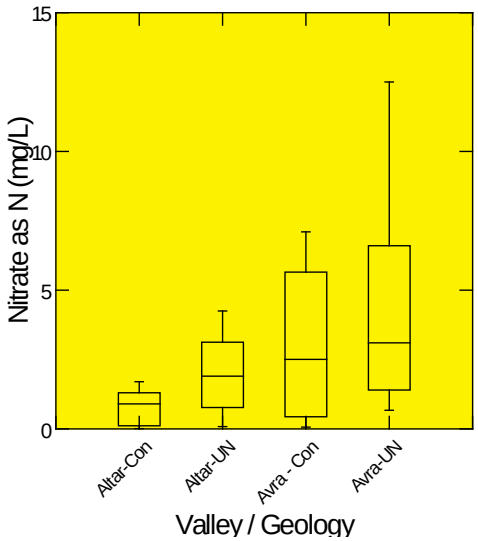


Diagram 11 – Samples collected from sites in unconsolidated sediment in Avra Valley have significantly higher nitrate concentrations than samples collected from sites in consolidated rock in Altar Valley (Kruskal-Wallis, $p \leq 0.05$). There are no significant differences with nitrate concentrations in consolidated rock in Avra Valley or unconsolidated sediments in Altar Valley. The elevated nitrate concentrations in the Avra Valley basin fill are likely linked to irrigation recharge, treated sewage effluent released into the Santa Cruz River, and improperly operating and/or high densities of septic systems.[14]

Table 14. Variation in Groundwater Quality Constituent Concentrations among Four Valley/Geologic Groups

Constituent	Sites Sampled	Significance	Significant Differences between Four Valley/Geologic Groups
Temperature - field	42	*	Avra Valley Unconsolidated > Altar Valley Consolidated Rock *
pH – field	42	ns	-
pH – lab	42	ns	-
SC - field	42	*	Avra Valley Unconsolidated > Altar Valley Consolidated Rock ** Avra Valley Unconsolidated > Altar Valley Unconsolidated Rock *
SC - lab	42	*	Avra Valley Unconsolidated > Altar Valley Consolidated Rock * Avra Valley Unconsolidated > Altar Valley Unconsolidated Rock *
TDS	42	*	Avra Valley Unconsolidated > Altar Valley Consolidated Rock * Avra Valley Unconsolidated > Altar Valley Unconsolidated Rock *
Turbidity	42	**	Altar Valley Consolidated Rock > Avra Valley Unconsolidated Sediment *
Hardness	42	ns	-
Calcium	42	ns	-
Magnesium	42	ns	-
Sodium	42	**	Avra Valley Unconsolidated > Altar Valley Unconsolidated Rock *
Potassium	42	ns	-
Bicarbonate	42	ns	-
Chloride	42	*	-
Sulfate	42	**	-
Nitrate (as N)	42	**	Avra Valley Unconsolidated > Altar Valley Consolidated Rock *
Fluoride	42	ns	-
Zinc	42	ns	-
Gross alpha	24	ns	-
Gross beta	24	ns	-
Radon	19	*	Altar Valley Consolidated Rock > Avra Valley Unconsolidated Sediment ** Altar Valley Consolidated Rock > Altar Valley Unconsolidated Sediment **

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

Table 15. Summary Statistics for Four Valley/Geologic Groups with Significant Constituent Differences

Constituent	Significance	Altar Valley Consolidated Rock	Altar Valley Unconsolidated Sediment	Avra Valley Consolidated Rock	Avra Valley Unconsolidated Sediment
Temperature – field (ºC)	*	19.4 to 26.8	-	-	26.6 to 29.6
pH – field (su)	ns	-	-	-	-
pH – lab (su)	ns	-	-	-	-
SC – field (µS/cm)	*	341 to 667	335 to 392	-	489 to 713
SC – lab (µS/cm)	*	345 to 683	349 to 393	-	493 to 732
TDS	*	218 to 397	214 to 264	-	310 to 462
Turbidity (ntu)	**	-6.4 to 38.1	-	-	0 to 1.3
Hardness	ns	-	-	-	-
Calcium	ns	-	-	-	-
Magnesium	ns	-	-	-	-
Sodium	**	-	25 to 41	-	50 to 75
Potassium	ns	-	-	-	-
Bicarbonate	ns	-	-	-	-
Chloride	*	-	-	-	-
Sulfate	**	-	-	-	-
Nitrate (as N)	**	0.3 to 1.3	-	-	2.6 to 5.5
Fluoride	ns	-	-	-	-
Zinc	ns	-	-	-	-
Gross alpha (pCi/L)	ns	-	-	-	-
Gross beta (pCi/L)	ns	-	-	-	-
Radon (pCi/L)	*	-462,586 to 550124	-	-	177 to 1287

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.

DISCUSSION

ADEQ sampled 42 wells to characterize water quality in the Avra Valley sub-basin of the Tucson AMA. Constituents above health-based, water quality standards in the ADEQ study include arsenic (two sites), gross alpha (five sites), uranium (two sites), and one site each for nitrate and radium-226+228. Arsenic, gross alpha, and nitrate are three of the four constituents that most commonly exceed health-based water quality standards in Arizona. [28]

Based on results from the ADEQ study, groundwater in the Avra Valley sub-basin is generally suitable for drinking water uses. This is a conclusion also reached by previous groundwater quality studies.[22] The ADEQ study, however, sampled for constituents that had not previously been collected during baseline studies, allowing for the identification of new water quality issues in the sub-basin.

Particularly noteworthy is that the most common health-based exceedance was for radionuclides, despite these samples being collected at only 24 of 42 sample sites. Besides Primary MCL exceedances for gross alpha, uranium, and radium-226+228, the ADEQ study also collected the highest radon concentration, 83,620 pCi/L ever recorded by the agency's ambient groundwater monitoring program.

Radionuclides - The wells which had radionuclide concentrations exceeding water quality standards were located in both Avra and Altar valleys. Two of the exceedances were located in granitic geology, which is often associated with elevated radionuclide concentrations in groundwater.[20] The other wells having radionuclide exceedances were located in a variety of geologic substrates. The only commonality is that all the wells were located on the east side of their respective valleys (Map 11).

In other ambient groundwater studies in Arizona, wells with radionuclide exceedances were sometimes located in proximity to active or inactive mines. Mines are often correlated with elevated radionuclide concentrations because of increased rock surface exposure. [20] None of the five wells in the Avra Valley sub-basin were located near mines. Future groundwater quality studies in the sub-basin should better characterize gross alpha concentrations by collecting additional radionuclide samples since this was the most common Primary MCL exceedance.

