



Janet Napolitano, Governor
Stephen A. Owens, ADEQ Director

Ambient Groundwater Quality of the Meadview Basin A 2000-2003 Baseline Study

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Ambient Groundwater Quality of the Meadview Basin: A 2000-2003 Baseline Study

By Douglas C. Towne
Maps by Lisa Rowe

Arizona Department of Environmental Quality Open File Report 2005-01

ADEQ Water Quality Division
Hydrologic Support & Assessment Section
Groundwater Monitoring Unit
1110 West Washington St.
Phoenix, Arizona 85007-2935

Thanks:

Field Assistance: Elizabeth Boettcher, Maureen Freark, and Angela Lucci

Report Cover: Nancy Caroli

ADEQ Management: Linda Taunt - Manager, Hydrologic Support and Assessment Section
Wang Yu - Supervisor, Groundwater Monitoring Unit

Photo Credits: Douglas Towne

Report Cover: *Marking the transition zone between the Colorado Plateau and Basin and Range provinces, the Grand Wash Cliffs are an area of rugged canyons, scenic escarpments and colorful sandstone buttes. The cliffs form the eastern boundary of the Meadview groundwater basin. In the foreground, the now derelict Grapevine Windmill, in Grapevine Wash, rises among the yucca.*

Other Publications of the ADEQ Ambient Groundwater Monitoring Program

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

San Simon Sub-Basin	OFR 04-02, October 2004, 78 p.
Detrital Valley Basin	OFR 03-03, November 2003, 65 p.
San Rafael Basin	OFR 03-01, February 2003, 42 p.
Lower San Pedro Basin	OFR 02-01, July 2002, 74 p.
Willcox Basin	OFR 01-09, November 2001, 55 p.
Sacramento Valley Basin	OFR 01-04, June 2001, 77 p.
Upper Santa Cruz Basin	OFR 00-06, Sept. 2000, 55 p. (With the U.S. Geological Survey)
Prescott Active Management Area	OFR 00-01, May 2000, 77 p.
Upper San Pedro Basin	OFR 99-12, July 1999, 50 p. (With the U.S. Geological Survey)
Douglas Basin	OFR 99-11, June 1999, 155 p.
Virgin River Basin	OFR 99-04, March 1999, 98 p.
Yuma Basin	OFR 98-07, September, 1997, 121 p.

ADEQ Ambient Groundwater Quality Factsheets (FS):

Meadview Basin	FS 05-01, January 2005, 4 p.
San Simon Sub-basin	FS 04-06, October 2004, 4 p.
Detrital Valley Basin	FS 03-07, November 2003, 4 p.
San Rafael Basin	FS 03-03, February 2003, 4 p.
Lower San Pedro Basin	FS 02-09, August 2002, 4 p.
Willcox Basin	FS 01-13, October 2001, 4 p.
Sacramento Valley Basin	FS 01-10, June 2001, 4 p.
Yuma Basin	FS 01-03, April 2001, 4 p.
Virgin River Basin	FS 01-02, March 2001 4 p.
Prescott Active Management Area	FS 00-13, December 2000, 4 p.
Douglas Basin	FS 00-08, September 2000, 4 p.
Upper San Pedro Basin	FS 97-08, August 1997, 2 p. (With the U.S. Geological Survey)

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

An Assessment of Methyl Tertiary-Butyl Ether (MTBE) Groundwater Occurrence in Maricopa County.
ADEQ Open File Report 02-03, February 2003, 48 p.

The Impacts of Septic Systems on Water Quality of Shallow Perched Aquifers: A Case Study of Fort Valley, Arizona. ADEQ Open File Report 97-7, February 1997, 70 p.

Most of these publications are available on-line.
Visit the ADEQ Ambient Groundwater Monitoring Program at:

<http://www.azdeq.gov/environ/water/assessment/ambientst.html>

<http://www.azdeq.gov/environ/water/assessment/targeted.html>

Status of GW Basins in the Ambient Monitoring Program

January 2005

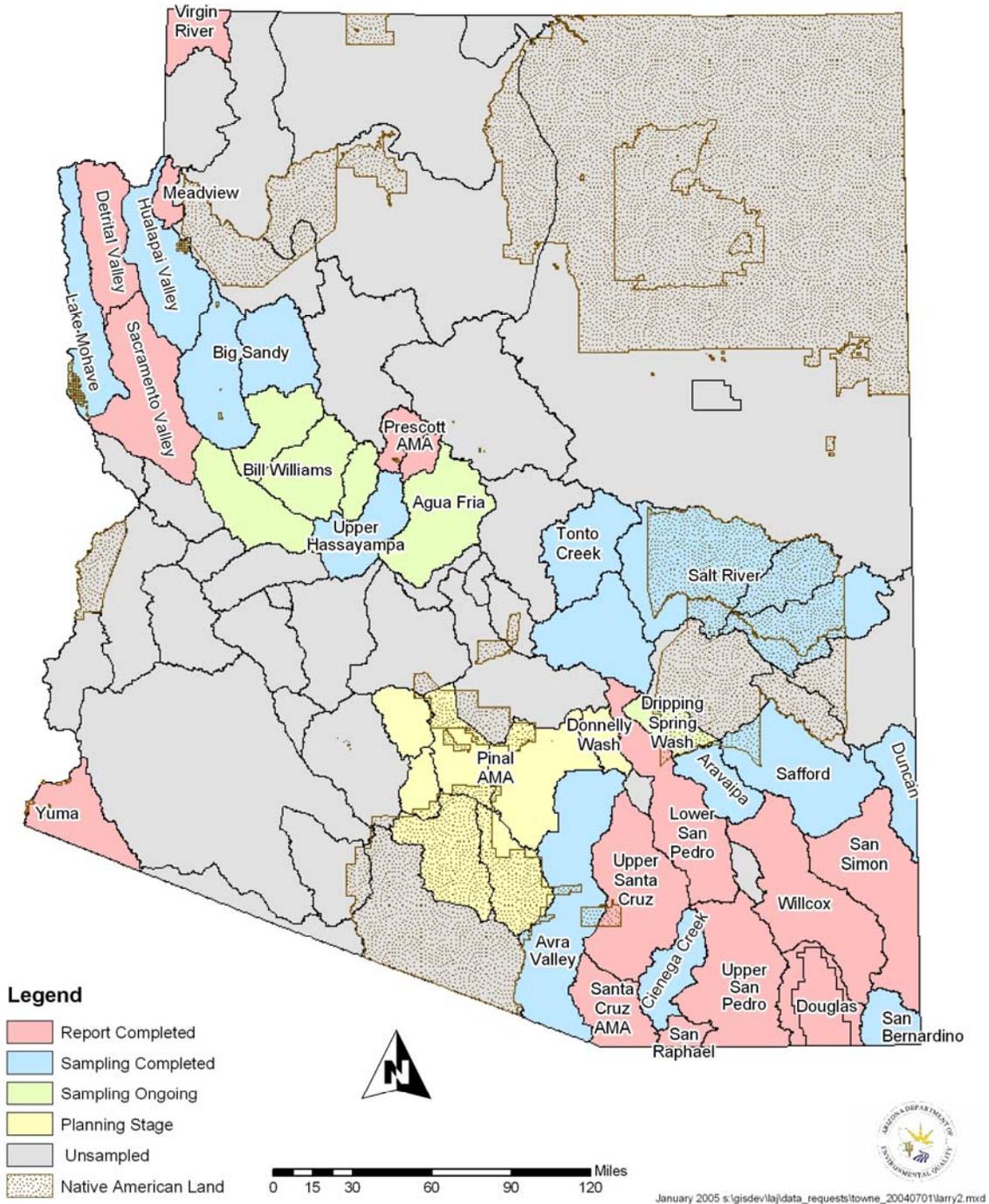


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Abbreviations

amsl	above mean sea level
af	acre-feet
af/yr	acre-feet per year
ADEQ	Arizona Department of Environmental Quality
ADHS	Arizona Department of Health Services
ADWR	Arizona Department of Water Resources
ARRA	Arizona Radiation Regulatory Agency
AZGS	Arizona Geological Survey
As	arsenic
bls	below land surface
BLM	U.S. Department of the Interior Bureau of Land Management
°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 pesticide
HCl	hydrochloric acid
LLD	Lower Limit of Detection
Mn	manganese
MCL	Maximum Contaminant Level
MEA	Meadview groundwater basin
ml	milliliter
msl	mean sea level
F g/L	micrograms per liter
F m	micron
F S/cm	microsiemens per centimeter at 25E Celsius
mg/L	milligrams per liter
MRL	Minimum Reporting Level
MTBE	Methyl tertiary-Butyl Ether
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
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound

“I can count the hydrology/geohydrology references about the Meadview basin on one hand with plenty of fingers left over.”

Raymond Harris
Arizona Geological Survey

Ambient Groundwater Quality of the Meadview Basin: A 2000-2003 Baseline Study

By Douglas Towne

Abstract - The Meadview groundwater basin (MEA), known unofficially as “Where Lake Mead Meets the Grand Canyon,” comprises approximately 190 square miles in northwestern Arizona.⁴ This small basin is sometimes considered a sub-basin of the Hualapai groundwater basin.²¹ Lightly populated, most land within the MEA is managed by the Bureau of Land Management or the National Park Service as part of the Lake Mead National Recreation area.³ Most residents live in the retirement and recreation-oriented community of Meadview that was founded in the early 1960s.¹⁷ Meadview is supplied with water by the Joshua Valley Utility Company.⁴

The basin is drained by Grapevine Wash, an ephemeral waterway that debouches into Lake Mead. A short perennial reach in the wash is caused by discharge from Grapevine Spring.⁴ The Muddy Creek Formation is the main aquifer in the basin and can be divided into three units: an upper limestone unit, a middle sandstone/siltstone unit, and a basal conglomerate.¹⁸ Although each unit is capable of producing water, most wells draw from the basal conglomerate because of its high hydraulic conductivity.⁴ Where sufficiently fractured and faulted, mountain bedrock at the margins also provides limited supplies.

A baseline groundwater quality study of the MEA was conducted by the Arizona Department of Environmental Quality from 2000-2003. For the study, 8 groundwater sites were sampled for inorganic constituents. Samples were also collected at selected sites for isotopes of oxygen and hydrogen (6 sites), radon gas (2 sites), radiochemistry (2 sites), and volatile organic compounds (VOCs) (1 site) analyses.

