Groundwater Quality in Arizona: A 20-Year Overview of the ADEQ Ambient Groundwater Monitoring Program 1995-2015

By Douglas C. Towne and Jason D. Jones

ADEQ Water Quality Division - Surface Water Section - Monitoring Unit

1110 West Washington Street - Phoenix, Arizona - 85007-2935

Open File Report 16-02

Groundwater Quality in Arizona:

A 20-Year Overview of the ADEQ Ambient Groundwater Monitoring Program 1995-2015

By Douglas C. Towne and Jason D. Jones

Arizona Department of Environmental Quality
Open File Report 16-02

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

Report Cover: A domestic well also provides water for stock use in the McMullen Valley basin.

Table of Contents

Figures

Tables

Abstract

More than 330,000 Arizonians, or five percent of the state's population, use a private well for drinking water. Yet an estimated one-third of these unregulated wells produce water that exceeds health-based standards for arsenic, fluoride, nitrate, gross alpha, or uranium. Arizonans can likely determine if their well has a water quality problem by testing for these five constituents, along with total coliform bacteria, copper, and lead, which can be introduced to the water supply through the plumbing system.

Private domestic wells are not subject to the Environmental Protection Agency's (EPA's) Safe Drinking Water Act (SDWA) regulations. Sampling is not required and seldom conducted. One factor is the analysis cost. Inorganic, radionuclide, and bacteria testing costs about $570. Testing for arsenic, fluoride, nitrate, uranium, gross alpha, copper, lead and total coliform is an economical ($300) alternative.[1]

The Arizona Department of Environmental Quality (ADEQ) recommends sampling for all SDWA constituents. However, testing for the above-mentioned five constituents, which constitute 98 percent of Primary MCL exceedances in a long-term study in Arizona, is an important initial step for private well owners in evaluating the safety of water for domestic use to determine if their water needs treatment.

These recommendations are the result of more than 20 years of study by ADEQ's Ambient Groundwater Monitoring program. This program has collected samples from 1,766 sites between 1995 and 2015. They predominantly consisted of domestic, stock, irrigation, and public water supply wells along with springs, mainly used for stock and wildlife use. Samples were collected from 39 of the state's 51 groundwater basins, and covered much of Arizona with the exception of Native American lands.

Groundwater samples were analyzed for most inorganic constituents listed in the SDWA. Approximately one-third of wells had samples collected for SDWA radionuclide constituents, and lesser numbers of samples were collected for Volatile Organic Compounds (VOCs), and pesticide analysis.

Of the 1,766 sites sampled, 35 percent exceeded at least one health-based water quality standard, called Primary Maximum Contaminant Levels (MCLs). Constituents commonly exceeding Primary MCLs were arsenic (22 percent of sites), fluoride (11 percent of sites), nitrate (10 percent of sites) and gross alpha and/or uranium (16 percent of 641 radionuclide sites). These five constituents caused more than 98 percent of the Primary MCL exceedances. VOCs and pesticides had no water quality exceedances.

Most sites (86 percent) with Primary MCL exceedances also had Secondary MCL or aesthetics-based exceedances. Overall, Secondary MCL exceedances occurred at 57 percent of sites, while 38 percent of sites had no exceedances of water quality standards. These findings were similar to two other recent studies: a regional study of Southwest, and a state-wide analysis.[2] [3]

Basins in southeastern Arizona had the lowest frequency of Primary MCL exceedances, while the highest were in the southwestern part of the state. Arsenic exceedances followed this pattern. Fluoride was similar but influenced by the occurrence of confined aquifers. Nitrate exceedances were most common in basins with extensive agricultural development. Gross alpha and/or uranium exceedances were influenced by geology, mining activity, and irrigated agriculture.

Introduction

Sampling by the Arizona Department of Environmental Quality's (ADEQ's) 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*."[4]

Figure 1 – Most groundwater pumped in Arizona is used for irrigation.

In pursuing its mandated mission to characterize groundwater quality in the state, ADEQ's Ambient Groundwater Monitoring program sampled 1,766 wells and springs throughout most of the state with the exception of Native American tribal lands. Sample collection occurred over a 20-year period between 1995 and 2015.

Groundwater samples were tested for most inorganic constituents listed in the U.S. Environmental Protection Agency (EPA's) Safe Drinking Water (SDW) Act. Approximately one-third of wells also had samples collected for SDW radionuclide constituents, and lesser numbers of samples were collected for Volatile Organic Compounds (VOCs), and pesticide analysis.

This data set is unique in that it was collected under the auspices of one state program, and mostly by one individual over two decades. These factors make the data collection process an unusually standardized process, and reliable for state-wide comparison purposes.

These elements allow for a broad statewide groundwater quality characterization, which has never been accomplished before with a data set of this size in conjunction with collection and analysis standardization. The results will illuminate regional groundwater quality patterns and provide an estimate of the overall percentage of wells in Arizona that meet SDW standards.

Benefits of Study

This study is designed to provide the following benefits:

- Providing domestic well owners with guidance on the quality of their groundwater.
- Characterizing regional groundwater quality conditions throughout much of Arizona.
- Identifying water quality variations between groundwater basins.
- Identifying sources of groundwater quality impacts for specific constituents.

Background

Groundwater constitutes about 3.1 million acre-feet or 43 percent of Arizona's annual water use.[5] The vast majority of groundwater pumped in the state is used to irrigate crops and for public water supplies (Figure 1).

To a lesser extent, groundwater is also used for mining, industrial, domestic, stock (Figure 2), and other purposes throughout Arizona. Groundwater discharge also creates the base flow for streams, lakes (Figure 4), and wetlands, thereby directly impacting surface water quality.

Figure 2 - Windmills provide water for stock in remote parts of Arizona.

Groundwater quality is of major importance, especially when utilized for municipal (Figure 3) and domestic water supplies. All aquifers in the state are protected for drinking water designated use by legislation including Arizona's Groundwater Management Act of 1980 and the Environmental Quality Act and Protected Use Classification of 1986 (R18-11, Article 5). Arizona's Aquifer Water Quality Standards (R18-11, Article 4) are protective of the drinking water use and are generally equivalent to the SDWA standards except for arsenic.[6]

Despite this safeguard, groundwater contamination can be a serious problem.

Potential point sources of pollution in Arizona include industrial waste, underground storage tanks, landfills, mines, and wastewater treatment plants. These activities are specifically regulated and monitored through programs operated by ADEQ.

Agricultural activities and septic wastewater disposal systems are both major nonpoint source pollution sources and are not directly regulated by ADEQ.

To fill this information gap, ADEQ's Ambient Groundwater Monitoring program characterizes groundwater quality conditions in Arizona.

The majority of the sampled wells (98 percent) were collected as part of baseline investigations of groundwater quality in 39 of the state's 51 groundwater basins officially designated by the Arizona Department of Water Resources (ADWR).[7] These studies, summarized in Table 1 and Figure 5, were designed to examine broad, regional groundwater quality conditions existing within the basins, and can be found on the agency's website at https://www.azdeq.gov/node/882. Limited sampling was conducted in three additional basins.

Figure 3 - Public water systems supplied by wells serve communities throughout the state.

Figure 4 - The SU Knoll Spring was sampled ADEQ's Elizabeth Boettcher near Crescent Lake.

Table 1 - ADEQ Ambient Groundwater Monitoring Program Studies

Basin	Year(s) Sampled	Year Report Published	Comments
Yuma	1995	1997	
Douglas	1995-96	1999	
Duncan Valley	1995-2016	-	Currently sampling
Upper San Pedro	1996-97	1999	Joint Study w/ U.S. Geological Survey
Virgin River	1997	1999	
Prescott AMA	1997-98	2001	
Upper Santa Cruz	1998	2000	Joint Study w/ U.S. Geological Survey
Avra Valley	1998-2001	2014	
Sacramento Valley	1999	2001	
Willcox	1999	2001	
Lower San Pedro	2000	2002	
Hualapai Valley	2000	2005	
Meadview	2000-03	2005	
San Rafael	2002	2003	
Detrital Valley	2002	2003	
San Simon	2002	2004	
Cienega Creek	2002	2012	
Salt River	2002-15	2016	
Tonto Creek	2002-12	2013	
San Bernardino	2002	2011	
Lake Mohave	2003	2005	
Aravaipa Canyon	2003	2013	
Big Sandy	2003-04	2006	
Bill Williams	2003-09	2011	
Upper Hassayampa	2003-09	2013	
Little Colorado River	2003-	-	Limited ADEQ sampling
Gila Valley	2004	2010	
Dripping Springs	2004-05	2011	
Agua Fria	2004-06	2008	
Phoenix AMA	2004-	-	Limited ADEQ sampling
Pinal AMA	2005-06	2008	
McMullen Valley	2008-09	2011	
Ranegras Plain	2008-11	2012	
Butler Valley	2008-12	2012	
Harquahala	2009-14	2014	
Gila Bend	2012-15	2011	
Lower Gila	2013-16	-	Currently sampling
Tiger Wash	2014	2014	
Morenci	2014		Limited ADEQ sampling

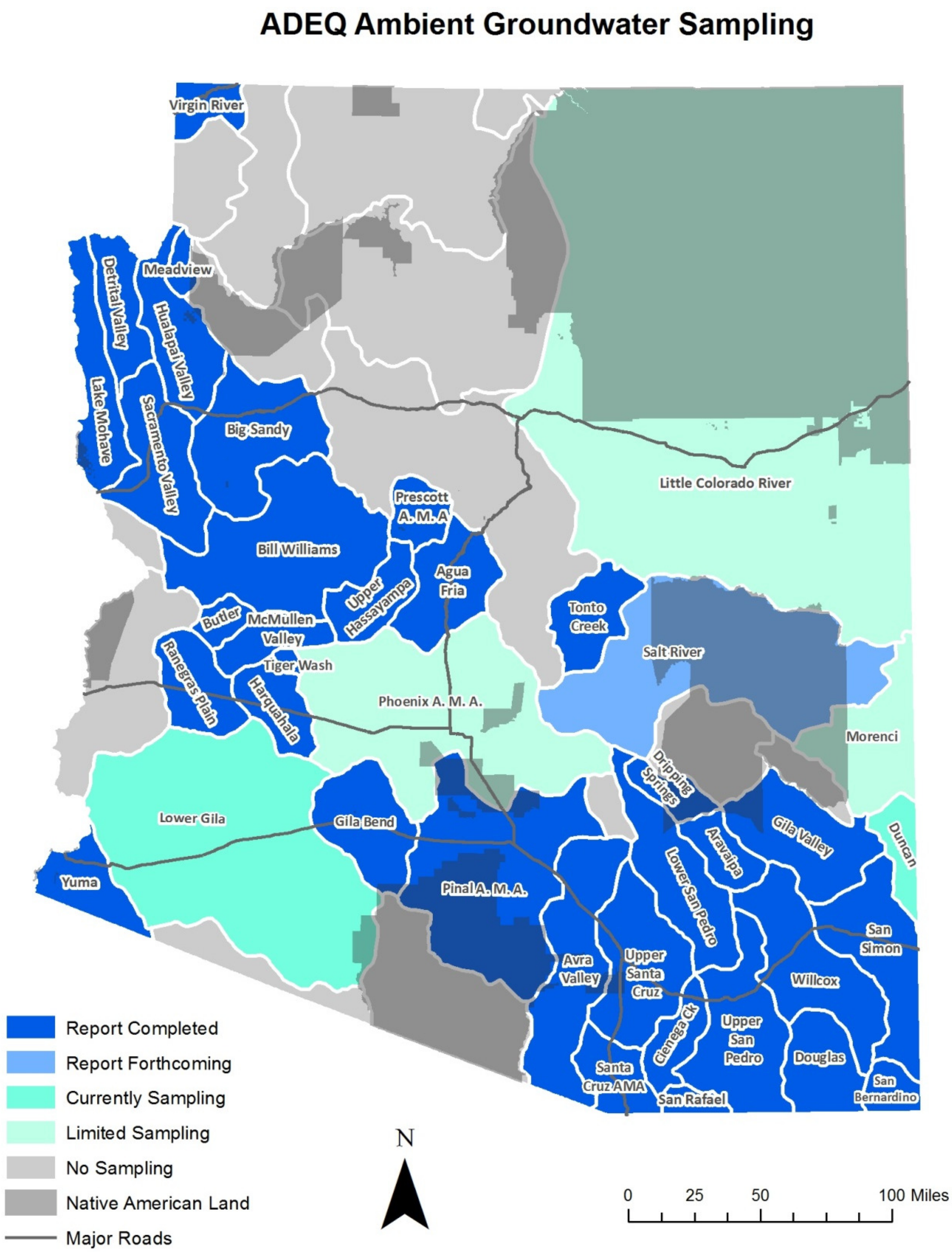

Figure 5 – Sampling by ADEQ Ambient Groundwater Monitoring Program

Previous Studies

In a national survey of about 2,100 domestic wells, 23 percent of sampled wells contained one or more contaminants at a concentration greater than a human-health benchmark http://pubs.usgs.gov/circ/circ1332/includes/circ1332.pdf. These contaminants were most often inorganic chemicals with all but nitrate derived primarily from natural sources. Almost half (48 percent) of the sampled wells contained at least one constituent at a concentration outside the range of aesthetic values recommended by U.S. EPA Secondary drinking water guidelines.[8]

Figure 6 - ADEQ's Patti Spindler samples a domestic well located north of Globe.