Arsenic - Arsenic was exceeded in two wells, one located by Marana (AVB-6) and the other in the Sierrita Mountains in Altar Valley (AVB-39). Both wells also exceeded standards for gross alpha. The AVB-6 sample was collected from a 265-feet-deep windmill that also exceeded aesthetics-based standards for fluoride. These two constituents are frequently significantly correlated in other Arizona groundwater basins.[28] The AVB-6 sample also had the highest pH-field value of 8.19 su, and the softest water (40 mg/L) recorded in the study. High arsenic and fluoride concentrations are often significantly correlated to high pH values and low hardness concentrations. [27]

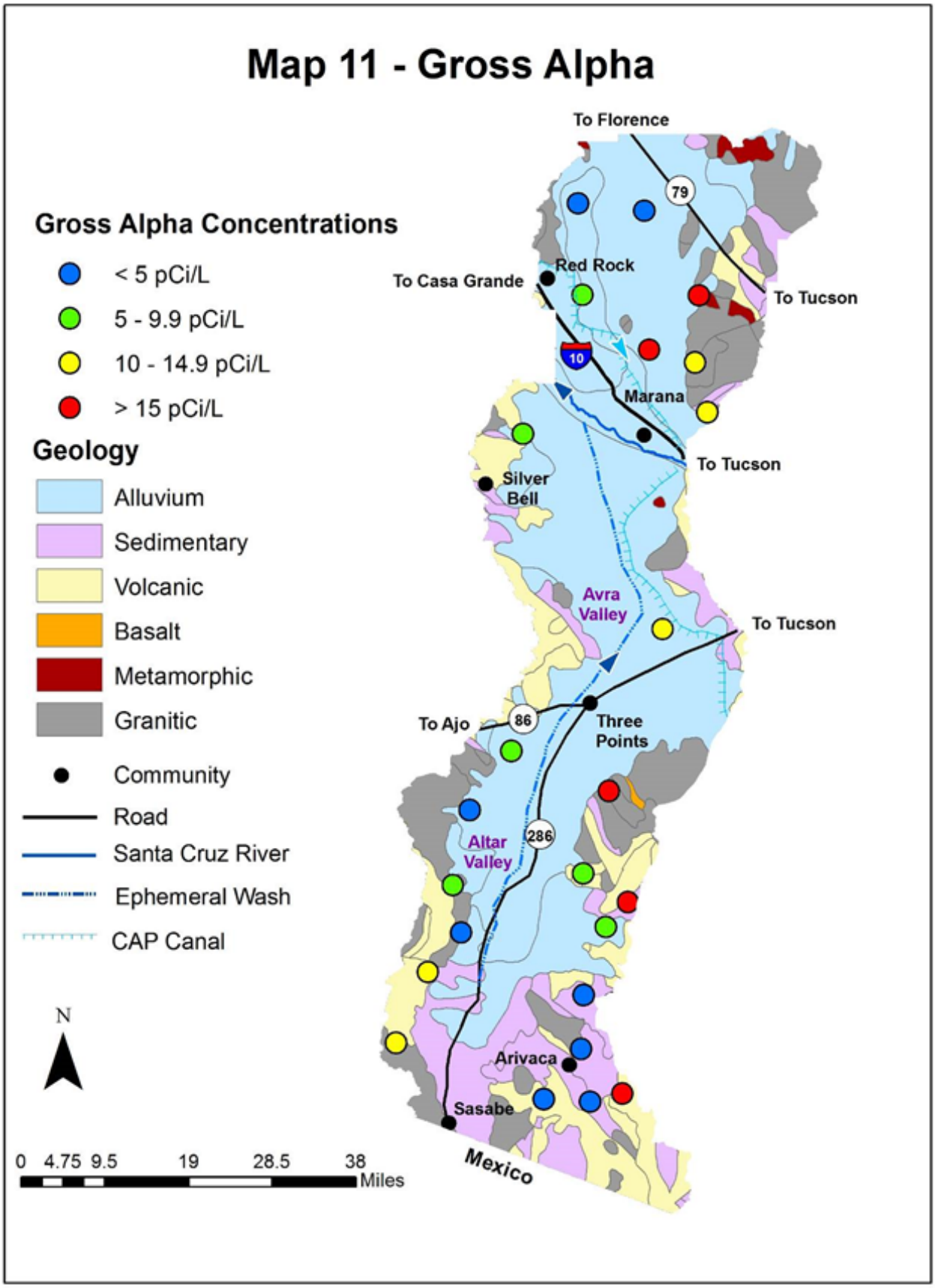
Arsenic concentrations are effected by reactions with hydroxyl ions. Elevated arsenic concentrations are also influenced by factors such as aquifer residence time, an oxidizing environment, and lithology. [25]

Fluoride - The Avra Valley sub-basin is unusual in that unlike other groundwater basins in southeast Arizona, fluoride concentrations are generally low. Although five wells exceeded aesthetics-based standards, the highest concentration was only 2.8 mg/L, well below the 4.0 mg/L health-based standard. The highest fluoride concentrations in the ADEQ study were found northeast of Interstate 10. This area, as well as northwest of Three Points, was previously noted as having the sub-basin's highest fluoride concentrations.[14] Elevated fluoride concentrations appear to be rare in the sub-basin. In a previous study of 120 wells, fluoride concentrations ranged from 0.2 to 8.7 mg/L, with only five samples exceeding 1.6 mg/L. [22]

Fluoride concentrations in groundwater are often controlled by calcium through precipitation or dissolution of the mineral, fluorite.[25]The five sites with elevated fluoride concentrations in the ADEQ study however, are not depleted in calcium and appear to be controlled by hydroxyl ion exchange or sorption-desorption reactions. These often provide controls on lower (< 5 mg/L) levels of fluoride. As pH values increase downgradient, greater levels of hydroxyl ions may affect an exchange of hydroxyl for fluoride ions thereby increasing fluoride in solution. [25]

Nitrate - Nitrate exceeded health-based, water quality standards in just one sample and only 17 percent of wells exceeded 5 mg/L or one-half the 10 mg/L health-based, water quality standard. Despite the generally low nitrate concentrations, there are two areas of concern with the sub-basin.