To characterize this small basin, 8 sites were sampled. Three sites met all federal and State water quality standards. Concentrations of at least one constituent exceeded a health-based, federal or State water-quality standard at 3 different sites. These enforceable standards define the maximum concentrations of constituents allowed in water supplied to the public and are based on a lifetime daily consumption of two liters per person.²⁷ Health-based exceedances included arsenic (0 sites under current standards, 1 site under standards effective in 2006), gross alpha (2 sites) and uranium (1 site). At 4 sites, concentrations of at least one constituent exceeded an aesthetics-based, federal water-quality guideline. These are unenforceable guidelines that define the maximum concentration of a constituent that can be present in drinking water without an unpleasant taste, color, odor, or other effect.²⁷ Aesthetics-based exceedances included fluoride (3 sites) and total dissolved solids (TDS) (2 sites).

Based on sample results, groundwater chemistry is typically a calcium/mixed-bicarbonate/mixed type. Groundwater is considered *fresh* (TDS less than 1,000 milligrams per Liter (mg/L)), *slightly alkaline* (greater than 7 standard units pH), and *moderately to very hard* (greater than 150 mg/L).^{11, 14} Nitrate concentrations frequently exceeded 3 mg/L, which is often an indication that human activities have impacted groundwater quality.²⁰ Similar patterns in other nearby basins have shown this is more likely the result of natural soil organic matter because of deep groundwater depths and nitrogen isotope results.^{25, 26} Fluoride, boron, chromium, and zinc were trace elements detected at more than 33 percent of sample sites. Antimony, arsenic, barium, beryllium, cadmium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, and thallium were rarely detected. Isotope results (available for six of eight sites) matched those from sites in the nearby Detrital Valley basin that were from deep wells and/or springs.²⁶ These sites are thought to represent the oldest water in the basin, recharged during a colder climate. This groundwater age corresponds to the low precipitation and recharge rates occurring in the Meadview basin.⁴

Groundwater movement in the basin is from south to north.²¹ Bicarbonate and calcium concentrations were significantly higher in samples influenced by granitic geology in the south than in the alluvium/sedimentary rock further north; the opposite pattern occurs with chloride and nitrate concentrations (ANOVA test, $p \leq 0.05$). This illustrates a groundwater flow path with calcium-bicarbonate (often indicative of recharge zones) of the highland areas gradually evolving into more of a mixed chemistry as it moves downgradient to the north.²⁴ As frequently occurs, sample sites impacted by granite often exceeded health-based water quality standards for gross alpha and uranium.¹⁹ Aesthetics-based standards for fluoride and TDS also occurred. In contrast, sample sites further north in alluvium/sedimentary rock usually met water quality standards with the exception of arsenic, fluoride, and TDS at one site apiece. The arsenic exceedance of 0.01 mg/L occurred at Grapevine Spring. This arsenic concentration is the 2006 health-based water quality standard effective in 2006 and the minimum reporting limit for the state laboratory used in the study.^{23, 27}

INTRODUCTION

Purpose and Scope

The Meadview groundwater basin (MEA) is located in a remote portion of Mohave County in northwestern Arizona (Map 1). The north-south trending basin is drained by Grapevine Wash, a largely ephemeral drainage that debouches into Lake Mead. Groundwater is the primary source for municipal, domestic, and stock water uses in the MEA.⁴

The Arizona Department of Environmental Quality (ADEQ) Groundwater Monitoring Unit designed a study to characterize the current (2000-2003) groundwater quality conditions in the MEA. Sampling by ADEQ was completed as part of the Ambient Groundwater Monitoring Program, which is based on the legislative mandate in the Arizona Revised Statutes §49-225 that authorizes:

“...ongoing monitoring of waters of the state, including...aquifers to detect the presence of new and existing pollutants, determine compliance with applicable water quality standards, determine the effectiveness of best management practices, evaluate the effects of pollutants on public health or the environment, and determine water quality trends.”²

An important resource in Arizona, groundwater provides a buffer against future water shortages, base flow for rivers, and protects against land subsidence. The ADEQ ambient groundwater monitoring program examined the regional groundwater quality of MEA to:

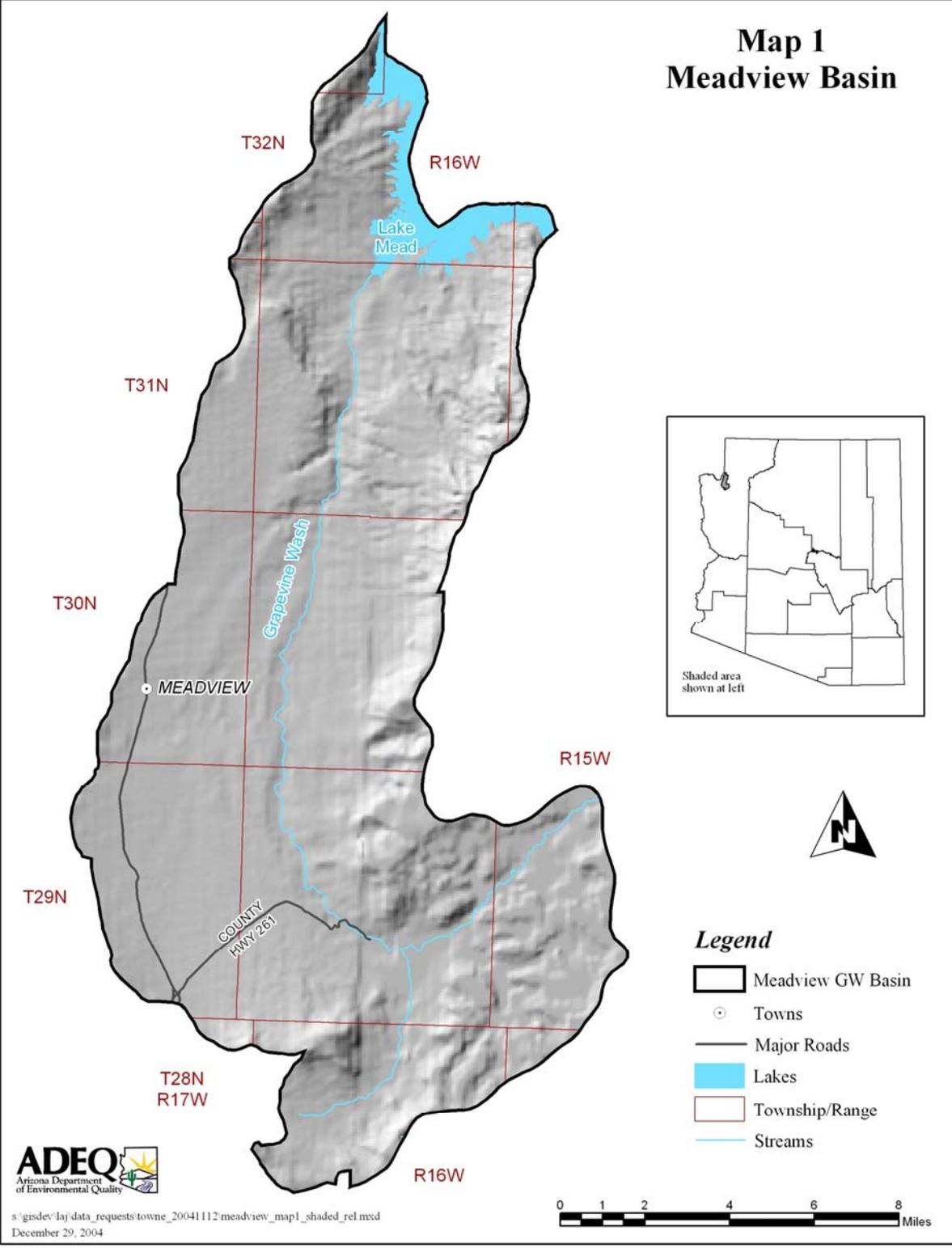
- Provide a comprehensive baseline study that will help guide the multi-state issues affecting the Colorado River watershed.
- Determine if there are areas where groundwater does not currently meet U.S. Environmental Protection Agency (EPA) Safe Drinking Water Act (SDWA) water quality standards.²⁷
- Examine water quality differences between physiographic areas within the basin.

ADEQ collected samples from 8 sites for this groundwater quality assessment of the MEA. Types and numbers of samples collected and analyzed include inorganic constituents (physical parameters, major ions, nutrients, and trace elements) (8 sites), oxygen and hydrogen isotopes (6 sites), radiochemistry (2 sites), radon (2 sites), and volatile organic compounds (VOCs) (1 site).

Benefits of Study – The purpose of this study was to produce a scientific report utilizing accepted sampling techniques and quantitative data analysis to investigate groundwater quality in the MEA. The report’s conclusion concerning groundwater quality will provide the following:

- A general characterization of regional groundwater quality. Testing all private wells for a wide variety of groundwater quality concerns is prohibitively expensive. An affordable alternative is this type of statistically-based groundwater study which describes regional groundwater quality conditions and identifies areas with impaired groundwater conditions.
- The water quality of private wells is seldom tested for a wide variety of possible pollutants. Arizona statutes only require well drilling contractors to disinfect for potential bacteria contamination in new wells which are used for human consumption.² Wells are typically not tested for other groundwater quality concerns. Thus, contamination affecting groundwater pumped from private wells may go undetected for years and have adverse health effects on users of this resource.
- A process for evaluating potential groundwater quality impacts arising from a variety of sources including mineralization, mining, agriculture, livestock, septic tanks, and poor well construction.
- Considerations for identifying future locations of public supply wells.

Map 1 Meadview Basin



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Physical and Cultural Characteristics

Geography – The MEA is located within the Basin and Range physiographic province which consists of northwest-trending alluvial basins separated by elongated fault-block mountain ranges.⁴ Oriented north south, the MEA is approximately 16 miles long and 6-7 miles wide. Encompassing approximately 190 square miles, the basin is bounded to the east by the Grand Wash Cliffs, to the west by Wheeler Ridge, to the south by the Garnet Mountains, and to the north by Lake Mead (Figure 1). The basin floor slopes from approximately 4,400 feet above mean sea level (msl) at its southern end to approximately 1,400 feet msl at Lake Mead.⁴ The highest point in the basin is 6,024 feet msl on an unnamed point along the Grand Wash Cliffs. The MEA mostly consists of sedimentary rock (Map 3) with granite hard rock in the southern part of the basin in the Garnet Mountains and alluvium occurring along and to the west of Grapevine Wash.²²

The MEA is located in Mohave County; most of the land in the basin is federally managed by the U.S. Bureau of Land Management and the Lake Mead National Recreation Area (Map 2). Private land, Hualapai Indian Reservation and State Trust land make up the remainder of the basin.³

Climate - The climate of the MEA is semiarid, characterized by hot summers and mild winters. In general, precipitation increases with elevation. Although no records are available for the MEA, nearby Detrital Valley averages about 7 inches annually.²¹ Rainfall occurs during two periods: gentle storms of long-duration during the winter and intense, short-duration monsoon storms during July and August.