In a regional survey of examining the water quality of 656 wells located in basin-fill aquifers in the Southwest, 35 percent contained one or more contaminants at a concentration greater than a human-health benchmark http://pubs.usgs.gov/circ/1358/. The wells were used for domestic purposes (48 percent), public water supply (39 percent), with the remainder (12 percent) mostly irrigation wells with a few stock and industrial wells.[9]

Arsenic was the most common inorganic Primary MCL exceedance (31 percent) in a study of 49 wells sampled in seven counties in Arizona http://crawl.prod.proquest.com.s3.amazonaws.com/fpcache/24fd11ca3fe2c3314242192a389fdb97.pdf?AWSAccessKeyId=AKIAJF7V7KNV2KKY2NUQ&Expires=1451326420&Signature=EDrJuc5WNMwgb1nfjigK%2F%2Fx8Mhc%3D. Uranium concentrations exceeded standards in 13 percent of samples, while fluoride and nitrate concentrations were all under Primary MCLs.[10]

Objective

The quality of water delivered through public supplies is strictly regulated; this resource is routinely monitored to verify it meets state and federal standards set to protect public health. However, there are more than 100,000 private domestic wells whose owners represent about 300,000 people or five percent of Arizona's population that are not subject to SDW regulations required of public water systems, and thus, are not required to conduct water quality tests.[11]

Private well owners often have not had analytical tests conducted on the quality of water produced by their wells and may be unaware of the presence of contaminants that could adversely affect their health. The large numbers of untested private domestic wells make reliable information on the occurrence and levels of contaminants in groundwater essential to protect public health in Arizona.

This study will also assess Arizona groundwater quality by utilizing a much larger population of samples collected over a 20-year period from 1995-2015 by the ADEQ Ambient Groundwater Monitoring program.

Investigation Methods

Three sampling strategies were used to characterize basin groundwater quality: stratified random sampling using computer-generated equal-area polygons, stratified random sampling using townships and/or physiographic areas, and random sampling.

Targeted sampling sometimes occurred near sites having constituent concentrations with health-based water quality standards in order to determine the spatial extent of impacted groundwater quality.

Several factors were considered in selecting the number of sites to sample during basin studies. Important considerations included physical characteristics, land uses, hydrologic complexity (such as the presence of multiple sub-basins, aquifers and/or perennial streams) and the number and distribution of wells and springs.

Sampling Protocol

Production wells used for domestic, stock, irrigation, industrial, and public water supply were sampled for the studies. Monitoring wells originally installed to delineate the extent of fuel leaks from underground storage tanks were occasionally sampled to assist in characterizing shallow aquifers. Springs for stock, wildlife and/or domestic use were sampled, especially in remote areas lacking wells.

Sampling protocols followed the *ADEQ Quality Assurance Project Plan* with only minor deviations.[12] In all instances, the collected sample consisted of freshly pumped groundwater as determined by well casing capacity and field parameters such as temperature, pH, and specific conductivity.

Ideally, three bore volumes were purged prior to sample collection. In some instances, less than three bore volumes were evacuated before sampling because of factors inherent in field work. These factors range from well owner concerns to uncertainty of how long windmills would continue to pump water. However, in all cases field parameters indicated freshly pumped water from the aquifer was collected.

Inorganic Analyses

At each site, an inorganic sample was collected for physical parameters, general mineral characteristics, major ions, nutrients, and trace elements.

Analysis was conducted by Arizona Department of Health Services (ADHS) laboratory in Phoenix, Arizona (1995-2009), Test America Laboratory in Phoenix (2010-2013), and Accutest Laboratory in San Jose, California (2014-2015).

The inorganic suite incorporated the vast majority of constituents regulated by the U.S. EPA SDW Act. These include health-based, water quality standards called Primary Maximum Contaminant Levels (MCLs), and aesthetics-based, water quality guidelines called Secondary MCLs. These water quality standards are provided in Table 2.[13]

Figure 7 - Purging is especially important for intermittently used stock wells.

Table 2 - U.S. EPA Maximum Contaminant Level Standards and Guidelines

Primary Constituent	Primary MCL
Nutrients	
Nitrite (NO_2-N)	1.0
Nitrate (NO_3-N)	10.0
Trace Elements	
Antimony (Sb)	0.006
Arsenic (As) (federal/State standard)	0.01 / 0.05
Barium (Ba)	2.0
Beryllium (Be)	0.004
Cadmium (Cd)	0.005
Chromium (Cr)	0.1
Copper (Cu)	1.3
Fluoride (F)	4.0
Lead (Pb)	0.015
Mercury (Hg)	0.002
Nickel (Ni)	0.1
Selenium (Se)	0.05
Thallium (Tl)	0.002
Radiochemistry Constituents	
Gross Alpha	15 pCi/L
Ra-226+Ra-228	5 pCi/L
Radon-proposed (as part of State multimedia program)	300 pCi/L
Radon-proposed (if no State multimedia program)	4,000 pCi/L
Uranium	30 ug/L
Secondary Constituent	**Secondary MCL**
Physical Parameters	
pH - field	<6.5 su ; >8.5 su
General Mineral Characteristics	
TDS	500
Major Ions	
Chloride (Cl)	250
Sulfate (SO_4)	250
Trace Elements	
Aluminum (Al)	0.05 to 0.2
Fluoride (F)	2.0
Iron (Fe)	0.3
Manganese (Mn)	0.05
Silver (Ag)	0.1
Zinc (Zn)	5.0

Units in milligrams per Liter (mg/L) except standard units (su), pico curies per liter (piC/L), and micrograms per liter (ug/L).

Federal Primary MCLs are synonymous with state Aquifer Water Standards: Drinking Water Protected Use (AWQ) with three exceptions. There are no state aquifer water quality standards for copper or turbidity and arsenic has 0.05 mg/L state standard compared with the 0.01 mg/L Primary MCL.[14]

Other Analyses

Radionuclide samples were collected at 641 sites (37 percent), with many sites targeted because of granitic geology and/or mining activity use. Analytical work was conducted by the Arizona Regulatory Radiation Agency (ARRA) laboratory in Phoenix, Arizona (1995-2009) and the Radiation Safety Engineering Laboratory in Chandler, Arizona (2010-2015).

Volatile Organic Compounds (VOCs) samples were collected at 287 sites (16 percent) mostly in urban areas. Samples for currently registered pesticides were collected at 72 sites (four percent) and for banned pesticides at 43 sites (three percent) in areas of irrigated farmland. Both VOC and pesticide analysis was conducted by the ADHS laboratory in Phoenix, Arizona.

Data Validation

The effects of sampling equipment and procedures were evaluated using quality control samples including equipment blanks, duplicate samples, split samples and, occasionally, spiked samples. Data were also validated using seven measurements including cation/anion balances.

In two studies conducted in conjunction with the U.S. Geological Survey, the field protocols and laboratories of each agency were evaluated using split samples. Based on these indices, the impacts of sampling procedures and lab analysis were found not to be significant except in very specific circumstances.[15]

Figure 8 - Conducting a split sample with the U.S. Geological Survey at a well near Gila Bend.

Table 3a - Summary of Types of Samples Collected, 1995-2015

Basin	Sites Sampled	Inorganic Samples	Radionuclide Samples	Radon Samples	VOC Samples	Pesticide Samples
Little Colorado / San Juan Watershed						
Morenci	1	1	1	1	-	-
Little Colorado River	7	7	3	6	-	-
Colorado / Grand Canyon Watershed						
Virgin River	38	38	10	-	-	3
Hualapai Valley	26	26	16	8	21	-
Meadview	8	8	2	2	1	-
Detrital Valley	28	28	11	11	-	-
Bill Williams Watershed						
Big Sandy	56	56	29	36	-	-
Bill Williams	101	101	55	46	-	-
Verde Watershed						
Prescott AMA	58	58	10	-	-	2
Salt Watershed						
Salt River	75	75	54	16	22	-
Tonto Creek	31	31	18	5	8	-
Upper Gila Watershed						
San Simon	77	77	23	33	-	4
Duncan Valley	55	55	20	11	10	12
Gila Valley	65	65	20	31	-	4
San Pedro Watershed						
San Bernardino	14	14	-	12	-	-
Douglas	52	52	7	-	13	7
Willcox	58	58	44	-	54	4
Aravaipa Canyon	15	15	-	15	-	-
Dripping Springs	12	12	7	3	-	-
Upper San Pedro	73	73	-	-	2	-
Lower San Pedro	63	63	19	19	25	2
Santa Cruz Watershed						
San Rafael Valley	20	20	5	5	2	-
Cienega Creek	20	20	6	7	10	-
Upper Santa Cruz	65	65	-	36	36	4
Avra Valley	42	42	22	16	19	-
Pinal AMA	86	86	25	41	14	14

Table 3b - Summary of Types of Samples Collected, 1995-2015--continued

Basin	Sites Sampled	Inorganic Samples	Radionuclide Samples	Radon Samples	VOC Samples	Pesticide Samples
Middle Gila Watershed						
Agua Fria	46	46	33	30	-	-
Upper Hassayampa	34	34	14	15	-	-
McMullen Valley	124	124	53	94	-	2
Tiger Wash	5	5	3	3	-	-
Harquahala	51	51	10	31	-	-
Phoenix AMA	18	18	1	6	-	-
Gila Bend	77	77	19	51	-	-
Colorado / Lower Gila Watershed						
Lake Mohave	43	43	15	31	-	-
Sacramento Valley	48	48	40	-	48	-
Butler Valley	9	9	3	6	-	-
Ranegras Plain	55	55	18	33	-	-
Lower Gila	51	51	21	29	-	-
Yuma	55	55	7	-	-	57
Total	**1766**	**1766**	**641**	**683**	**287**	**115**

Figure 9 - Sample bottles collected from a domestic well in the McMullen Valley basin.

Sampling Results

Basins in which limited sampling has taken place, such as the Little Colorado River, Morenci, and the Phoenix Active Management Area (AMA) are incorporated into the statistics but not included in the following maps because the overall groundwater quality has not been characterized.

Inorganic Results – Primary MCLs

Water quality data was compared to inorganic EPA SDW requirements and/or AWQ standards. Of the 1,766 sites sampled, 547 sites (31 percent) exceeded at least one inorganic water quality standard. Three constituents were the cause of water quality standards at 98 percent of sites: arsenic, fluoride, and nitrate.

Other inorganic Primary MCL exceedances included antimony (8 sites), barium (1 site), beryllium (4 sites), cadmium (2 sites), chromium (1 site), lead (2 sites), and selenium (2 sites). These 11 constituents combined to exceed water quality standards at little over one percent of sites. Mercury, nitrite, and thallium had no exceedances

The spatial variability, by groundwater basin, of Primary MCL exceedances is provided in Figure 10. A combination of hydrologic factors and land uses help account for the patterns found in the inorganic Primary MCL map. Although the map is a useful guide, it aggregates the data of the three-dimensional groundwater system into an easily readable two-dimensional representation.

Southeastern Arizona basins had sample sites which exceeded inorganic Primary MCLs some of the lowest frequencies. These included three remote basins with little water development: Aravaipa Canyon, Dripping Springs Wash, and San Bernardino which had no Primary MCL exceedances.

In contrast, basins in southwestern Arizona had sample sites which typically exceeded inorganic Primary MCLs at frequencies more than 50 percent. Factors impacting the poor groundwater quality in these basins include shallow aquifers, irrigated farming, and older groundwater with a high pH and sodium chemistry which tends to produce elevated levels of arsenic and fluoride.