The five wells sampled in the Marana area all had elevated concentrations of nitrate, including sample


Map 11 - Gross Alpha
Gross Alpha Concentrations
< 5 pCi/L
5 - 9.9 pCi/L
10 - 14.9 pCi/L
> 15 pCi/L
Geology
Alluvium
Sedimentary
Volcanic
Basalt
Metamorphic
Granitic
Community
Road
Santa Cruz River
Ephemeral Wash
CAP Canal
N
0 4.75 9.5 19 28.5 38
Miles
To Florence
79
Red Rock
To Casa Grande
To Tucson
10
Marana
To Tucson
Silver Bell
Avra Valley
To Tucson
To Ajo
86
Three Points
286
Altar Valley
Arivaca
Sasabe
Mexico

AVB-9 at 12.5 mg/L. The recharge of salt and nitrate-laden irrigation water through the unsaturated vadose zone likely contributes to groundwater nitrate concentrations. Irrigation water that directly recharges groundwater through vertical leakage along well casings is also a potential pathway for nitrate contamination.[14] Treated sewage effluent released into the Santa Cruz River by wastewater treatment plants since 1969 may also contribute to elevated concentrations of nitrate in ground water near Marana. [14] Prior to this, sewage effluent was used near Marana for irrigation. [36]

Since irrigated agriculture in the Avra Valley sub-basin is largely confined to the Marana area, other wells sampled as part of the ADEQ study with slightly elevated nitrate concentrations likely have different sources. Nitrate can impact groundwater from leaking residential septic systems, especially where there is a high density of houses. [14] This source might explain the slightly elevated nitrate concentration (6.6 mg/L) in the sample collected from a well located in the community of Three Points. More research, however, is needed to better understand the relative contributions of nitrate from both anthropomorphic and natural sources. [21, 35]

TDS – TDS concentrations in the sub-basin were also generally low with only 17 percent of wells exceeding the Secondary MCL of 500 mg/L. The highest concentrations were two wells at 720 mg/L. In a previous study consisting of 120 well samples, only 21 exceeded 500 mg/L., with 1,200 mg/L the highest concentration. [22]

Many of the Secondary MCL exceedances occurred near Marana and are likely the result of salt-laden irrigation recharge. Evaporate deposits in this area may also impact TDS concentrations.[36] TDS also generally increases from south to north in the sub-basin, corresponding to the direction of groundwater flow. Increases in TDS along flow paths are often observed in ground water. [25]

REFERENCES

[1] Andrews, D.A., Ground water in Avra-Altar Valley, Arizona, 1937: U.S. Geological Supply Paper 796-E, 18 p.

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

[3] Arizona Department of Environmental Quality, 2011-2012, Arizona Laws Relating to Environmental Quality: St. Paul, Minnesota, West Group Publishing, §49-221-224, p 134-137.

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

[5] Arizona Department of Water Resources, 1994, Arizona Water Resources Assessment – Volume II, Hydrologic Summary, Hydrology Division, pp. 174-187.

[6] Arizona Department of Water Resources Water Atlas website, 2014, http://www.azwater.gov/azdwr/StatewidePlanning/WaterAtlas/ActiveManagementAreas/PlanningAreaOverview/Groundwater-TucsonAMA.htm, accessed 6/26/14.

[7] Arizona Department of Water Resources Water Atlas website, 2014, http://www.azwater.gov/AzDWR/GeneralServices/Imaging/ accessed 6/26/14.

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

[9] Bloomquest, William, Schlager, Edella, and Heikkila, Tanya, 2004, *Common Waters, Diverging Streams: Linking Institutions and Water Management in Arizona, California, and Colorado*: Washington D.C, Resources for the Future, 210 p.

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

[11] Central Arizona Project website, http://www.cap-az.com/index.php/departments/recharge-program, accessed 7/3/14.

[12] City of Tucson website, http://www.tucsonaz.gov/water/recharged_water, accessed 7/3/14.

[13] Coes, A.L., Gellenbeck, D.J., Towne, D.C., and Freark, M.C., 1998, Ground-Water quality in the Upper Santa Cruz basin, Arizona, 1998: U.S. Geological Survey Water Resources Investigations Report 00-4117, 55 p.

[14] Conner, L.L., 1986, Geochemistry of ground water in Avra Valley, Pima County, Arizona: Master's thesis, University of Arizona, 81 p.

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

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

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

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

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

[20] Lowry, J.D. and Lowry, S.B., 1988, "Radionuclides in Drinking Waters," in *American Water Works Association Journal*, 80 (July), pp. 50-64.

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

[22] Reeter, R.W. and Cady, C.V., 1982, Maps showing ground-water conditions in the Avra/Altar Valley area, Pima and Santa Cruz counties, Arizona—1981; Arizona Department of Water Resources Hydrologic Map Series Report Number 7, 2 sheets, scale, 1:250,000.

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

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

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

[26] Test America, 2013, Personal communication from Test America staff.

[27] Towne, Douglas and Freark, Maureen, 2000, Ambient groundwater quality of the Prescott Active Management Area: A 1997-1998 baseline study: Arizona Department of Environmental Quality Open File Report 00-01, 77 p.

[28] Towne, Douglas and Jones, Jason, 2011, Groundwater quality in Arizona: a 15 year overview of the ADEQ ambient groundwater monitoring program (1995-2009): Arizona Department of Environmental Quality Open File Report 11-04, 44 p.

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

[30] U.S. Environmental Protection Agency website, http://water.epa.gov/lawsregs/rulesregs/sdwa/radon/regulations.cfm, accessed 6/18/14.

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

[32] White, N.D., Matlock, W.G., and Schwalen, H.C., An appraisal of the ground-water resources of Avra and Altar valleys, 1966: Arizona State Land Department Water Resources Report #25, 64 p.

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

[34] Bitton, G. and Gerba, C.P., 1994, *Groundwater Pollution Microbiology*: Malabar, FL: Krieger Publishing Company, 377 p.

[35] Thiros, S.A., Bexfield, L.M., Anning, D.W., and Huntington, J.M., eds., 2010, Conceptual understanding and groundwater quality of selected basin-fill aquifers in the Southwestern United States: U.S. Geological Professional Paper 1781, 288 p.

[36] Gellenbeck, D.J. and Coes, Alissa L., 1999, Ground-Water quality in alluvial basins that have minimal urban development, South-Central Arizona: U.S. Geological Survey Water Resources Investigations Report 99-4005, 27 p.