Vegetation - Vegetation varies with precipitation and elevation. Low precipitation zones in valley areas are characterized by several varieties of cactus, yucca (including Joshua trees), and desert shrubs such as mesquite, creosote bush, and ocotillo. Higher elevation areas evolve into a mix of grasses, chaparral, oak, and juniper.¹⁷

Surface Water - Almost all stream flow in the MEA is ephemeral, generated in the mountains in response to summer and winter storms. Surface flow rarely reaches the central parts of the valley because of evapotranspiration and infiltration. Upland areas provide most of the groundwater recharge in the sub-

basin.²⁶ Perennial surface water occurs only at Lake Mead along the northern end of the basin and in a short segment of Grapevine Wash as a result of discharge from Grapevine Spring.⁴ The MEA is within the Colorado-Grand Canyon Watershed and contains no impaired waters on the 303 (d) list.

History – The first settlement in the MEA was the Pearce Ferry site. The ferry transported travelers across the Colorado River from 1863 until 1891.¹⁷ When Lake Mead filled in the 1930s, Pearce Ferry was used as a debarkation point for boat tours of the lake. Today, Pearce Ferry serves as the primary terminus for river runners floating through the Grand Canyon.¹⁷

The main community in the basin is the retirement and recreation-oriented town of Meadview, established in 1962. Meadview has grown to about 1,500 residents in 800 homes.¹⁷ The basin also includes some new developments such as the unincorporated Lake Mead City and scattered ranches.

HYDROLOGY

Aquifers

The Muddy Creek Formation is the main aquifer in the basin.¹⁸ The aquifer is commonly divided into three units:

- An upper limestone unit that has good permeability in its lower sections; its upper sections have a crystalline composition which decreases permeability. This unit yields water to some shallow wells and a number of springs. It is uncertain if the springs are caused by a perched water table or from an impermeable layer within the limestone.
- A middle sandstone/siltstone unit with medium to fine sands and high clay content that inhibits its ability to transmit water. Wells tapping this unit have limited production.
- A basal conglomerate unit with high hydraulic conductivity, composed of pebble to boulder-sized particles, coarse sand, and silt. Most wells in the MEA draw water from this unit.

Map 2 Meadview Basin Land Ownership

Legend

Hardness (mg/L)

- Medium Hard 75 - 149
- Hard 150 - 299
- Very Hard 300 - 599

Meadview GW Basin

Towns

— Roads

— Major Roads

Land Ownership:

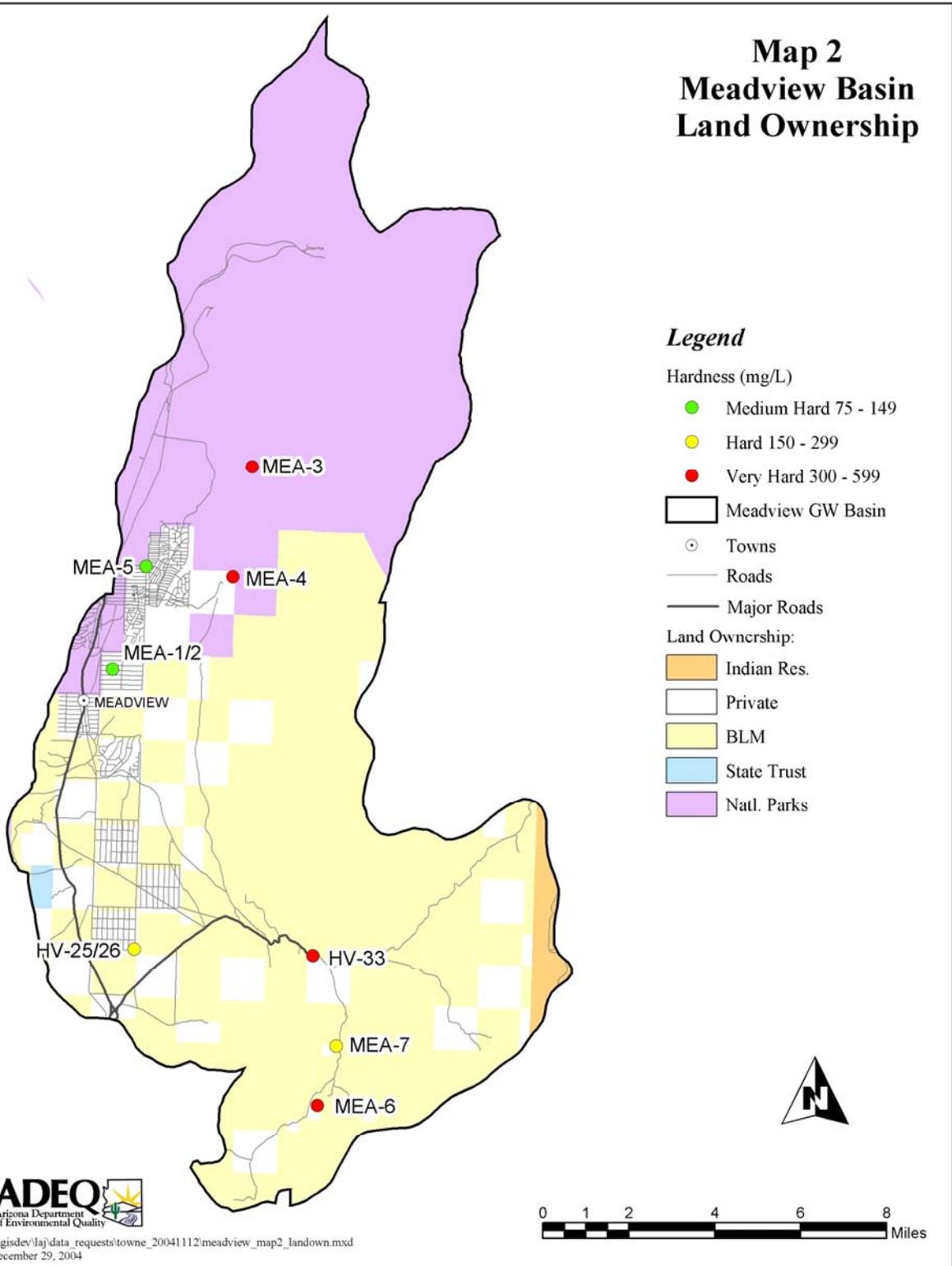
Indian Res.