The Yuma basin is an exception to this pattern because of the use of surface water from the Colorado River for irrigation. This fresh source of water flushes the aquifers, and groundwater rapidly moves out of the basin assisted by a system of drainage wells.

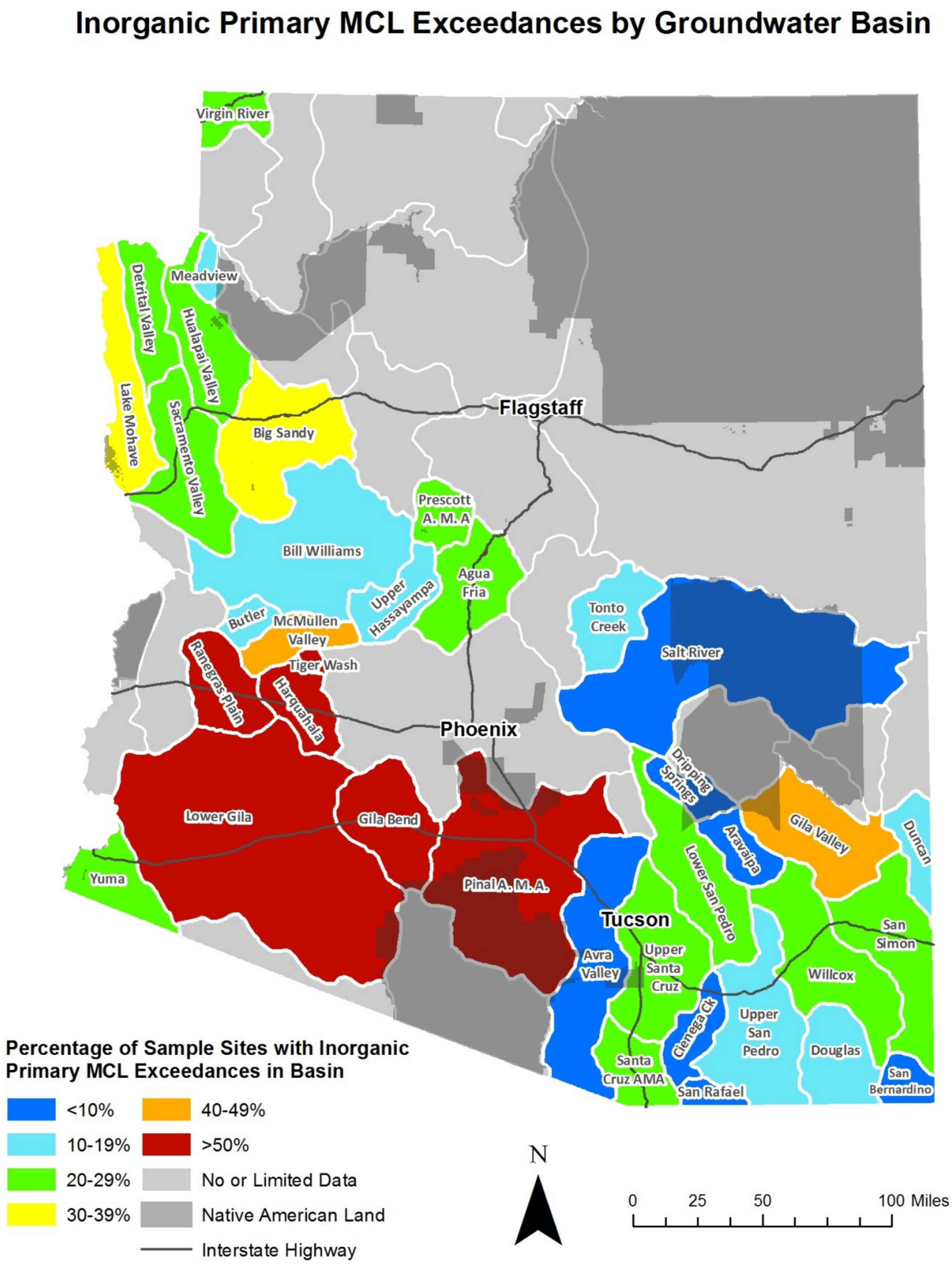

Figure 10 - Primary MCL Exceedances by Groundwater Basin

Inorganic Results – Arsenic

Arsenic concentrations at 381 sites (or 22 percent) exceeded the 0.01 milligram per Liter (mg/L) Primary MCL that became effective January 26, 2006. This is similar to the 16 percent arsenic Primary MCL exceedance rate in a recent groundwater study of the Southwest.[16]

In contrast, only 39 sites (or two percent) had arsenic concentrations that exceeded the former Primary MCL and current state AQW standard of 0.05 mg/L.

The arsenic standard was lowered from 0.05 mg/L to 0.01 mg/L in 2006, which dramatically increased the number of wells not meeting the standard in Arizona .

Although elevated arsenic concentrations are found throughout Arizona, the highest concentrations are generally located in the western and central parts of the state (Figure 11). Elevated arsenic concentrations occur when natural geochemical factors favor dissolution of this constituent from aquifer materials. Factors such as the type of source rock, groundwater residence time, geochemical conditions, and evaporative concentration affect arsenic concentrations.[17]

Low rates of natural recharge results in long groundwater residence times, which allow for interactions with aquifer materials that tend to increase pH levels. High pH levels promote detachment of arsenic from aquifer sediments, elevating its concentration in groundwater.[18] Irrigation can also increase arsenic concentrations in groundwater in areas where recharge from watering crops encounters sediments containing arsenic.[19]

Some basins such Lake Mohave in northwestern Arizona have significant sub-basin patterns. Wells tapping the older Bouse formation had significantly higher concentrations than wells pumping Colorado River or local recharge.[20]

Southwestern Arizona tended to have the highest frequencies of arsenic Primary MCLs. Factors influencing this pattern include extensive irrigated cropland along with older water with a sodium chemistry which tends to produce elevated concentrations of arsenic. The Yuma basin is an exception to this pattern because of the use of Colorado River water for irrigation. This fresh source of water flushes the aquifers, and is rapidly moved out of the basin assisted by a system of drainage wells and canals.[21]

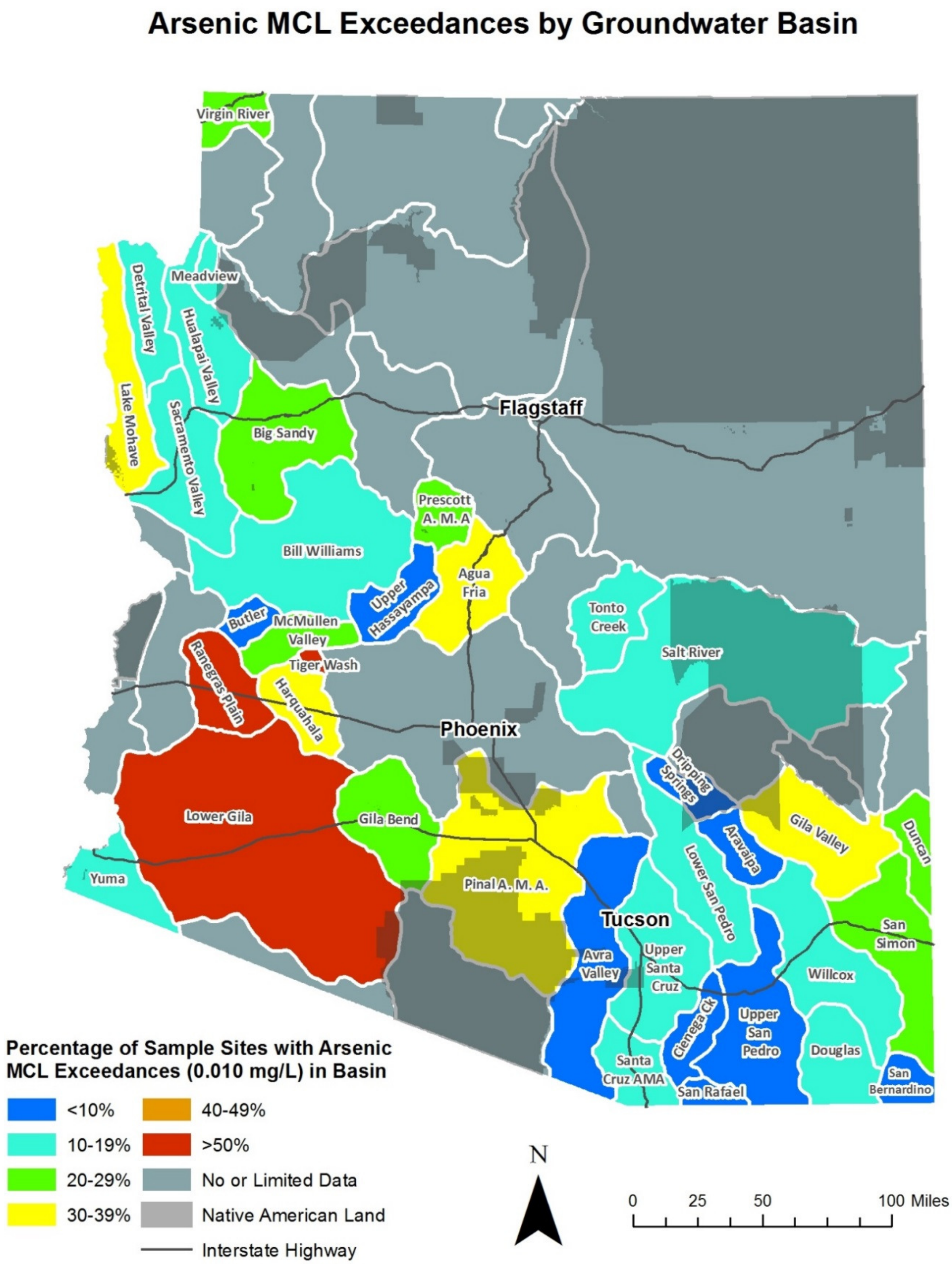

Figure 11 - Arsenic Primary MCL Exceedances by Basin

Inorganic Results – Fluoride

Fluoride concentrations at 198 sites (11 percent) exceeded the 4.0 mg/L federal Primary MCL / state AQW standard (Figure 13). This rate is much higher than the 1.2 percent fluoride Primary MCL exceedance rate in a recent groundwater quality study of the Southwest.[22]

Fluoride concentrations above 5 mg/L are controlled by calcium through precipitation or dissolution of the mineral fluorite. In a chemically closed hydrologic system, calcium is removed from solution by precipitation of the calcium carbonate and the formation of smectite clays. High concentrations of dissolved fluoride may occur in groundwater depleted in calcium if a source of fluoride ions is available for dissolution.[23]

Thus, sites exhibiting soft, older water with a sodium chemistry, such as artesian wells tapping deep confined aquifers in southeastern Arizona, are likely to have elevated fluoride concentrations.

Most fluoride exceedances in southeastern Arizona basins were from artesian wells tapping older water in confined aquifers. Confined aquifers also occur in other southeastern basins, and typically produce water having elevated fluoride concentrations.[24]

In other parts of Arizona, basins with high frequencies of fluoride exceedances such as the Big Sandy (20 percent), is explained by most fluoride exceedances occurring in the downgradient sub-basin which has sodium, rather than a calcium, cation chemistry.[25]

Similarly, in basins in the southwestern part of the state, elevated fluoride concentrations appear to be the result of older, highly evolved groundwater. In the Ranegras Plain basin, fluoride exceedances are strongly correlated with older groundwater as determined by oxygen and deuterium isotopes.[26]

Figure 12 – Artesian wells, which tap confined aquifers, often produce high fluoride levels.