Appendix A. Data for Sample Sites, Avra Valley Sub-Basin, 1998-2001

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Valley / Geology
1st Field Trip, May 10-11, 2000 – Flora &Yu (VOC Travel Blank)									
AVB-1/1D duplicate	D(7-10)33cc submersible	32°45'52.407" 111°19'32.751"	636121	58799	Walker North Well	Inorganic, VOC, Radon, Radionuclide	120'	70'	Avra Unconsolidated
AVB-2	D(9-10)16dbb submersible	32°38'19" 111°19'08.6"	615625	33855	Walker South Well	Inorganic, Radon Radionuclide	303'	238'	Avra Unconsolidated
AVB-3	D(8-12)20cca submersible	33°43'01.890" 111°07'57.938"	804176	58798	Goff Well	Inorganic	500'	228'	Avra Consolidated
2nd Field Trip, May 25, 2000 – Flora & Yu									
AVB-4	D(09-12)20acb windmill	32°38'15.564" 111°07'36.430"	615644	33894	ASLD Windmill	Inorganic, VOC Radionuclide	265'	180'	Avra Consolidated
AVB-5	D(8-11)09aaa submersible	32°45'15.769" 111°13'01.933"	623946	58761	Martin Well	Inorganic, VOC Radionuclide	1800'	427'	Avra Unconsolidated
3rd Field Trip, June 20-21, 2000 – Flora & Yu (VOC Travel Blank)									
AVB-6	D(10-11)15cbc submersible	32°26'48.916" 111°15'13.694"	634826	58821	Bringhurst Well	Inorganic, VOC, Radon, Radionuclide	740'	580'	Avra Unconsolidated
AVB-7/54	D(11-09)27bda submersible	32°26'48.473" 111°24'57.877"	634241	34495	Lucer Well	Inorganic, VOC Radon Radionuclide	150'	39'	Avra Unconsolidated
AVB-8	D(12-10)01dcc turbine	32°20'06.715" 110°20'18.409"	618390	35039	Kai Farm Well #1	Inorganic, Radon	650'	290'	Avra Unconsolidated
AVB-9/9D duplicate	D(11-11)30 submersible	32°33'45.174" 111°12'29.497"	800462	58825	Heatley Well	Inorganic, Radon Radionuclide, VOCs	400'	230'	Avra Unconsolidated
4th Field Trip, July 18, 2000 – Flora & Yu									
AVB-10	D(13-10)21aad windmill	32°17'23.749" 111°19'15.624"	629192	58800	Earley Well	Inorganic	700'	292'	Avra Unconsolidated
5th Field Trip, August 9-10, 2000 – Flora & Yu (VOC Travel Blank)									
AVB-11	D(14-11)26ddd submersible	32°10'36.38" 111°11'12.417"	634956	37358	Robillard Well	Inorganic, VOCs Radionuclide	480'	356'	Avra Unconsolidated
AVB-12	D(15-10)33dbc turbine	32°04'32.468" 111°19'37.947"	603527	38415	Buckelew FarmWell	Inorganic, VOCs	617'	170'	Avra Unconsolidated
AVB-13	D(18-9)27bda submersible	31°50'09.202" 111°24'44.834"	616202	40887	ASLD Well	Inorganic	-	287'	Altar Unconsolidated
AVB-14/14D duplicate	D(16-9)28b submersible	32°00'28.402" 111°26'05.781"	633673	58823	Schach Well	Inorganic, Radon Radionuclide	400'	295'	Altar Unconsolidated
AVB-15 Radon dup	D(17-10)13bdd submersible	31°57'09.205" 111°16'27.786"	-	58824	Greene Well	Inorganic, Radon, Radionuclide	300'	30'	Altar Consolidated
6th Field Trip, September 7, 2000 – Flora & Yu									
AVB-16	D(15-12)21b submersible	32°06'58.905" 111°07'30.464"	-	58871	Camacho Well	Inorganic	-	-	Avra Unconsolidated

Appendix A. Data for Sample Sites, Avra Valley Sub-Basin, 1998-2001--Continued

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Sub-basin / Aquifer
7th Field Trip, February 26-28, 2001 – Boettcher & Lucci (Equipment Blank AVB-23 & VOC Travel Blank)									
AVB-17	D(21-10)21aab submersible	31°35'35.578" 111°19'12.256"	529932	59092	Reichelt Well	Inorganic, Radionuclide, VOCs	335'	171'	Altar Consolidated
AVB-18/19 split	D(22-11)03bdb windmill	31°32'42.400" 111°12'28.312"	517078	59093	Apache Windmill	Inorganic, Radionuclide, VOCs	150'	40'	Altar Unconsolidated
AVB-20/21 duplicate	D(22-10)10ba windmill	31°31'09.859" 111°18'20.970"	642691	59094	Yellow Jacket	Inorganic, Radionuclide	120'	20'	Altar Consolidated
AVB-22	D(22-9)11dda windmill	31°31'23.725" 111°22'54.976"	641652	59095	Up Mill Well	Inorganic, Radionuclide, VOCs	50'	30'	Altar Consolidated
8th Field Trip, April18-19, 2001 – Boettcher & Lucci (Equipment Blank AVB-25& VOC Travel Blank)									
AVB-24	D(20-10)25da windmill	31°39'27.501" 111°16'01.186"	804186	59196	Mailbox Well	Inorganic Radionuclide,	150'	10'	Altar Consolidated
AVB-26/27 duplicate	D(19-8)22cdb windmill	31°45'19.474" 111°31'01.573"	616240	59197	Lane Well	Inorganic, VOCs Radionuclide	-	16'	Altar Consolidated
AVB-28/29 split	D(14-10)12ba submersible	32°13'58" 111°16'53"	632949	59198	Bobwhite Well	Inorganic, Radon	-	-	Avra Unconsolidated
9th Field Trip, June 9-10, 2001 – Harmon & Lucci (Equipment Blank AVB-35& VOC Travel Blank)									
AVB-30/30a/31 duplicate partial duplicates	D(16-10)28bbc submersible	32°00'50.464" 111°19'58.398"	616059	59232	Santa TeresaWell	Inorganic, Radon	500'	-	Altar Unconsolidated
AVB-32/33 split	D(17-09)23aac submersible	31°56'18.606" 111°23'14.808"	616135	59233	Williams Well	Inorganic, Radon	500'	238'	Altar Unconsolidated
AVB-34	D(17-08)23dcb submersible	31°55'31.974" 111°30'13.254"	616129	59234	Milagro Well	Inorganic, VOCs Radionuclide	776'	710'	Altar Unconsolidated
AVB-36	D(21-07)16add submersible	31°36'05.412" 111°37'27.206"	616351	59235	Agua del OroWell	Inorganic Radionuclide	305'	133'	Altar Consolidated
AVB-37	D(20-08)07cbc windmill	31°42'00.041" 111°34'20.286"	616288	59236	Upper Mormon	Inorganic, VOCs Radionuclide	301'	45'	Altar Consolidated
AVB-38	D(18-11)33ada windmill	31°49'18.852" 111°13'00.526"	804631	59237	Champ-urradoWell	Inorganic, VOCs Radionuclide	-	-	Altar Unconsolidated
AVB-39	D(19-11)8 windmill	31°45'45.734" 111°16'48.708"	616244	59323	Ridge Well	Inorganic, VOCs Radionuclide	-	-	Altar Unconsolidated
10th Field Trip, May 22-23, 2001 - Harmon & Lucci (Equipment Blank AVB-45& VOC Travel Blank)									
AVB-40/40a/41 partial duplicate split	D(10-10)34caa submersible	32°30'28.799" 111°18'25.588"	533158	56296	Evergreen Air Well	Inorganic, VOCs, Radon	-	-	Avra Unconsolidated
AVB-42/43 duplicate	D(13-11)18acc submersible	32°17'59.715" 111°15'35.108"	532647	59242	Mattison Well	Inorganic, Radon	505'	365'	Avra Unconsolidated
AVB-46	D(18-8)33acc submersible	31°49'15.777" 111°31'51.823"	639713	59245	Elkhorn Well	Inorganic, Radionuclide	200'	95'	Altar Consolidated
AVB-47	D(21-08)27 submersible	31°34'24.425" 111°30'18.917"	604205	59246	BA Well #8	Inorganic, VOCs, Radon	400'	316'	Altar Unconsolidated
AVB-48	D(19-9)15ada submersible	31°46'41.451" 111°24'14.278"	607355	41587	BA Well #2	Inorganic, Radon	570'	326'	Altar Unconsolidated
AVB-49	D(11-12)26bdc submersible	32°26'47.328" 111°05'26.189"	526187	59247	Moseman Well	Inorganic, Radon Radionuclide	641'	350'	Avra Unconsolidated