Private

BLM

State Trust

Natl. Parks



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Figure 1 – This stream flow in a short perennial length of Grapevine Wash is the result of discharge from Grapevine Spring (MEA-3). The spring was estimated to flow at 60 gallons per minute in the 1980s.¹⁹



Figure 2 – Willow Spring (MEA-7) is piped into a trough for stock use. Also pictured is a portion of the 10 mile long, King Tut Mine Pipeline that supplied water from Willow Spring from 1931-1942 to a placer gold mine in the Lost Basin Mining



Figure 3 – The southern part of the Meadview basin is characterized by Joshua trees and the granite geology of the Garnet Mountains.



Figure 4 – ADEQ’s Elizabeth Boettcher samples a 600-foot deep well (MEA-1) that supplies water for Meadview. The water produced by this well met all health and aesthetic-based water quality standards.²⁷



Figure 5 – Hoover Dam, completed in 1935, impounds the Colorado River to form Lake Mead. The lake is the northern boundary of the Meadview groundwater basin.



Figure 6 – The Grand Wash Cliffs at sunset, from south along the Diamond Bar Road. Las Vegas visitors often take tours that transport them along this road for a glimpse of Grand Canyon West.

Groundwater Characteristics

Groundwater movement in the MEA is from the southern highlands to the north, towards Lake Mead. Depth to water varies from 935 feet below land surface (bls) in the southern portion of the basin to 135 feet bls to the north, near Grapevine Wash east of Meadview.²¹ Groundwater levels near Meadview are declining about 1 foot per year due to increased pumpage to meet Meadview's growth.⁸

The Arizona Department of Water Resources estimates groundwater pumpage to be approximately 100 acre-feet per year. Of this total, Joshua Valley Utility Company supplied 71 acre-feet of water to customers in the Meadview area.⁴ An estimated 62,500 acre-feet of groundwater is stored in the upper 700 feet of the basin, based on a 300 foot saturated thickness.⁸ No estimates are available on the annual average amount of recharge to the basin, though it is minor due to high evapotranspiration rates and low rainfall. The recharge that does occur is from infiltration of runoff from the basin's higher elevations.⁴

GROUNDWATER SAMPLING RESULTS

To characterize the regional groundwater quality of the Meadview basin, ADEQ personnel sampled 8 groundwater sites (3 wells and 5 springs) over a three-year period. This sample size was considered sufficient to characterize this small basin. The wells were equipped with submersible pumps and used for domestic and/or municipal use. The springs were used for livestock watering. Information on the characteristics of these groundwater sample sites is provided in Appendix A.

The following types of samples were collected: inorganic samples at 8 sites, hydrogen and oxygen isotope samples at 6 sites, radiochemistry samples at 2 sites, radon samples at 2 sites; and a VOC sample at 1 site.

Water Quality Standards/Guidelines

The ADEQ ambient groundwater monitoring program characterizes regional groundwater quality. One of the most important determinations ADEQ makes concerning the collected samples is how the analytical results compare to various drinking water quality standards. Three sets of drinking water

standards were used to evaluate the suitability of these groundwater sites for domestic purposes:

- 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.²⁷
- State of Arizona Aquifer Water-Quality Standards applies to aquifers that are classified for drinking water protected use.² All aquifers within Arizona are currently regulated for drinking water use. These enforceable State standards are almost identical to the federal Primary MCLs.
- 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 effect on the water.²⁷

Health-based drinking water quality standards (such as Primary MCLs) are based on a lifetime consumption of two liters of water per day and, as such, are chronic not acute standards.²⁷

Water Quality Standard/Guideline Exceedances

Of the 8 sites sampled for the study, only 3 (38 percent) met all SDW Primary and Secondary MCLs.