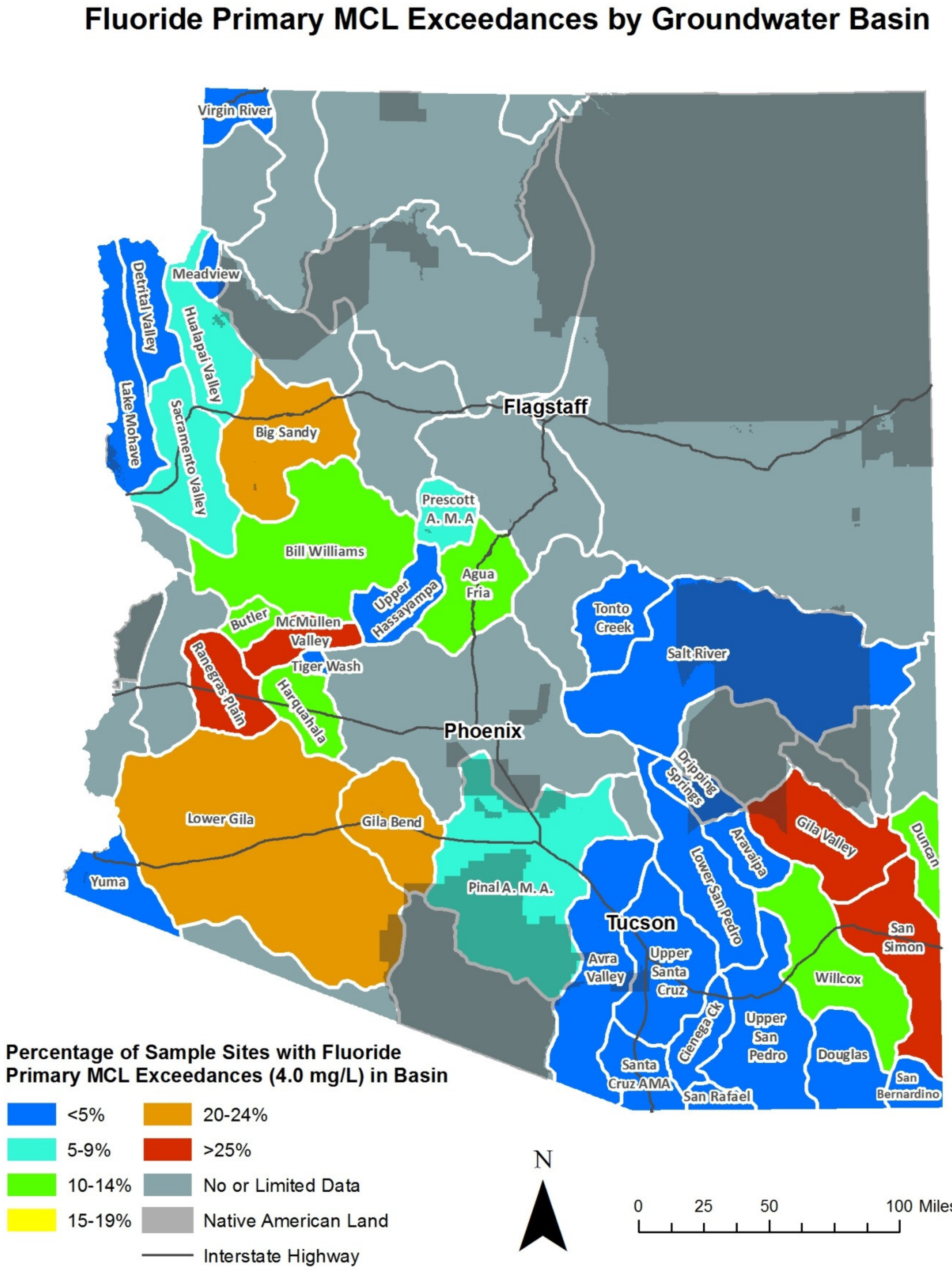

Figure 13 - Fluoride Primary MCL Exceedances by Basin

Inorganic Results – Nitrate

Nitrate concentrations at 172 sites (10 percent) exceeded the 10 mg/L federal Primary MCL (Figure 15). This exceedance frequency matches the 11 percent rate for nitrate found in a recent groundwater quality study of the Southwest.[27]

Unlike arsenic and fluoride concentrations, which are largely dependent on natural geohydrology influences, nitrate concentrations are predominantly the result of human activities.[28]

Although nitrate occurs naturally in parts of the Sonoran Desert from legumes, two important anthropomorphic sources are wastewater discharges from household septic systems and fertilizer used in the irrigation of agricultural and urban lands. Irrigated farmland is the more important factor since it takes a large density of septic systems to impact nitrate concentrations in groundwater on a regional scale.

The majority of basins have sample sites exceeding the nitrate Primary MCL at frequencies less than 15 percent. Some of these are likely the result of septic system wastewater discharges. The occurrence of these exceedances is difficult to predict.

The five basins with nitrate exceedance frequencies greater than 20 percent are central and western basins such as Gila Bend, Harquahala, McMullen Valley, the Pinal AMA, and the Ranegras Plain. All of these have significant expanses of irrigated cropland.

While many deep irrigation wells have low nitrate concentrations, shallow domestic wells located among extensive irrigated fields are very likely to have nitrate concentrations exceeding the Primary MCL. This phenomena is better quantified by examining intra-basin patterns.

Nitrate concentrations are significantly higher in the shallow perched aquifer, recharged largely by irrigation applications, than six other aquifers in the McMullen Valley basin.[29] In the Gila Bend basin, nitrate concentrations in younger groundwater of recent recharge is significantly higher than older groundwater.[30]

Figure 14 - ADEQ's Jade Dickens samples a shallow domestic well among irrigated fields.

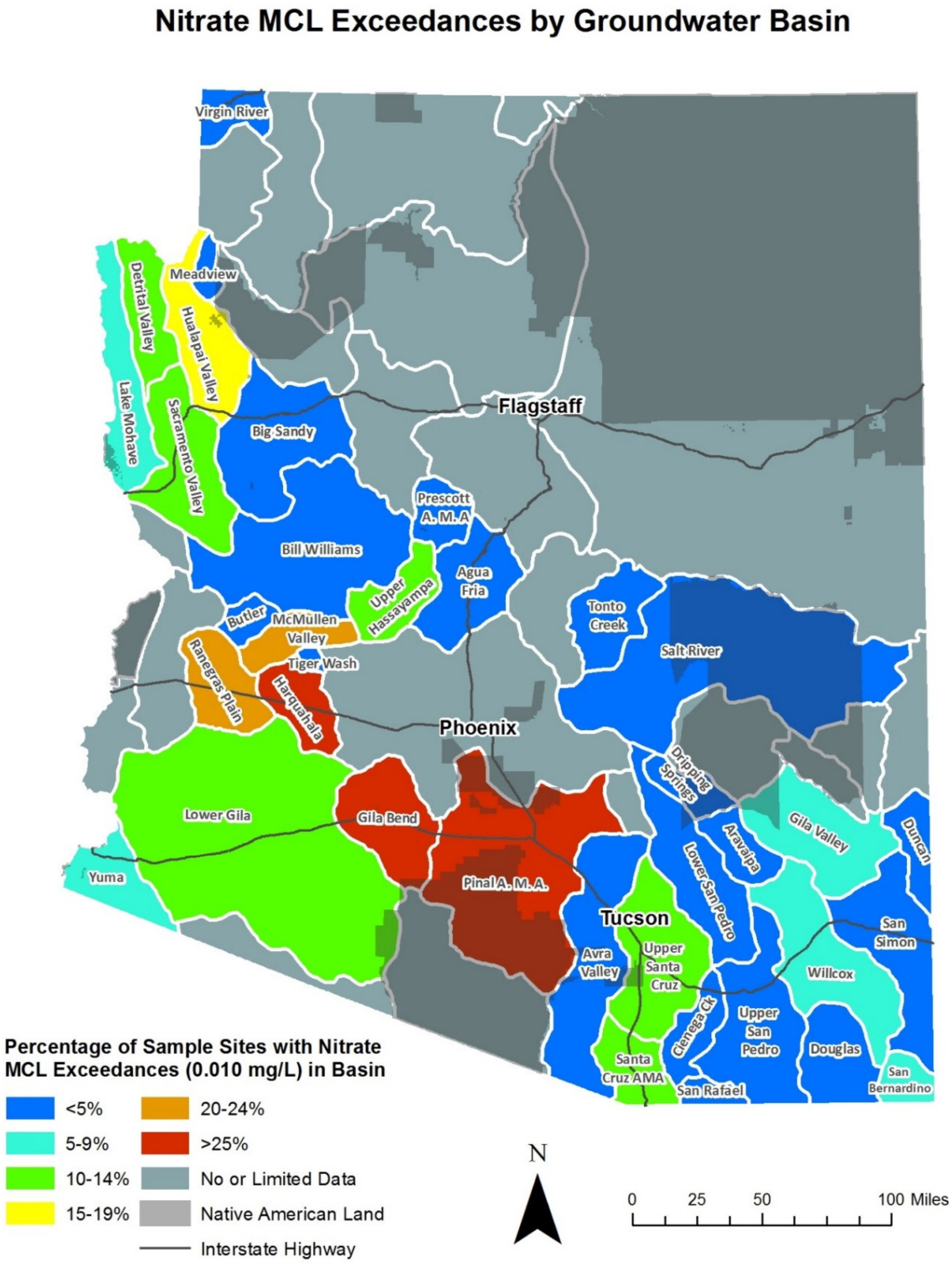

Figure 15 - Nitrate Primary MCL Exceedances by Basin

Radionuclide Primary MCL Exceedances

There are three radionuclide constituents that have Primary MCLs: gross alpha, radium-226 and 228, and uranium. Radionuclide samples were collected at 641 of the 1,766 sites that were typically in or near bedrock, particularly in areas in proximity to mines and/or granite rock.

SDW exceedances included gross alpha (102 sites or 16 percent) (Figure 16), uranium (47 sites or seven percent) and radium-226 and 228 (12 sites or two percent). Most uranium and radium-226 and 228 exceedances occurred at sites where gross alpha also exceeded health-based, water quality standards.

Gross alpha exceedances occur throughout the state, but are most common (> 25 percent frequency) in northwestern Arizona especially in the Cerbat and Hualapai mountains. Gross alpha exceedances are significantly correlated with granitic geology in basins such as Sacramento Valley.[31] Mining activity also impacts gross alpha concentrations because of the increased rock surface exposure.[32]

The many gross alpha exceedances in this region may be explained by the numerous radionuclide samples were collected there, and an imprecise test was used in the analysis. Caution should be exercised in using radionuclide results conducted before 2010 by the Arizona Regulatory Radiation Agency (ARRA) laboratory in Phoenix, Arizona. This lab used at that time the 900 method, which involves evaporating the sample into a planchet and counting it. The method, however, works poorly in hard waters. This leads to huge error bars due to alpha self-absorption in the sample mass, which are not measurable as they depend on the uniformity of the lumpy mess in the planchet.[33]

Since 2010, gross alpha analysis has been conducted by a co-precipitation method (EPA 00-02). While more expensive, it separates the radionuclides from calcium, magnesium and other inert materials in the water. The result is a planchet of relatively uniform weight, and vastly more reproducible results.[34] Since the changeover of labs for radionuclide analysis, there has been a major decrease in the frequency of SDW exceedances.

Uranium exceedances are caused by weathering of rocks or sediments, especially granite. An alkaline pH along with high concentrations of bicarbonate increases the solubility of uranium. Elevated uranium concentrations in groundwater can be produced by excess percolating irrigation water reaching uranium-bearing aquifer sediments. Uranium subsequently bonds with calcium and bicarbonate, and the resulting recharge negatively impacts groundwater quality.[35]