Appendix A. Data for Sample Sites, Avra Valley Sub-Basin, 1998-2001--Continued

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Sub-basin / Aquifer
AVB-50	D(18-10)28ada submersible	31°50'15.433" 111°19'02.364"	804711	59265	Cinco de Mayo Well	Inorganic, Radon Radionuclide	-	-	Altar / Consolidated
11th Field Trip, May 30, 2001 - Harmon & Lucci (Equipment Blank AVB-45& VOC Travel Blank)									
AVB-51/51a partial duplicate	D(12-11)9bba submersible	32°24'09.971" 111°13'01.241"	531335	59243	Avra Vly Airpark Wl	Inorganic, Radon VOCs	450'	325'	Avra / Unconsolidated
AVB-52	D(11-10)25dda submersible	32°26'18.556" 111°16'11.500"	615764	34543	Kai Farm Well #2	Inorganic, Radon	-	-	Avra / Unconsolidated
AVB-53	D(10-12)20cbc submersible	32°32'42.524" 111°07'58.743"	515847	59244	Charnis Well	Inorganic, Radionuclides, VOCs	315'	35'	Avra / Consolidated
12th Field Trip, December 12, 1998 - Towne & Freark									
AVB-55	D(11-9)27bbc submersible	32°26'55.292" 111°25'22.160"	636944	34494	Reeves Well	Inorganic, VOCs	325'	40'	Avra / Unconsolidated
AVB-56	D(11-9)27bbb submersible	32°26'56.565" 111°25'24.967"	636945	57594	Davis #3 Well	Inorganic, VOCs	88'	80'	Avra / Unconsolidated

Appendix B. Groundwater Quality Data, Avra Valley Sub-Basin, 1998-2001

Site #	MCL Exceedances	Temp (ºC)	pH-field (su)	pH-lab (su)	SC-field (µS/cm)	SC-lab (µS/cm)	TDS (mg/L)	Hard (mg/L)	Hard - cal (mg/L)	Turb (ntu)
AVB-1/1D	-	30.1	7.88	*7.65*	856	810	445	100	98	0.72
AVB-2	F	28.0	8.00	7.3	485	440	270	73	71	0.35
AVB-3	TDS	28.9	7.35	*7.3*	890	800	**510**	340	320	1.1
AVB-4	TDS, F, Gross α	29.3	7.93	*8.2*	836	870	**500**	180	170	0.50
AVB-5	-	31.1	7.73	7.8	468	480	270	150	130	0.53
AVB-6	F, As, Gross α	33.4	8.19	*8.4*	417	430	280	40	42	0.26
AVB-7/54	-	23.6	7.125	***7.25***	589	620	380	315	310	0.045
AVB-8	-	29.7	7.62	7.5	405	430	280	130	130	0.01
AVB-9	TDS, NO_3	23.5	7.09	*7.3*	1024	1100	**720**	420	410	0.17
AVB-10	-	30.6	7.73	*8.2*	338	340	230	97	95	0.05
AVB-11	-	31.3	7.86	*7.6*	321	330	220	90	88	0.80
AVB-12	-	27.7	7.78	*7.4*	531	560	360	120	120	0.81
AVB-13	-	26.0	7.71	*7.6*	347	370	240	110	110	0.58
AVB-14/14D	-	28.9	7.75	*7.55*	360	380	240	110	110	0.29
AVB-15	TDS, F, Mn, Gross α, Ra,U	29.0	7.30	*7.3*	961	1000	**560**	350	330	0.76
AVB-16	TDS, SO_4	32.7	7.52	*7.7*	1001	1100	**720**	300	290	0.35
AVB-17	-	22.6	7.85	*7.8*	382	400	250	160	160	ND
AVB-18/19	Gross α, U	16.6	7.95	7.75	307	330	180	150	140	18
AVB-20/21	Fe, Mn	17.7	7.16	*7.0*	529	560	335	245	230	91.5
AVB-22	-	17.9	7.09	*7.0*	256	270	180	91	89	8.4
AVB-24	-	20.3	7.92	*8.2*	580	580	340	200	190	7.8
AVB-26/27	-	20.3	7.12	*7.7*	302	305	190	120	120	3.1
AVB-28/29	-	30.6	7.69	*7.84*	435	455	260	110	110	7.05
AVB-30/30a/31	-	25.8	7.57	*8.1*	357	360	235	130	130	0.02
AVB-32/33	-	26.1	7.54	*8.05*	385	385	235	120	120	0.03
AVB-34	-	27.2	7.23	*8.2*	345	340	230	92	92	3.0
AVB-36	-	21.5	7.56	*7.9*	381	380	230	130	130	2.7
AVB-37	-	28.0	8.0	*7.84*	614	610	360	230	220	20

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

Appendix B. Groundwater Quality Data, Avra Valley Sub-Basin, 1998-2001--continued

Site #	MCL Exceedances	Temp (ºC)	pH-field (su)	pH-lab (su)	SC-field (µS/cm)	SC-lab (µS/cm)	TDS (mg/L)	Hard (mg/L)	Hard - cal (mg/L)	Turb (ntu)
AVB-38	-	23.6	7.13	*8.2*	409	410	270	140	140	0.98
AVB-39	As, Gross α	27.5	7.48	8.1	403	390	280	130	130	0.15
AVB-40/41	-	32.0	7.57	*7.89*	644	660	410	210	210	0.17
AVB-42/43	-	29.3	7.84	*8.1*	330	320	215	86.5	88	ND
AVB-46	-	24.3	7.10	8.1	621	600	410	260	260	0.03
AVB-47	-	25.7	7.96	8.3	338	330	220	82	84	ND
AVB-48	-	25.2	7.88	*8.2*	334	320	220	120	120	0.28
AVB-49	-	28.6	7.65	8.2	727	700	440	200	200	0.79
AVB-50	-	30.4	7.32	*7.8*	532	520	320	210	200	8.6
AVB-51	TDS	24.0	7.43	*8.2*	1010	1000	**660**	320	320	0.12
AVB-52	TDS	22.8	7.19	*8.1*	914	960	**590**	300	320	0.04
AVB-53	F	24.3	7.33	*8.2*	743	760	440	270	280	0.03
AVB-55	-	25.6	7.26	*7.2*	717	760	480	280	-	0.05
AVB-56	-	24.4	7.10	*7.2*	716	720	440	280	-	0.01