Health-based Primary MCL water quality standards and State aquifer water quality standards were exceeded at 3 of 8 sites (38 percent) (Map 3) (Table 1). Constituents exceeding Primary MCLs include arsenic (0 sites under current standards, 1 site under standards which take effect in 2006), gross alpha (2 sites), and uranium (1 site). Potential health effects of Primary MCL exceedances are provided in Table 1.^{27 30}

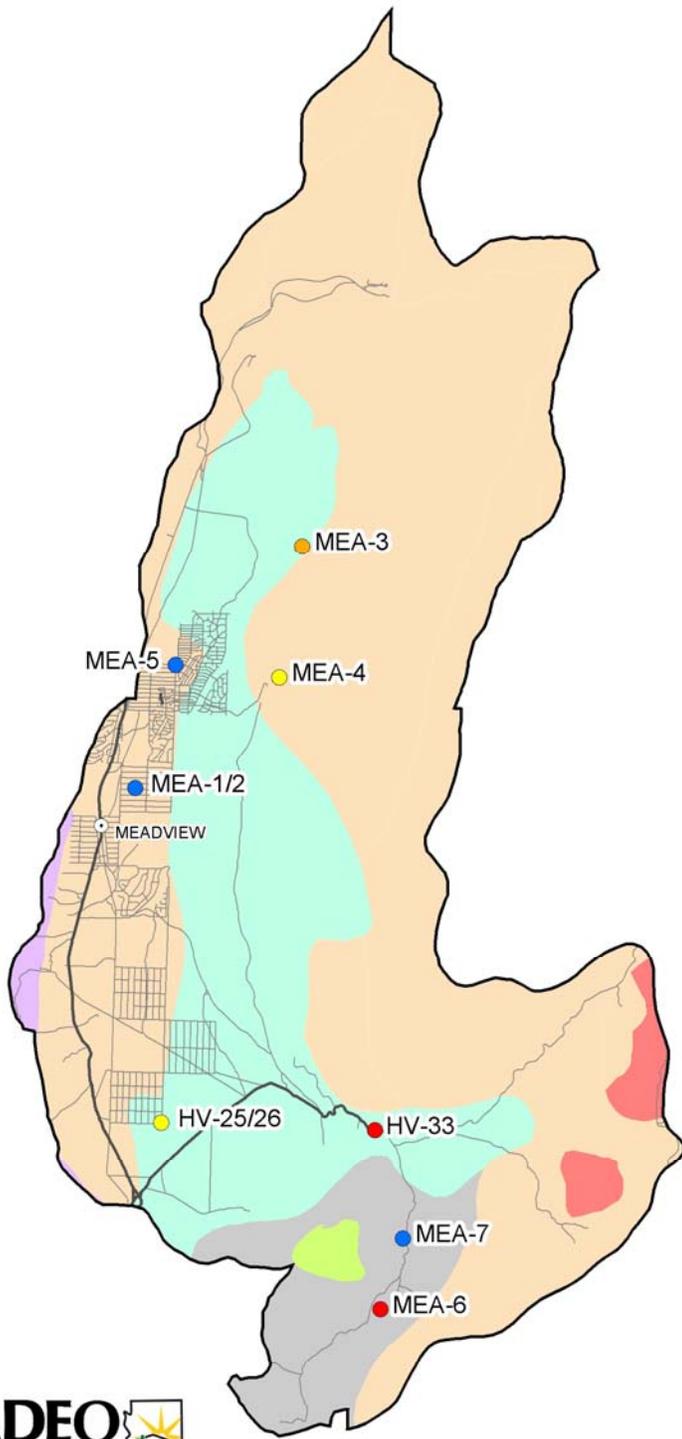
Aesthetics-based Secondary MCL water quality guidelines were exceeded at 4 of 8 sites (50 percent) (Map 3)(Table 2). Constituents above Secondary MCLs include fluoride (3 sites) and TDS (2 sites).

No VOCs were detected at the one site at which they were collected.

Map 3 Meadview Basin Geology

Legend

-  Meadview GW Basin
- Exceedences**
-  Primary and Secondary
-  Primary
-  Secondary
-  None
- Geology**
-  alluvium
-  basalt
-  granitic
-  metamorphic
-  sedimentary
-  volcanic
-  Towns
-  Roads
-  Major Roads



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December 29, 2004

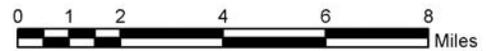


Table 1. MEA Sites Exceeding Health-Based Water Quality Standards (Primary MCLs)

Constituent	Primary MCL	Sites Exceeding Primary MCL	Concentration Range of Exceedances	Potential Health Effects of MCL Exceedances *
Nutrients				
Nitrite (NO ₂ -N)	1.0	0		
Nitrate (NO ₃ -N)	10.0	0		
Trace Elements				
Antimony (Sb)	0.006	0		
Arsenic (As)	0.05 0.01**	0 1	0.01	Dermal and nervous system toxicity
Barium (Ba)	2.0	0		
Beryllium (Be)	0.004	0		
Cadmium (Cd)	0.005	0		
Chromium (Cr)	0.1	0		
Copper (Cu)	1.3	0		
Fluoride (F)	4.0	0		
Lead (Pb)	0.015	0		
Mercury (Hg)	0.002	0		
Nickel (Ni)	0.1	0		
Selenium (Se)	0.05	0		
Thallium (Tl)	0.002	0		
Radiochemistry Constituents				
Gross Alpha	15	2	22-27 pCi/L	Cancer
Ra-226 + Ra-228	5	0		
Uranium	30	1	30 F g/L	Cancer and kidney toxicity

All units in mg/L except gross alpha and radium-226+228 (pCi/L), and uranium (F g/L).

* Health-based drinking water quality standards such as Primary MCLs are based on a lifetime consumption of two liters of water per day (USEPA). Therefore, these are considered chronic, not acute, standards.