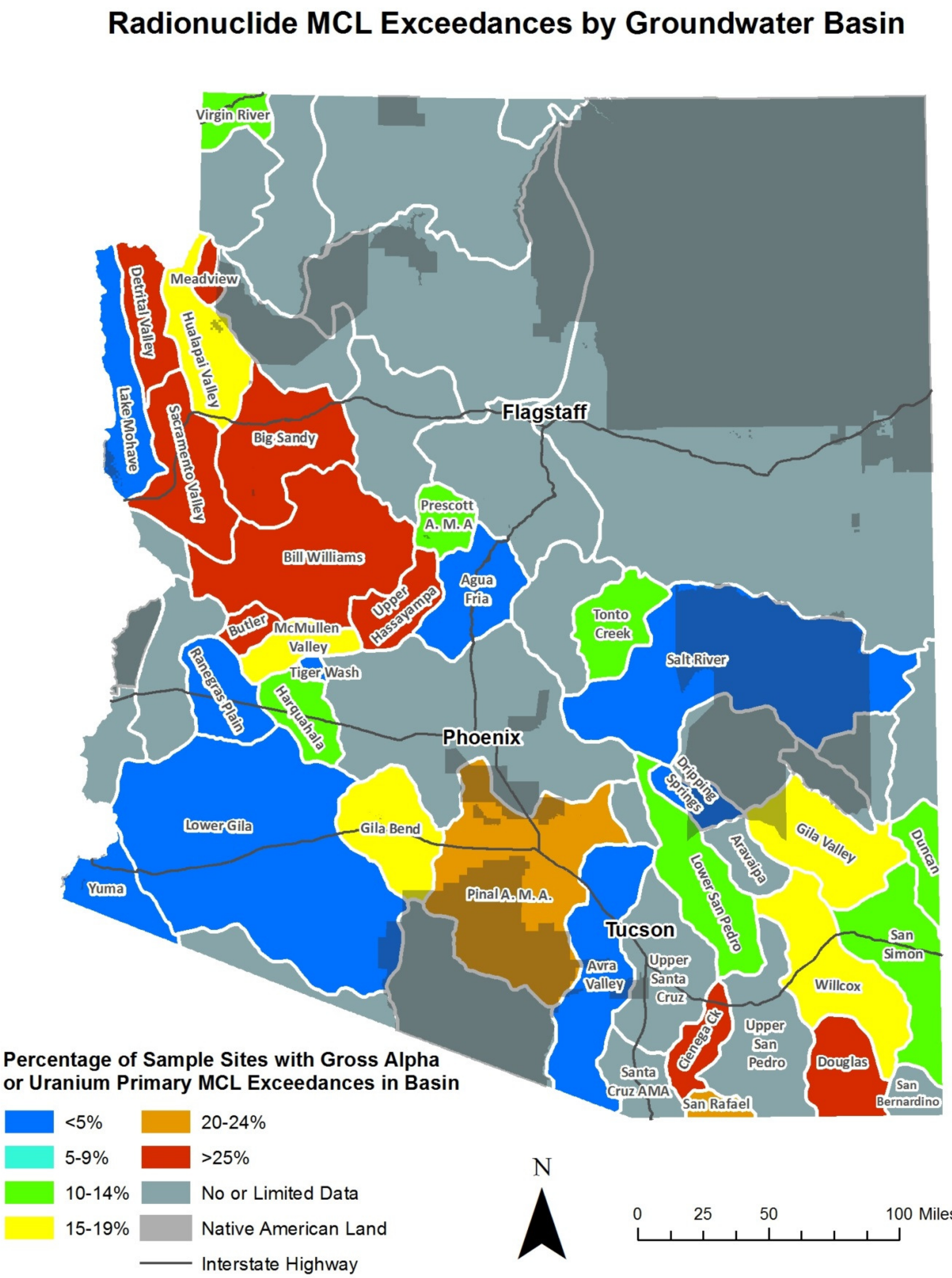

Figure 16 – Radionuclide MCL Exceedances by Basin

Table 4a – Arsenic, Fluoride, Nitrate, and Radionuclide Primary MCL Exceedances by Basin

Basin	# of Sites Inorganic / Radionuclide	Sites Exceeding Arsenic MCL		Sites Exceeding Fluoride MCL		Sites Exceeding Nitrate MCL		Sites Exceeding Radionuclide MCL	
Little Colorado / San Juan Watershed									
Morenci	1 / 1	0	0 %	0	0 %	0	0 %	0	0 %
Ltl Colorado River	7 / 3	0	0 %	0	0 %	0	0 %	0	0 %
Colorado / Grand Canyon Watershed									
Virgin River	38 / 10	9	24 %	0	0 %	0	0 %	1	10 %
Hualapai Valley	26 / 26	3	12 %	2	8 %	3	12 %	3	19 %
Meadview	8 / 2	1	3 %	0	0 %	0	0 %	2	100 %
Detrital Valley	28 / 11	3	11 %	0	0 %	3	11 %	3	27 %
Bill Williams Watershed									
Big Sandy	56 / 29	13	23 %	11	20 %	0	0 %	8	28 %
Bill Williams	101 / 55	10	10 %	4	4 %	3	3 %	16	29 %
Verde Watershed									
Prescott AMA	58 / 10	15	26 %	4	5 %	1	2 %	1	10 %
Salt Watershed									
Salt River	75 / 54	7	9 %	1	1 %	0	0 %	1	2 %
Tonto Creek	31 / 19	6	19 %	0	0 %	1	3 %	2	11 %
Upper Gila Watershed									
San Simon	77 / 23	16	21 %	19	25 %	3	4 %	3	13 %
Duncan Valley	55 / 20	14	25 %	6	11 %	2	4 %	2	10 %
Gila Valley	65 / 20	21	32 %	20	31 %	4	6 %	3	15 %
San Pedro Watershed									
San Bernardino	14 / 0	0	0 %	0	0 %	0	0 %	0	0 %
Douglas	52 / 7	5	10 %	0	6 %	1	2 %	2	29 %
Willcox	58 / 44	9	16 %	8	14 %	5	9 %	7	16 %
Aravaipa Canyon	15 / 0	0	0 %	0	0 %	0	0 %	0	0 %
Dripping Spring	12 / 7	0	0 %	0	0 %	0	0 %	0	0 %
Upper San Pedro	73 / 0	6	8 %	3	4 %	0	0 %	0	0 %
Lower San Pedro	63 / 19	12	19 %	8	13 %	1	2 %	2	11 %
Santa Cruz Watershed									
San Rafael	20 / 5	0	0 %	0	0 %	0	0 %	1	20 %
Cienega Creek	20 / 6	1	5 %	0	0 %	0	0 %	2	33 %
Upper Santa Cruz	65 / 0	9	14 %	1	2 %	7	11 %	0	0 %
Avra Valley	42 / 22	2	5 %	0	0 %	0	0 %	3	14 %
Pinal AMA	86 / 25	33	38 %	7	8 %	23	27 %	5	20 %

Table 4b – Arsenic, Fluoride, Nitrate, and Radionuclide Primary MCL Exceedances by Basin--Continued

Basin	# of Sites Inorganic / Radionuclide	Sites Exceeding Arsenic MCL		Sites Exceeding Fluoride MCL		Sites Exceeding Nitrate MCL		Sites Exceeding Radionuclide MCL	
Middle Gila Watershed									
Agua Fria	46 / 33	12	26 %	5	11 %	1	2 %	1	3 %
Upr Hassayampa	34 / 14	1	3 %	0	0 %	4	12 %	5	36 %
McMullen Vly	124 / 53	29	23 %	32	26 %	30	22 %	10	19 %
Tiger Wash	5 / 2	3	60 %	0	0 %	0	0 %	0	0 %
Harquahala	51 / 10	19	37 %	5	10 %	24	47 %	1	10 %
Phoenix AMA	18 / 1	7	39 %	2	11 %	3	17 %	0	0 %
Gila Bend	77 / 19	18	23 %	17	22 %	21	27 %	19	3 %
Colorado / Lower Gila Watershed									
Lake Mohave	43 / 15	14	33 %	1	2 %	3	7 %	0	0 %
Sacramento Vly	48 / 40	6	13 %	4	8 %	6	13 %	18	45 %
Butler Valley	9 / 3	0	0 %	1	11 %	0	0 %	1	33 %
Ranegras Plain	55 / 18	35	64 %	28	51 %	12	22 %	0	0 %
Lower Gila	51 / 19	34	67 %	10	20 %	5	10 %	0	0 %
Yuma	55 / 7	9	16 %	0	0 %	5	9 %	0	0 %
Total	**1766 / 641**	**382**	**22 %**	**198**	**11 %**	**172**	**10 %**	**105**	**16 %**

Figure 17- ADEQ's Jason Jones collects a sample in the Agua Fria basin.

Overall Primary MCL Exceedances

Of the 1,766 sites sampled, 641 sites (35 percent) exceeded at least one inorganic and/or radionuclide water quality standard. Four constituents commonly exceeded water quality standards: arsenic, fluoride, nitrate, and gross alpha. Most sites (86 percent) with Primary MCL exceedances also had Secondary MCL or aesthetics-based exceedances. This frequency of exceedance matches the 35 percent Primary MCL exceedance found in a recent groundwater quality study of the Southwest.[36]

This data set is skewed, however, because radionuclide samples were not collected uniformly though out the state.

Some basins had high percentages of sites at which a radionuclide sample was collected, such as Hualapai Valley (100 percent), Sacramento Valley (83 percent), Willcox (76 percent), Salt River (72 percent), and Agua Fria (71 percent).

Figure 18 - ADEQ's Susan Determann samples a stock well by Coyote Peak in western Arizona.

Figure 19 - ADEQ's Douglas Towne samples a windmill in the Big Sandy basin north of I-40.

In comparison, Aravaipa Canyon, San Bernardino, Upper San Pedro, and the Upper Santa Cruz basins did not have any radionuclide samples collected.

Comparing the two maps (Overall Primary MCL exceedances vs. Inorganic Primary MCL exceedances) illustrates the impacts of the skewed radionuclide samples. The five basins with the highest percentage of radionuclide samples collected all had increased overall exceedances. In contrast, those with no radionuclide samples collected obviously had no change in exceedances.

As covered in the radionuclide section, some of the gross alpha exceedances may have actually been the result of a test used that is sometimes inaccurate.