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

Appendix B. Groundwater Quality Data, Avra Valley Sub-Basin, 1998-2001--continued

Site #	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	T. Alk (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
AVB-1/1D	29	6.2	120	4.2	110	130	ND	160	23
AVB-2	22	3.9	69	4.1	140	170	ND	31	29
AVB-3	92	21	49	5.9	300	370	ND	38	49
AVB-4	45	14	130	1.9	210	260	ND	93	100
AVB-5	39	8.6	48	2.9	140	170	ND	43	36
AVB-6	12	2.8	84	1.9	160	195	ND	21	25
AVB-7/54	83	25	17	2.1	285	345	ND	15	10.5
AVB-8	41	6.4	41	2.7	140	170	ND	25	16
AVB-9	130	21	82.5	3.6	282.5	345	ND	74	130
AVB-10	31	5.3	41	1.9	150	180	ND	13	18
AVB-11	29	4.0	41	3.1	150	180	ND	9.0	12
AVB-12	39	5.6	72	2.4	120	150	ND	53	52
AVB-13	35	6.1	39	2.6	160	200	ND	12	14
AVB-14/14D	33	6.5	37.5	2.5	130	160	ND	29.5	ND
AVB-15	83	31	79	3.2	230	280	ND	140	88
AVB-16	82	20	110	7.2	120	150	ND	95	**290**
AVB-17	44	13	20	2.2	180	220	ND	13	5.4
AVB-18/19	39	11	11.5	2.35	143	178	ND	8.8	14
AVB-20/21	84	9.8	24.5	1.3	250	300	ND	25	14
AVB-22	28	4.5	20	1.9	110	130	ND	11	7.9
AVB-24	40	21	57	0.64	310	380	ND	11	5.2
AVB-26/27	33.5	8.4	15.5	1.05	110	130	ND	5.45	35.5
AVB-28/29	33	5.95	49.5	2.3	110	130	ND	29.5	41.5
AVB-30/30a/31	35	11	25	2.45	165	205	ND	13	11
AVB-32/33	37.5	6.0	36	2.45	150	180	ND	13	15.5
AVB-34	25	7.2	38	1.8	140	170	ND	22	8.4
AVB-36	37	9.9	31	2.0	170	210	ND	21	3.9
AVB-37	57	20	47	2.6	290	350	ND	40	4.0

bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Avra Valley Sub-Basin, 1998-2001--continued

Site #	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	T. Alk (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
AVB-38	43	7.8	36	2.8	180	220	ND	14	12
AVB-39	39	8.1	38	2.0	190	230	ND	15	13
AVB-40/41	68	9.8	51.5	2.6	155	200	ND	36.5	80.5
AVB-42/43	28	4.3	36	2.3	140	170	ND	10	6.8
AVB-46	76	18	30	1.1	230	280	ND	21	75
AVB-47	27	4.1	42	2.0	160	195	ND	9.9	3.0
AVB-48	39	5.8	20	2.4	140	170	ND	12	4.1
AVB-49	56	15	76	1.6	250	300	ND	54	52
AVB-50	35	28	40	1.8	270	330	ND	7.1	13
AVB-51	100	17	93	2.9	180	220	ND	81	200
AVB-52	100	16	81	2.7	234	285	ND	78	94
AVB-53	80	19	56	2.8	270	330	ND	52	30
AVB-55	60	31	70	1.4	290	350	ND	45	37
AVB-56	68	29	62	1.4	300	370	ND	38	35

bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Avra Valley Sub-Basin, 1998-2001--continued

Site #	T. Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	T. Phosphorus (mg/L)	SAR (value)	Irrigation Quality	Aluminum (mg/L)
AVB-1/1D	2.7	ND	0.0625	ND	0.028/nd	5.3	C3-S1	ND
AVB-2	1.4	ND	ND	ND	ND	3.6	C2-S1	ND
AVB-3	7.1	ND	0.11	ND	0.043	1.2	C3-S1	ND
AVB-4	0.81	-	-	-	-	4.3	C3-S1	-
AVB-5	3.8	-	-	-	-	1.8	C2-S1	-
AVB-6	1.8	-	-	-	-	5.7	C2-S1	-
AVB-7/54	7.05	-	-	-	-	0.4	C2-S1	-
AVB-8	6.8	-	-	-	-	1.6	C2-S1	-
AVB-9	**12.5**	-	-	-	-	1.8	C3-S1	-
AVB-10	1.1	-	-	-	-	1.8	C2-S1	-
AVB-11	1.6	-	0.072	ND	ND	1.9	C2-S1	-
AVB-12	6.6	-	0.22	ND	ND	2.9	C2-S1	-
AVB-13	1.3	-	0.096	ND	ND	1.6	C2-S1	-
AVB-14/14D	4.25	-	.087	ND	ND	1.5	C2-S1	-
AVB-15	ND	-	0.20	0.031	ND	1.9	C2-S1	-
AVB-16	0.67	-	-	-	-	2.8	C3-S1	-
AVB-17	1.5	ND	ND	ND	0.37	0.7	C2-S1	ND
AVB-18/19	0.082	ND	ND	ND	ND	0.4	C2-S1	ND
AVB-20/21	1.7	ND	0.070	ND	0.065	0.7	C2-S1	ND
AVB-22	0.90	ND	0.29	ND	0.034	0.9	C2-S1	ND
AVB-24	0.11	ND	ND	ND	ND	1.8	C2-S1	ND
AVB-26/27	0.10	ND	0.16	ND	ND	0.6	C2-S1	ND
AVB-28/29	1.25	ND	ND	ND	ND	1.9	C2-S1	ND
AVB-30/30a/31	1.7	ND	ND	ND	ND	0.9	C2-S1	ND
AVB-32/33	4.05	ND	ND	ND	ND	1.4	C2-S1	ND
AVB-34	2.1	ND	0.57	ND	ND	1.7	C2-S1	ND
AVB-36	0.49	ND	ND	ND	ND	1.2	C2-S1	ND
AVB-37	1.3	ND	0.073	ND	ND	1.4	C2-S1	ND

bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Avra Valley Sub-Basin, 1998-2001--continued

Site #	T. Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	T. Phosphorus (mg/L)	SAR (value)	Irrigation Quality	Aluminum (mg/L)
AVB-38	2.2	ND	ND	ND	0.041	1.3	C2-S1	ND
AVB-39	0.24	ND	0.098	ND	0.025	1.4	C2-S1	ND
AVB-40/41	7.4	ND	ND	ND	ND	1.4	C2-S1	ND
AVB-42/43	1.8	ND	0.056	ND	ND	1.7	C2-S1	ND
AVB-46	0.63	ND	ND	ND	0.028	0.8	C2-S1	ND
AVB-47	1.4	ND	ND	ND	ND	2.0	C2-S1	ND
AVB-48	3.1	ND	ND	ND	ND	0.8	C2-S1	ND
AVB-49	1.1	ND	ND	ND	ND	2.3	C2-S1	ND
AVB-50	1.0	ND	ND	ND	ND	1.2	C2-S1	ND
AVB-51	4.8	ND	ND	-	-	2.3	C3-S1	ND
AVB-52	9.8	ND	ND	-	-	2.0	C3-S1	ND
AVB-53	4.2	ND	ND	-	-	1.5	C2-S1	ND
AVB-55	4.2	ND	0.14	ND	ND	1.8	C3-S1	ND
AVB-56	3.5	ND	0.072	ND	ND	1.6	C2-S1	ND

bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Avra Valley Sub-Basin, 1998-2001--continued

Site #	Antimony (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Fluoride (mg/L)
AVB -1/1D	ND	ND	0.185	ND	0.19	ND	ND	ND	0.51
AVB-2	ND	ND	0.12	ND	0.17	ND	ND	ND	**2.1**
AVB-3	ND	ND	ND	ND	ND	ND	ND	ND	0.45
AVB-4*	ND	ND	ND	ND	0.34	ND	ND	ND	**2.77**
AVB-5*	ND	ND	0.2	ND	0.14	ND	ND	ND	0.54
AVB-6*	ND	**0.016**	ND	ND	0.15	ND	0.014	ND	**2.2**
AVB-7*/54	ND	ND	0.19	ND	0.11.5	ND	ND	ND	0.24
AVB-8*	ND	ND	ND	ND	ND	ND	ND	ND	0.46
AVB-9*	ND	ND	0.10	ND	0.165	ND	ND	ND	0.335
AVB-10*	ND	ND	ND	ND	ND	ND	ND	ND	0.56
AVB-11*	ND	ND	0.14	ND	ND	ND	ND	ND	0.35
AVB-12*	ND	ND	ND	ND	0.12	ND	ND	ND	1.3
AVB-13*	ND	ND	ND	ND	ND	ND	ND	ND	1.1
AVB-14/14D*	ND	ND	ND	ND	ND	ND	ND	ND	0.55
AVB-15*	ND	ND	ND	ND	0.16	ND	ND	ND	**2.8**
AVB-16*	ND	ND	ND	ND	0.21	ND	ND	ND	0.64
AVB-17	ND	ND	0.42	ND	ND	ND	ND	ND	0.26
AVB-18/19	ND	ND	0.16	ND	ND	ND	ND	ND	0.16
AVB-20/21	ND	ND	0.10	ND	ND	ND	ND	ND	0.125
AVB-22	ND	ND	0.20	ND	ND	ND	ND	ND	0.22
AVB-24	ND	ND	0.35	ND	0.18	ND	ND	ND	0.37
AVB-26/27	ND	ND	ND	ND	ND	ND	ND	ND	0.505
AVB-28/29	ND	ND	ND	ND	ND	ND	ND	ND	0.62
AVB-30/30a/31	ND	ND	ND	ND	ND	ND	ND	ND	0.395
AVB-32/33	ND	ND	ND	ND	ND	ND	ND	ND	0.43
AVB-34	ND	ND	ND	ND	ND	ND	ND	ND	1.0
AVB-36	ND	ND	ND	ND	ND	ND	ND	ND	1.1
AVB-37	ND	ND	ND	ND	0.11	ND	ND	0.073	0.53

* = result for Total Recoverable Metals rather than Dissolved Metals
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Avra Valley Sub-Basin, 1998-2001--continued

Site #	Antimony (mg/L)	Arsenic (mg/L)	Barium (mg/L)	Beryllium (mg/L)	Boron (mg/L)	Cadmium (mg/L)	Chromium (mg/L)	Copper (mg/L)	Fluoride (mg/L)
AVB-38	ND	ND	0.13	ND	ND	ND	ND	ND	0.31
AVB-39	ND	**0.038**	ND	ND	ND	ND	ND	ND	0.30
AVB-40/41	ND	ND	ND	ND	ND	ND	ND	ND/.011	0.365
AVB-42/43	ND	ND	ND	ND	ND	ND	ND	ND	0.38
AVB-46	ND	ND	ND	ND	ND	ND	ND	ND	0.39
AVB-47	ND	ND	ND	ND	ND	ND	ND	ND	0.50
AVB-48	ND	ND	0.11	ND	ND	ND	ND	ND	0.23
AVB-49	ND	ND	ND	ND	ND	ND	ND	ND	0.42
AVB-50	ND	ND	0.25	ND	0.16	ND	ND	ND	0.31
AVB-51	ND	ND	ND	ND	0.105	ND	ND	ND	0.49
AVB-52	ND	ND	ND	ND	0.13	ND	ND	ND	0.34
AVB-53	ND	ND	ND	ND	0.11	ND	ND	ND	**2.8**
AVB-55	ND	ND	ND	ND	0.20	ND	ND	ND	1.0
AVB-56	ND	ND	ND	ND	0.16	ND	ND	ND	0.87

bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Avra Valley Sub-Basin, 1998-2001--continued

Site #	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Zinc (mg/L)
AVB-1/1D	ND	ND	ND	ND	ND	ND	ND/.0056	ND	0.18
AVB-2	ND	ND	ND	ND	ND	ND	ND	ND	0.22
AVB-3	ND	ND	ND	ND	ND	ND	ND	ND	0.098
AVB-4*	ND	ND	ND	ND	ND	ND	ND	ND	0.12
AVB-5*	ND	ND	ND	ND	ND	ND	ND	ND	0.18
AVB-6*	ND	ND	ND	ND	ND	ND	ND	ND	0.052
AVB-7*/54	ND	ND	ND	ND	ND	ND	ND	ND	0.0665
AVB-8*	ND	ND	ND	ND	ND	ND	ND	ND	ND
AVB-9*	ND	ND	ND	ND	ND	ND	ND	ND	0.074
AVB-10*	ND	ND	ND	ND	ND	ND	ND	ND	ND
AVB-11*	ND	ND	ND	ND	ND	ND	ND	ND	0.19
AVB-12*	ND	ND	ND	ND	ND	ND	ND	ND	ND
AVB-13*	ND	ND	ND	ND	ND	ND	ND	ND	0.074
AVB-14/14D*	ND	ND	ND	ND	ND	ND	ND	ND	0.083
AVB-15*	ND	ND	**0.052**	ND	ND	ND	ND	ND	ND
AVB-16*	ND	ND	ND	ND	ND	ND	ND	ND	0.24
AVB-17	ND	ND	ND	ND	ND	ND	ND	ND	ND
AVB-18/19	ND	ND	ND	ND	ND	ND	ND	ND	1.7
AVB-20/21	**0.475**	ND	**0.051**	ND	ND	ND	ND	ND	3.8
AVB-22	0.26	ND	ND	ND	ND	ND	ND	ND	0.068
AVB-24	ND	ND	ND	ND	ND	ND	ND	ND	0.058
AVB-26/27	ND	ND	ND	ND	ND	ND	ND	ND	0.20/ND
AVB-28/29	ND	ND	ND	ND	ND	ND	ND	ND	0.24
AVB-30/30a/31	ND	ND	ND	ND	ND	ND	ND	ND	0.12/ND
AVB-32/33	ND	ND	ND	ND	ND	ND	ND	ND	0.084
AVB-34	ND	ND	ND	ND	ND	ND	ND	ND	0.36
AVB-36	ND	ND	ND	ND	ND	ND	ND	ND	ND
AVB-37	0.22	ND	ND	ND	ND	ND	ND	ND	ND