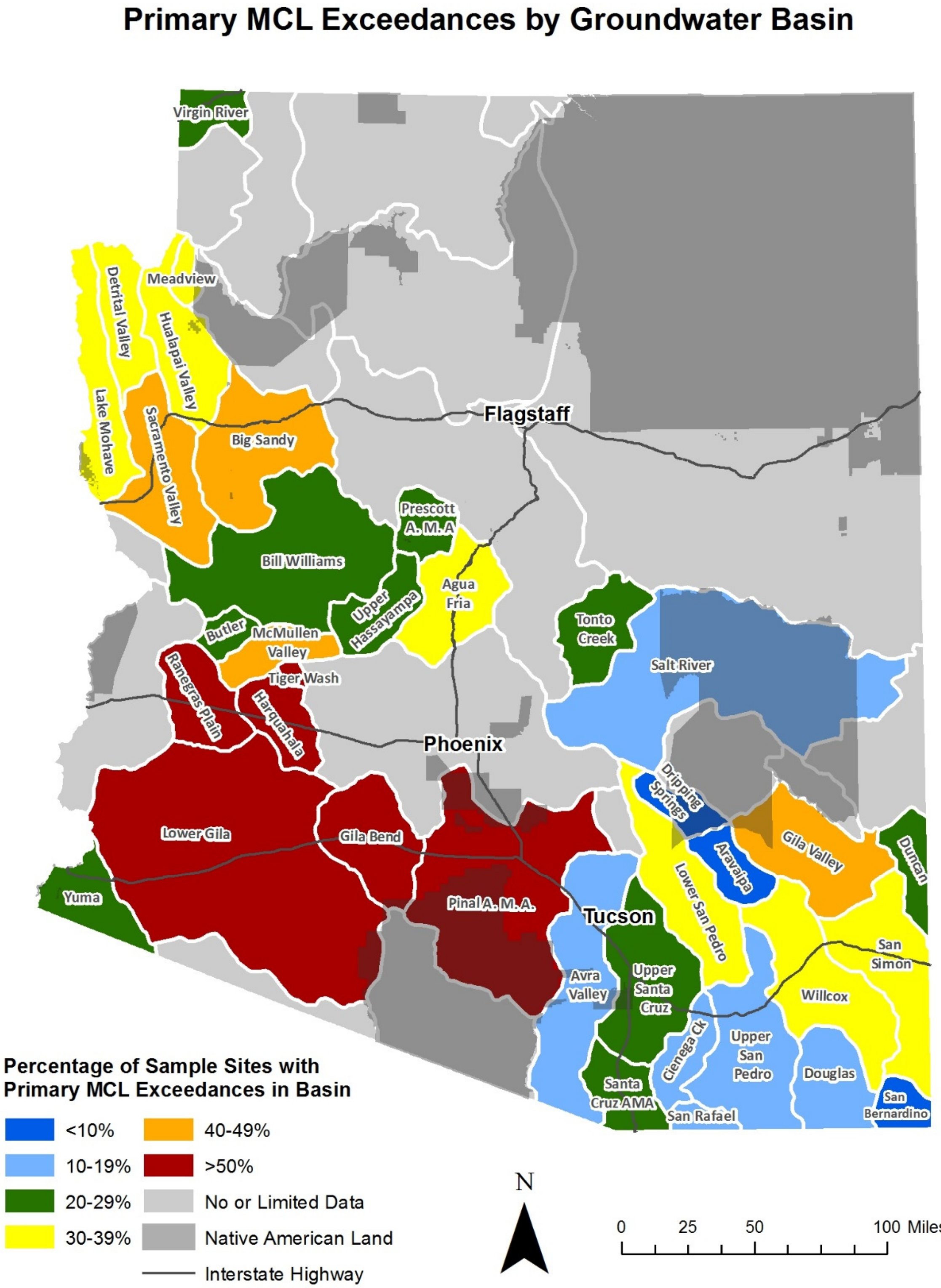

Figure 20 - Overall Primary MCL Exceedances by Basin

Table 5a – Water Quality Status of Samples by Groundwater Basin

Basin	# of Sites Sampled	Primary MCL Exceedances		Primary and Secondary MCL Exceedances		Secondary MCL Exceedances		No MCL Exceedances	
Little Colorado / San Juan Watershed									
Morenci	1	0	0 %	0	0 %	0	0 %	0	0 %
Ltl Colorado Rvr	7	0	0 %	0	0 %	4	57 %	3	43 %
Colorado / Grand Canyon Watershed									
Virgin River	38	9	24 %	5	13 %	20	53 %	9	24 %
Hualapai Valley	26	9	35 %	9	35 %	8	31 %	9	35 %
Meadview	8	3	38 %	2	25 %	2	25 %	3	38 %
Detrital Valley	28	9	32 %	5	18 %	6	21 %	13	46 %
Bill Williams Watershed									
Big Sandy	56	24	43 %	19	34 %	9	16 %	23	41 %
Bill Williams	101	27	27 %	24	24 %	25	25 %	49	0 %
Verde Watershed									
Prescott AMA	58	17	29 %	5	9 %	4	7 %	37	64 %
Salt Watershed									
Salt River	75	6	8 %	6	8 %	26	35 %	47	63 %
Tonto Creek	31	8	26 %	4	13 %	4	13 %	22	71 %
Upper Gila Watershed									
San Simon	77	25	32 %	24	31 %	24	31 %	28	36 %
Duncan Valley	55	12	21 %	8	14 %	26	46 %	19	33 %
Gila Valley	65	30	46 %	30	46 %	24	37 %	11	17 %
San Pedro Watershed									
San Bernardino	14	0	0 %	0	0 %	6	43 %	8	57 %
Douglas	52	8	15 %	6	6 %	10	20 %	34	65 %
Willcox	58	22	46 %	20	42 %	3	6 %	33	57 %
Aravaipa Canyon	15	0	0 %	0	0 %	4	27 %	11	73 %
Dripping Spring	12	0	0 %	0	0 %	0	0 %	12	100 %
Upper San Pedro	73	7	10 %	5	7 %	19	26 %	47	64 %
Lower San Pedro	63	19	30 %	17	27 %	12	19 %	32	51 %
Santa Cruz Watershed									
San Rafael	20	2	10 %	2	10 %	1	5 %	17	85 %
Cienega Creek	20	3	15 %	0	0 %	2	10 %	15	75 %
Upper Santa Cruz	65	12	19 %	7	11 %	10	15 %	36	55 %
Avra Valley	42	4	10 %	2	5 %	8	19 %	30	71 %
Pinal AMA	86	60	70 %	42	49 %	18	21 %	8	9 %

Table 5b – Water Quality Status of Samples by Groundwater Basin--Continued

Basin	# of Sites Inorganic / Radionuclide	Sites Exceeding Arsenic MCL		Sites Exceeding Fluoride MCL		Sites Exceeding Nitrate MCL		Sites Exceeding Radionuclide MCL	
Middle Gila Watershed									
Avra Valley	42	4	10 %	2	5 %	8	19 %	30	71 %
Upr Hassayampa	34	9	26 %	8	24 %	5	15 %	20	59 %
McMullen Valley	124	56	45 %	52	42 %	35	28 %	33	27 %
Tiger Wash	5	3	60 %	0	0 %	0	0 %	2	40 %
Harquahala	51	3	75 %	3	75 %	1	25 %	0	0 %
Phoenix AMA	18	9	45 %	8	44 %	14	78 %	3	17 %
Gila Bend	77	42	55 %	42	55 %	77	100 %	0	0 %
Colorado / Lower Gila Watershed									
Lake Mohave	43	15	35 %	12	28 %	19	44 %	9	21 %
Sacramento Vly	48	23	48 %	22	46 %	6	8 %	19	40 %
Butler Valley	9	0	0 %	0	0 %	0	0 %	2	100 %
Ranegras Plain	55	6	86 %	6	86 %	1	14 %	0	100 %
Lower Gila	51	37	73 %	35	69 %	43	84 %	5	10 %
Yuma	55	11	20 %	11	20 %	44	80 %	0	0 %
Total	**1762**	**547**	**31 %**	**531**	**30 %**	**996**	**57 %**	**667**	**38 %**

Figure 21 - About one-third of sites had health-based water quality exceedances.

Secondary MCL Exceedances

There are 15 inorganic constituents that have Secondary MCLs: aluminum, chloride, color, corrosivity, fluoride, foaming agents, iron, manganese, odor, pH, silver, sulfate, total dissolved solids (TDS), and zinc.

The ADEQ ambient groundwater monitoring program does not routinely test for color, corrosivity, foaming agents, or odor which are somewhat subjective and can be evaluated by domestic well owners

Of the 1,766 sites where samples were collected, 996 or (57 percent) exceeded at least one water quality guideline or Secondary MCL.

Figure 22 - Tres Alamos Spring is a vital water source for wildlife in the Bill Williams basin.

Figure 23 - ADEQ's Jason Jones samples a well in the Eagletail Mountains Wilderness Area.

The constituents that most commonly exceeded water quality standards (Figure 24) include TDS (769 sites or 44 percent) (Figure 26), fluoride (510 sites or 29 percent), sulfate (384 sites or 22 percent), chloride (336 sites or 19 percent), manganese (152 sites or 9 percent), iron (118 sites or 7 percent), and pH (94 sites > 8.5 su and 6 sites < 6.5, or 6 percent outside range).

Aluminum (5 sites), silver (0 sites), and zinc (1 site) were rarely, if ever, detected at concentrations above water quality guidelines. These four constituents combined to exceed water quality standards at less than one percent of sites.

The Secondary MCL exceedance pattern is similar to the Primary MCL pattern (Figure 10).

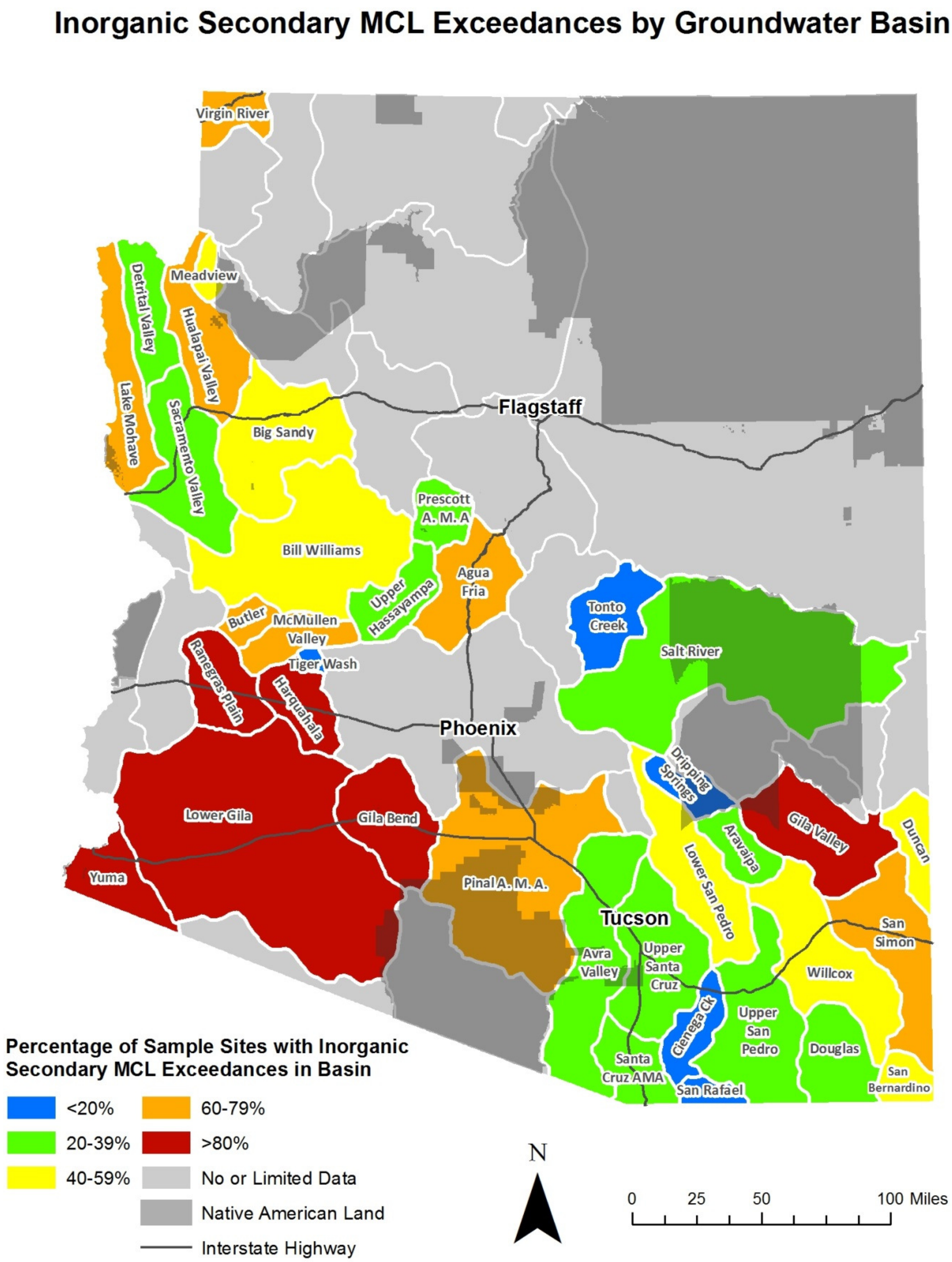

Figure 24 – Inorganic Secondary MCL Exceedances by Basin

TDS MCL Exceedances

TDS concentrations at 769 sites (44 percent) exceeded the 500 mg/L aesthetics-based, water quality standard (Figure 26). This is higher than the 26 percent exceedance rate found in a study covering the Southwest [37] and the 33 percent rate found in a previous Arizona study. [38]

The difference might be because ADEQ sampled a much higher percentage of irrigation wells than the regional study, which concentrated on public water supply and domestic wells. The regional study even noted the higher frequency of irrigation wells exceeding 2,000 mg/L, a concentration which can severely limit the types of crops grown, than in non-irrigation wells.[39]

Although TDS is a Secondary MCL, it is important because of its impact on the availability of potable water. Problems with elevated TDS concentrations include an objectionable taste, higher water-treatment costs, greater use of detergents and soaps because of usually greater water hardness, precipitation of minerals in plumbing, staining, corrosion of metallic surfaces, reduced equipment lifespan, and, to a lesser degree, restricted use of irrigation water.[40]

Elevated TDS concentrations are the result of natural processes, such as mineral dissolution as groundwater moves downgradient. Evaporative concentration can cause TDS to accumulate over time, particularly in closed basins. The upward movement of mineralized groundwater from geothermal areas is another source.[41]

Anthropomorphic sources may contribute to TDS concentrations, including agricultural activities and septic tank effluent. The use of fertilizers and treated wastewater for irrigation has resulted in the accumulation of TDS in shallow groundwater.[42]

Although TDS concentrations elevated over the aesthetics-based, water quality standard occur throughout Arizona, exceedances are highest (> 75 percent) in southwestern basins having extensive irrigated farmlands. Of note are two basins, Gila Bend and Yuma, in which every sample exceeded the Secondary MCL for TDS.

The lowest TDS concentrations are generally found in southeastern Arizona, with basins located in the northwestern part of the state generally somewhere in the middle.

Figure 25 - An irrigation well in the Safford Valley produces water for farming cotton.