* = result for Total Recoverable Metals rather than Dissolved Metals
bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Avra Valley Sub-Basin, 1998-2001--continued

Site #	Iron (mg/L)	Lead (mg/L)	Manganese (mg/L)	Mercury (mg/L)	Nickel (mg/L)	Selenium (mg/L)	Silver (mg/L)	Thallium (mg/L)	Zinc (mg/L)
AVB-38	ND	ND	ND	ND	ND	ND	ND	ND	0.066
AVB-39	ND	ND	ND	ND	ND	ND	ND	ND	ND
AVB-40/41	ND	ND	ND	ND	ND	ND	ND	ND	ND
AVB-42/43	ND	ND	ND	ND	ND	ND	ND	ND	0.061
AVB-46	ND	ND	ND	ND	ND	ND	ND	ND	ND
AVB-47	ND	ND	ND	ND	ND	ND	ND	ND	ND
AVB-48	ND	ND	ND	ND	ND	ND	ND	ND	0.27
AVB-49	ND	ND	ND	ND	ND	ND	ND	ND	0.13
AVB-50	ND	ND	ND	ND	ND	ND	ND	ND	0.79
AVB-51	ND	ND	ND	ND	ND	ND	ND	ND	0.0575
AVB-52	ND	ND	ND	ND	ND	ND	ND	ND	ND
AVB-53	ND	ND	ND	ND	ND	ND	ND	ND	0.46
AVB-55	ND	ND	ND	ND	ND	ND	ND	ND	0.16
AVB-56	ND	ND	ND	ND	ND	ND	ND	ND	ND

bold = constituent concentration exceeded Primary or Secondary Maximum Contaminant Level

Appendix B. Groundwater Quality Data, Avra Valley Sub-Basin, 1998-2001--continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Ra-226 + Ra-228 (pCi/L)	Uranium (µg/L)	Chemistry	VOCs
AVB-1/1D	**315**	3.0	3.9	-	-	sodium-chloride	ND
AVB-2	**427**	6.2	5.2	ND	--	sodium-bicarbonate	-
AVB-3	--	--	--	--	--	calcium-bicarbonate	-
AVB-4	--	**26.1**	6.7	< LLD	20	sodium-mixed	ND
AVB-5	--	<LLD	2.1	--	--	mixed-bicarbonate	ND
AVB-6	**587**	**15**	4.2	< LLD	16	sodium-bicarbonate	ND
AVB-7/54	**1,203**	6.5	5.3	< LLD	--	calcium-bicarbonate	ND
AVB-8	209	--	--	--	--	mixed-bicarbonate	-
AVB-9	**3918**	--	--	--	--	calcium-mixed	ND
AVB-10	--	--	--	--	--	mixed-bicarbonate	ND
AVB-11	--	13	7.6	< LLD	--	mixed-bicarbonate	ND
AVB-12	--	--	--	--	--	sodium-bicarbonate	ND
AVB-13	--	--	--	--	--	mixed-bicarbonate	-
AVB-14/14D	**1,019**	7.9	4.7	--	--	mixed-bicarbonate	-
AVB-15	**83,620**	**170**	110	**30.8**	**140**	mixed-mixed	-
AVB-16	--	--	--	--	--	mixed-sulfate	-
AVB-17	--	1.6	2.9	--	--	calcium-bicarbonate	ND
AVB-18/19	--	**49**	24	< LLD	**67**	calcium-bicarbonate	ND
AVB-20/21	--	2.2	2.4	--	--	calcium-bicarbonate	-
AVB-22	--	3.0	4.5	--	--	calcium-bicarbonate	ND
AVB-24	--	< LLD	1.1	--	--	mixed-bicarbonate	-
AVB-26/27	--	1.9	2.2	--	--	calcium-bicarbonate	ND
AVB-28/29	**862**	--	--	--	--	mixed-bicarbonate	-
AVB-30/30a/31	**615**	--	--	--	--	mixed-bicarbonate	-
AVB-32/33	**827**	--	--	--	--	mixed-bicarbonate	-
AVB-34	--	2.5	1.7	--	--	mixed-bicarbonate	ND
AVB-36	--	14	4.3	< LLD	--	mixed-bicarbonate	-
AVB-37	--	11	3.3	< LLD	--	mixed-bicarbonate	ND

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

Appendix B. Groundwater Quality Data, Avra Valley Sub-Basin, 1998-2001--continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Ra-226 + Ra-228 (pCi/L)	Uranium (µg/L)	Chemistry	Ion Balance % Difference Pass / Fail
AVB -38	--	6.5	2.9	< LLD	--	mixed-bicarbonate	ND
AVB -39	--	**15**	2.2	< LLD	3.6	mixed-bicarbonate	ND
AVB -40/41	**321**	--	--	--	--	calcium-bicarbonate	ND
AVB -42/43	**750**	--	--	--	--	calcium-bicarbonate	-
AVB -46	--	9.5	4.1	< LLD	--	calcium-bicarbonate	-
AVB -47	212	--	--	--	--	mixed-bicarbonate	ND
AVB -48	**558**	--	--	--	--	calcium-bicarbonate	-
AVB -49	170	13	7.5	< LLD	--	mixed-bicarbonate	-
AVB -50	**3918**	5.6	2.7	< LLD	--	mixed-bicarbonate	-
AVB -51	**340**	--	--	--	--	mixed-mixed	ND
AVB -52	**380**	--	--	--	--	calcium-mixed	-
AVB -53	--	9.2	6.2	< LLD	--	mixed-bicarbonate	ND
AVB -55	--	--	--	--	--	mixed-bicarbonate	ND
AVB -56	--	--	--	--	--	mixed-bicarbonate	ND

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