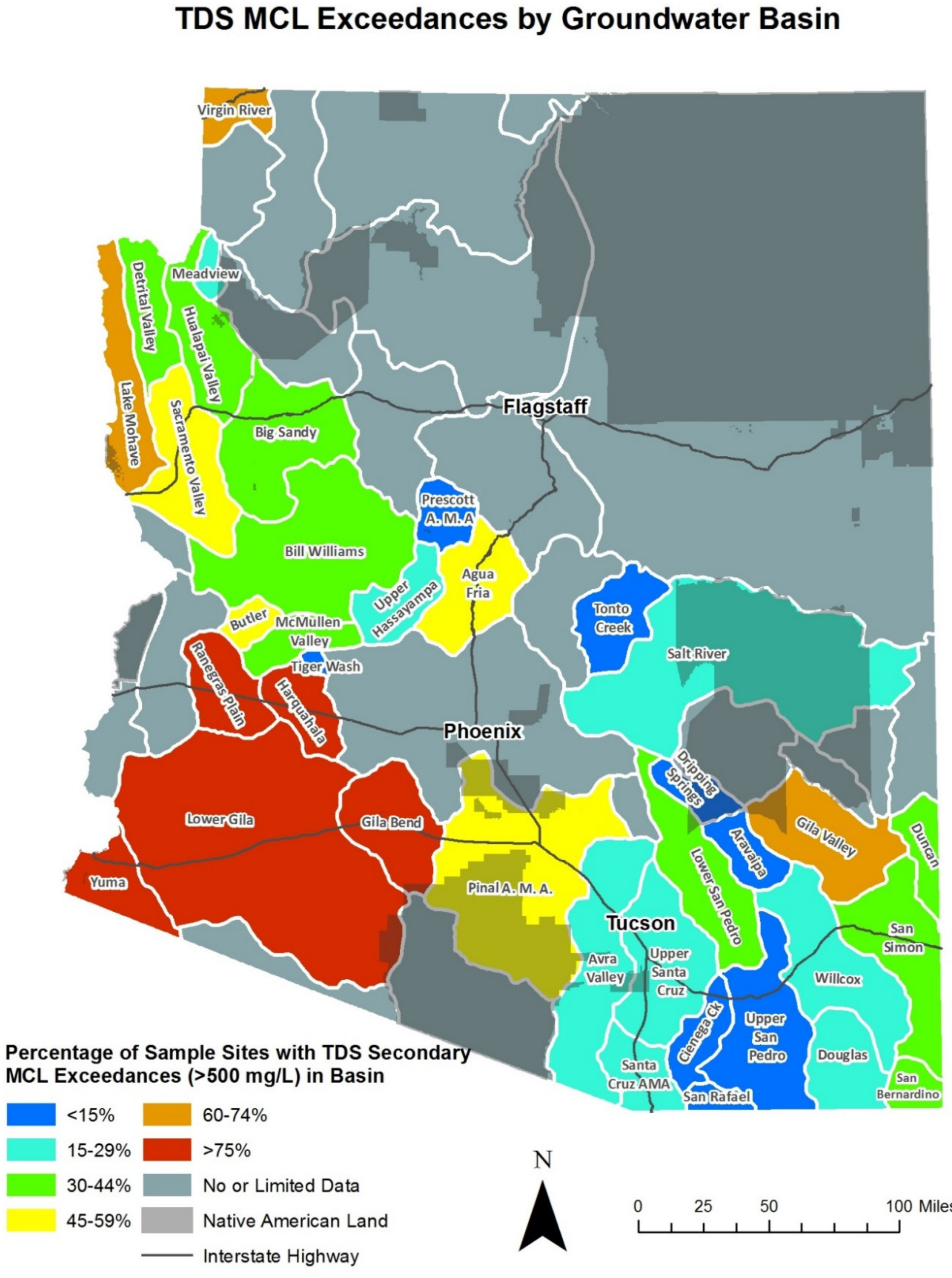

Figure 26 – TDS Secondary MCL Exceedances by Groundwater Basin

Water Chemistry

Water chemistry is the dominant (> 50 percent) cation and anions of the sample. If one of the major cations (calcium, magnesium or sodium) and anions (bicarbonate, chloride or sulfate) does not constitute more than 50 percent of the chemistry is considered mixed.

There are no standards for water chemistry, but it's important in explaining the spatial distribution of water quality exceedances. Patterns of chemistry evolving as groundwater moves through an aquifer occurs both statewide and within individual basins. The lowest frequencies of water quality standards are typically found in basins with predominately a calcium-bicarbonate chemistry. This chemistry is indicative of recent recharge, and is typically found in higher elevations near the basin's margin.[43]

As the groundwater moves downgradient through the basin, it typically evolves into a

Figure 27 - A sample's chemistry reveals the likelihood of water quality exceedances.

Figure 28 - ADEQ's Aiko Condon samples a calcium-rich well in the Agua Fria basin.

chemistry where sodium, chloride, and sulfate make up a larger portion of the chemistry. These also tend to have higher concentrations of arsenic and fluoride. The specific chemistry is dependent on many factors including residence time, the solubility of aquifer material, pH levels, and evaporate deposits. The water chemistry map (Figure 29) provides the overall dominant water chemistry of each basin in Arizona. These range from calcium-bicarbonate in the southeast, mixed-bicarbonate in the northwest, and sodium-mixed/chloride in the southwest. Within these basins, there is moderate variability in water chemistry, which influences water quality standard exceedances at specific sites.

For instance, groundwater in the Agua Fria basin is predominantly composed of mixed-bicarbonate chemistry. When compared to a small subset of samples exhibiting a sodium chemistry, significantly higher TDS, chloride, sulfate, arsenic, and fluoride concentrations were found in the sodium samples.[44]

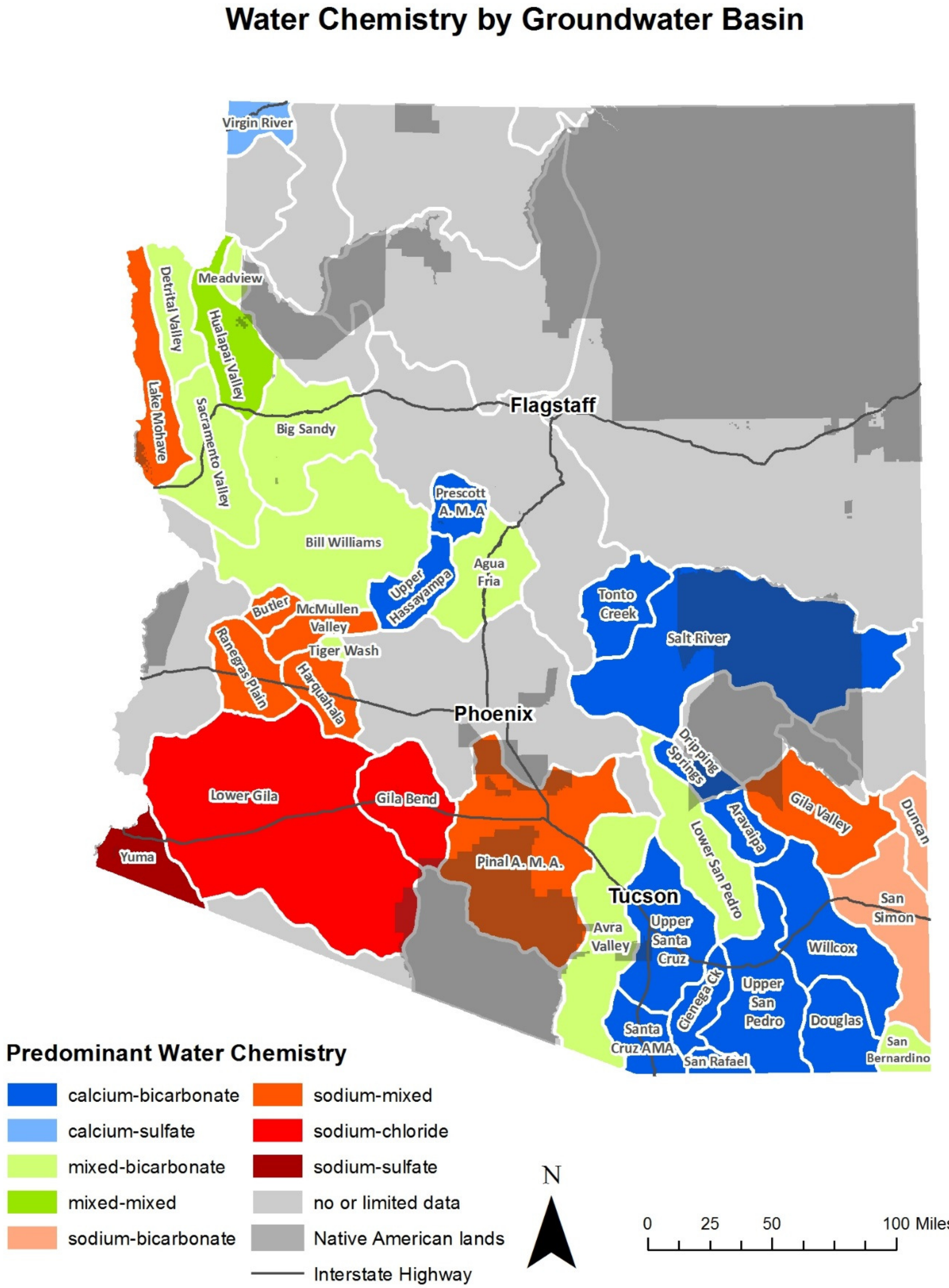

Figure 29 - Water Chemistry by Groundwater Basin

VOC and Pesticide Sampling

From the limited collection of VOC and pesticide samples, few anthropomorphic organic compounds were detected and these did not exceed Primary MCLs. VOC detections could usually be traced to disinfection by-products or by PVC glue used by the well owner to create a sample port near the wellhead a day or two before sampling by ADEQ.

In contrast, VOCs were detected in 43 percent of wells while pesticides, or pesticide degradates were detected in 45 percent of wells in a study covering the Southwest. The concentrations, however, were low and mostly below detection limits of labs used by ADEQ.

Figure 30 - This bilingual notice announces that pesticides have recently been applied.

Figure 31 - Although 115 wells were tested, there were few pesticide detections by ADEQ.

VOC contamination of groundwater is typically found in the vicinity of industrial or defense facilities. These sites are being remediated through various federal EPA programs or the state Water Quality Assurance Revolving Fund (WQARF) program.

These point-source sites are found throughout the state but many are located in the Phoenix and Tucson metropolitan areas.

A listing of sites is on the ADEQ website: www.azdeq.gov/environ/waste/sps/siteinfo.html

Conclusions

Of the 1,766 sites sampled, 35 percent exceeded at least one Primary MCL. This frequency is similar to other studies which examined water quality in Arizona and the Southwest, and provides a rough estimate of wells, state-wide, which do not meet health-based water quality standards. [4546]

Most sites (86 percent) with Primary MCL exceedances also had Secondary MCL or aesthetics-based exceedances. Overall, Secondary MCL exceedances occurred at 57 percent of sites, while 38 percent of sites had no exceedances of water quality standards. Thus, the majority of sites (65 percent) sampled for this Arizona groundwater quality study meet EPA's Primary MCLs, and could be used for public water supply without any more than standard treatment.

More than 98 percent of exceedances were caused by elevated concentrations of four constituents: arsenic (22 percent), fluoride (11 percent), nitrate (10 percent) and gross alpha and/or uranium (16 percent of 641 radionuclide samples). Water quality exceedances with VOCs and pesticides were only very rarely found, and often were influenced by above-ground plumbing.

Some specific constituents are summarized below.

Arsenic - The most significant groundwater regulatory impact was the lowering of the arsenic standard from 0.05 mg/L to 0.01 mg/L that took effect nationwide on January 26, 2006. The standard change resulted in Primary MCL exceedances for arsenic increasing from two percent under the former standard to 22 percent using the current standard. With the change, arsenic became, by far, the most prominent Primary MCL exceedance in Arizona.

Fluoride – This constituent is unique in that there is a higher frequency of exceedances in Arizona than nationwide, or even in the Southwest. Typically, "soft" groundwater with low concentrations of calcium is an indication that fluoride concentrations will likely exceed the Primary MCL.

Nitrate – The 11 percent exceedance frequency for this constituent matches the rate found in a study covering the Southwest. The predictability of wells exceeding the Primary MCL for nitrate depends on the source. In agricultural areas, shallow domestic wells have a high probability for elevated nitrate concentrations. In contrast, nitrate exceedances from wastewater disposal from septic systems and/or natural legume sources are challenging to predict.

Radionuclides – The extent of SDW exceedances by these constituents is the most difficult to ascertain. These samples were obtained at only 36 percent of sites, so determining their impact if collected at all 1,766 sites is difficult. Furthermore, recent information that the analysis method used for samples collected prior to 2010 had gross alpha biases towards higher values, putting in doubt the reliability of the data. Radionuclide exceedances are probably less than the 16 percent reported in this study, judging by the few exceedances since the new method was instituted in 2010.

VOCs and Pesticides – These samples were collected at far lower frequencies than radionuclides. Their results, overwhelmingly non-detect, indicate that sampling for these contaminants at each of the 1,766 sites would probably not have significantly impacted the frequency of Primary MCL exceedances.

The ADEQ study is arguably the most comprehensive overview of groundwater quality in Arizona. However, the report's water quality standard exceedance rates should be used cautiously because of several biases in the data. These biases include the varying sample sizes of each study, which depended on a basin's hydrologic complexity and the available sampling budget, which resulted in different sampling densities. The basins selected for study also impact the data, as exceedance frequencies varied by region.

Discussion

While these state-wide groundwater quality results provide a broad overview, the ADEQ Groundwater Monitoring Program is able to offer much more site-specific results in many areas to owners of domestic wells in Arizona. This hierarchy begins at a state-wide scale, and gets more specific moving to a basin-wide scale, sub-basin scale (i.e. sub-basins, aquifers, physiographic areas, watersheds, groundwater age, and/or geologic areas), and finally to examining sample sites located in the vicinity of the well.

State-wide, 35 percent of sites have Primary MCL exceedances, 27 percent of sites have only Secondary MCL exceedances, and 38 percent of sites have no water quality exceedances.

At the basin scale, sites with Primary MCL exceedances range from 71 percent (Harquahala, Lower Gila, and Ranegras Plain basins) to 0 percent (Aravaipa Canyon, Dripping Springs, and San Bernardino basins). Wells having no water quality exceedances range from 100 percent (Dripping Springs basin) to 0 percent (Gila Bend and Yuma basins).

Within these basins, there is often a high intra-basin variability with water quality. A good example is the Lower Gila basin, where 71 percent of the 63 sites exceed Primary MCLs. However, there were many intra-basin differences when examined by recharge source. Primary MCL exceedance rates were 82 percent for Colorado River recharge, 74 percent for Gila River recharge, and 17 percent for local recharge.

Another example is the Lower San Pedro basin, where 32 percent of the 63 sites exceed Primary MCLs. When examined by aquifer, there was a wide range of variability. Primary MCL exceedance rates were 80 percent for the confined aquifer, 30 percent for the floodplain aquifer, 26 percent for hard rock sites, and 22 percent for the basin-fill aquifer.[47]

The study also provides information on where there is a higher probability of locating groundwater without Secondary MCL exceedances, which occurred at 46 percent of sites in the basin. Frequencies for sites with no water quality exceedances were 20 percent for the confined aquifer, 30 percent for the floodplain aquifer, 52 percent for hard rock sites, and 78 percent for the basin-fill aquifer. Thus, Secondary MCL exceedances are common in the floodplain aquifer and rare in the basin-fill aquifer.[48]

Maps contained in the basin reports can also be used by domestic well owners to examine the water quality of wells in the vicinity. The maps should be used cautiously since there are limitations in representing a three-dimensional groundwater unit on a two-dimensional map. For example, two wells adjacent to one another could be drawing groundwater from different aquifers that have a very different water quality.

The tools offered by these reports will be helpful to domestic well owners in order to assess the potential threats of their water source. This is especially true in regards to where arsenic, fluoride, nitrate and gross alpha are likely to occur. Domestic well owners should be aware, however, that exceedances of these constituents can potentially occur in water produced by any well.

Recommendations

Private well owners should test for arsenic, fluoride, nitrate, gross alpha, and uranium at a minimum.

In addition, ADEQ recommends testing for total coliform bacteria, copper, and lead which can be introduced to the water supply through the plumbing system.

Although ADEQ recommends homeowners having a private well for domestic use have the water tested for the full suite of inorganic and radionuclide SDW requirements to ensure safety, the above recommendation is a less expensive venture. For 18 constituents (excluding asbestos, cyanide and turbidity), these combined analytical tests would cost approximately $550 at a local laboratory certified by the Arizona Department of Health Services.[49]

However, if the well owner doesn't desire such extensive testing, there is an alternative that will likely reveal most water quality standard exceedances. Arsenic, fluoride, nitrate, gross alpha, and uranium are the five constituents that caused 98 percent of health based water quality exceedances in 1,766 wells in Arizona. Analytical costs for these vie constituents along with total coliform bacteria, copper, and lead would cost approximately $300.[50]

Domestic well owners interested in testing their groundwater quality can find additional information on the EPA website (http://water.epa.gov/drink/index.cfm).

Local county extension offices can also provide technical assistance and occasionally offer limited water quality testing for well owners.

---

[1] Accutest, 2015, Email correspondence from Maureen Coloma, Project Manager, received December 28, 2015.
[2] Thiros, S.A., Paul, A.P., Bexfield, L.M., and Anning, D.W., 2014, The quality of our Nation's waters—Water quality in basin-fill aquifers of the southwestern United States: Arizona, California, Colorado, Nevada, New Mexico, and Utah, 1993-2009: U.S. Geological Survey Circular 1358, p. 4.
[3] Marrero-Ortiz, Roberto; Riley, Kelley R.; Karpiscak, Martin K. and Gerba, Charles P., "Groundwater quality of individual wells and small systems in Arizona," *American Water Works Association Journal*, Sept. 2009, 101:9, p. 95.
[4] Arizona Department of Environmental Quality (ADEQ), 2015-2016, Arizona laws relating to environmental quality: St. Paul, Minnesota, West Group Publishing, §49-221-224, p 134-137.
[5] Arizona Department of Water Resources (ADWR) website, http://www.azwater.gov/AzDWR/PublicInformationOfficer/documents/supplydemand.pdf, accessed 11/04/15.
[6] Arizona Department of Environmental Quality (ADEQ), 2015-2016, Arizona laws relating to environmental quality: St. Paul, Minnesota, West Group Publishing, §49-221-224, p 134-137.
[7] ADWR website, http://www.azwater.gov/azdwr/GIS/documents/GWBasin.pdf

[8] DeSimone, L.A., Hamilton, P.A., Gilliom, R.J., 2009, Quality of water from domestic wells in principal aquifers of the United States, 1991–2004—Overview of major findings: U.S. Geological Survey Circular 1332, 48 p.
[9] Thiros, S.A., Paul, A.P., Bexfield, L.M., and Anning, D.W., 2014, The quality of our Nation's waters—Water quality in basin-fill aquifers of the southwestern United States: Arizona, California, Colorado, Nevada, New Mexico, and Utah, 1993-2009: U.S. Geological Survey Circular 1358, p. 10.
[10] Marrero-Ortiz, Roberto; Riley, Kelley R.; Karpiscak, Martin K. and Gerba, Charles P., "Groundwater quality of individual wells and small systems in Arizona," *American Water Works Association Journal*, Sept. 2009, 101:9, p. 95.
[11] Artiola, Janick F., and Uhlman, Kristine, "Arizona Well Owner's Guide to Water Supply, University of Arizona AZ 1485, http://extension.arizona.edu/sites/extension.arizona.edu/files/pubs/az1485.pdf , p.6, accessed 11/04/15.
[12] ADEQ, 1991, Quality assurance project plan: ADEQ Water Standards Unit, 209 p.
[13] U.S. Environmental Protection Agency (EPA) website, http://water.epa.gov/drink/contaminants/, accessed 11/04/15.
[14] ADEQ website, http://apps.azsos.gov/public_services/Title_18/18-11.pdf, accessed 11/04/15.
[15] Coes, A.L., Gellenbeck, D.J., Towne, D.C., and Freark, M.C., 2000, Ground-water quality in the Upper Santa Cruz basin, Arizona, 1998, U.S. Geological Water-Resources Investigations Report 00-4117, 55 p.
[16] Thiros, S.A., Paul, A.P., Bexfield, L.M., and Anning, D.W., 2014, The quality of our Nation's waters—Water quality in basin-fill aquifers of the southwestern United States: Arizona, California, Colorado, Nevada, New Mexico, and Utah, 1993-2009: U.S. Geological Survey Circular 1358, p. 44.
[17] Ibid., p. 51.
[18] Ibid., p. 30.
[19]Ibid., p. 33.
[20] Towne, Douglas C., 2005, Ambient groundwater quality of the Lake Mohave basin: A 2003 baseline study: ADEQ Open File Report 05-08, p. 27.
[21] Towne, Douglas C. and Yu, Wang K., 1998, Ambient groundwater quality of the Yuma basin: A 1995 baseline study: ADEQ Open File Report 98-07, p. 83.
[22] Thiros, S.A., Paul, A.P., Bexfield, L.M., and Anning, D.W., 2014, The quality of our Nation's waters—Water quality in basin-fill aquifers of the southwestern United States: Arizona, California, Colorado, Nevada, New Mexico, and Utah, 1993-2009: U.S. Geological Survey Circular 1358, p. 44.
[23] 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, pp. 90.
[24] Coes, A.L., Gellenbeck, D.J., and Towne, D.C., 1999, Ground-water quality in the Sierra Vista sub-basin, Arizona, 1996-97, U.S. Geological Water-Resources Investigations Report 99-4056, 37 p.
[25] Towne, Douglas C., 2011, Ambient groundwater quality of the Ranegras Plain basin: A 2008-2011 baseline study: ADEQ Open File Report 11-07, p. 33.
[26] Towne, Douglas C., 2006, Ambient groundwater quality of the Big Sandy basin: A 2003-2004 baseline study: ADEQ Open File Report 06-09, p. 39.
[27] Thiros, S.A., Paul, A.P., Bexfield, L.M., and Anning, D.W., 2014, The quality of our Nation's waters—Water quality in basin-fill aquifers of the southwestern United States: Arizona, California, Colorado, Nevada, New Mexico, and Utah, 1993-2009: U.S. Geological Survey Circular 1358, p. 40.
[28] Ibid., p. 40.
[29] Towne, Douglas C., 2011, Ambient groundwater quality of the McMullen Valley basin: A 2008-2009 baseline study: ADEQ Open File Report 11-02, p. 47.
[30] Towne, Douglas C., 2015, Ambient groundwater quality of the Gila Bend basin: A 2012-2015 baseline study: ADEQ Open File Report 15-07, p. 47.
[31] Towne, Douglas C. and Freak, Maureen C. 1999, Ambient groundwater quality of the Sacramento Valley basin: A 1999 baseline study: ADEQ Open File Report 01-04, p. 30.
[32] Lowry, Jerry D. and Lowry, Sylvia B, 1988, "Radionuclides in Drinking Waters," in *American Water Works Association Journal*, July 1988.
[33] Radiation Safety Engineering, Inc, 2015, Personal communication from Robert L. Metzger, Ph.D.
[34] Ibid.

[35] Thiros, S.A., Paul, A.P., Bexfield, L.M., and Anning, D.W., 2014, The quality of our Nation's waters—Water quality in basin-fill aquifers of the southwestern United States: Arizona, California, Colorado, Nevada, New Mexico, and Utah, 1993-2009: U.S. Geological Survey Circular 1358, p. 63-64.
[36] Ibid., p. 40.
[37] Ibid., p. 74.
[38] Marrero-Ortiz, Roberto; Riley, Kelley R.; Karpiscak, Martin K. and Gerba, Charles P., "Groundwater quality of individual wells and small systems in Arizona," *American Water Works Association Journal*, Sept. 2009, 101:9, p. 97.
[39] Thiros, S.A., Paul, A.P., Bexfield, L.M., and Anning, D.W., 2014, The quality of our Nation's waters—Water quality in basin-fill aquifers of the southwestern United States: Arizona, California, Colorado, Nevada, New Mexico, and Utah, 1993-2009: U.S. Geological Survey Circular 1358, p. 46.
[40]Ibid., p. 70.
[41] Ibid., p. 71.
[42] Gail Cordy, et al, Water Quality in the Central Arizona Basins, Arizona, 1995-1998. U.S. Geological Survey Circular 1213, p. 2.
[43] 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, pp. 90
[44] Towne, Douglas C., 2008, Ambient groundwater quality of the Agua Fria basin: A 2004-2006 baseline study: ADEQ Open File Report 08-02, p. 36.
[45] Thiros, S.A., Paul, A.P., Bexfield, L.M., and Anning, D.W., 2014, The quality of our Nation's waters—Water quality in basin-fill aquifers of the southwestern United States: Arizona, California, Colorado, Nevada, New Mexico, and Utah, 1993-2009: U.S. Geological Survey Circular 1358, p. 4.
[46] Marrero-Ortiz, Roberto; Riley, Kelley R.; Karpiscak, Martin K. and Gerba, Charles P., "Groundwater quality of individual wells and small systems in Arizona," *American Water Works Association Journal*, Sept. 2009, 101:9, p. 95.
[47] Towne, Douglas C., 2002, Ambient groundwater quality of the Lower San Pedro basin: A 2000 baseline study: ADEQ Open File Report 02-01, p.40.
[48] ibid, p.40.
[49] Accutest, 2015, Email correspondence from Maureen Coloma, Project Manager, received December 28, 2015.
[50] Ibid.