** Revised arsenic primary MCL scheduled to be implemented in 2006

Source: ^{27, 30}

Table 2. MEA Sites Exceeding Aesthetics-Based Water Quality Standards (Secondary MCLs)

Constituents	Secondary MCL	Sites Exceeding Secondary MCLs	Concentration Range of Exceedances	Aesthetic Effects of MCL Exceedances
Physical Parameters				
pH - field	6.5 to 8.5	0		
General Mineral Characteristics				
TDS	500	2	540 - 600	Unpleasant taste
Major Ions				
Chloride (Cl)	250	0		
Sulfate (SO ₄)	250	0		
Trace Elements				
Fluoride (F)	2.0	3	2.1 – 3.6	Mottling of teeth enamel
Iron (Fe)	0.3	0		
Manganese (Mn)	0.05	0		
Silver (Ag)	0.1	0		
Zinc (Zn)	5.0	0		

All units mg/L except pH is in standard units (su).
 Source: ^{16, 27, 30}

Radon is a naturally occurring, intermediate breakdown product from the radioactive decay of uranium-238 to lead-206.¹⁰ Different opinions exist on the risk assessment of radon in drinking water, with proposed drinking water standards varying from 300 pCi/L to 4,000 pCi/L.¹² Both of the sites sampled for radon exceeded the 300 pCi/L standard; neither exceeded the 4,000 standard.

Suitability for Irrigation

The suitability of groundwater at each sample site was assessed for irrigation use based on salinity and sodium hazards. Irrigation water may be classified using specific conductivity (SC) and the Sodium Adsorption Ratio (SAR).²⁸ As salinity increases, it's necessary to utilize leaching, salt tolerant plants, and adequate drainage. Excessive levels of sodium causes physical deterioration of the soil.²⁸

Groundwater sites in the Meadview basin display a wide range of irrigation water classifications with salinity hazards greater than sodium hazards. Even sites characterized with a high salinity hazard tend to

be just over the boundary from the medium category. The 8 sample sites are divided into the following salinity hazards: low (C1) - 0, medium (C2) - 5, high (C3) - 3, and very high (C4) - 0. Likewise, the 8 sample sites are divided into the following sodium or alkali hazards: low (S1) - 8, medium (S2), high (S3) - 0, and very high (S4) - 0. As there is no large-scale irrigated farming taking place in the basin, this information is provided to landowners to assist their landscaping and gardening activities.

Analytical Results

Analytical inorganic and radiochemistry results of the 8 sample sites are summarized (Table 4) using the following indices: minimum reporting levels (MRLs), number of sample sites over the MRL, upper and lower 95 percent confidence intervals (CI_{95%}), and the median and mean. Confidence intervals are statistical measurements which indicate that 95 percent of a constituent's population lies within the stated confidence interval.¹⁵ Specific constituent information for each groundwater site is found in Appendix B.

Table 3. Summary Statistics for Meadview Groundwater Quality Data

Constituent	Minimum Reporting Limit (MRL)	Number of Samples Over MRL	Lower 95% Confidence Interval	Median	Mean	Upper 95% Confidence Interval
Physical Parameters						
Temperature (°C)	N/A	6	11.9	18.4	19.1	26.3
pH-field (su)	N/A	6	7.71	8.11	7.99	8.26
pH-lab (su)	0.01	8	7.75	7.95	7.96	8.17
Turbidity (ntu)	0.01	8	-0.10	0.23	0.46	1.02
General Mineral Characteristics						
Total Alkalinity	2.0	8	149	220	227	305
Phenol. Alk.	2.0	1	> 50% of data below MRL			
SC-field (F S/cm)	N/A	7	507	748	660	812
SC-lab (F S/cm)	N/A	8	553	713	702	850
Hardness-lab	10.0	8	200	300	279	359
TDS	10.0	8	338	435	432	526
Major Ions						
Calcium	5.0	8	39	65	59	78
Magnesium	1.0	8	20	30	34	48
Sodium	5.0	8	30	39	39	49
Potassium	0.5	7	1.1	2.5	2.8	4.6
Bicarbonate	2.0	8	181	265	276	371
Carbonate	2.0	1	> 50% of data below MRL			
Chloride	1.0	8	37	44	55	73
Sulfate	10.0	8	30	47	48	65
Nutrients						
Nitrate (as N)	0.02	7	1.1	3.0	2.6	4.1
Nitrite (as N)	0.02	0	> 50% of data below MRL			
Ammonia	0.02	1***	> 50% of data below MRL			
TKN	0.05	4	> 50% of data below MRL			
Total Phosphorus	0.02	2	> 50% of data below MRL			

All units mg/L except where noted with physical parameters

Table 3. Summary Statistics for Meadview Groundwater Quality Data—Continued

Constituent	Minimum Reporting Limit (MRL)	Number of Samples Over MRL	Lower 95% Confidence Interval	Median	Mean	Upper 95% Confidence Interval
Trace Elements						
Aluminum	0.5	0***		> 50% of data below MRL		
Antimony	0.005	0		> 50% of data below MRL		
Arsenic	0.01	1		> 50% of data below MRL		
Barium	0.1	2		> 50% of data below MRL		
Beryllium	0.0005	0		> 50% of data below MRL		
Boron	0.1	7	0.09	0.12	0.12	0.15
Cadmium	0.001	0		> 50% of data below MRL		
Chromium	0.01	3		> 50% of data below MRL		
Copper	0.01	0		> 50% of data below MRL		
Fluoride	0.20	8	1.0	1.5	1.8	2.5
Iron	0.1	0		> 50% of data below MRL		
Lead	0.005	0		> 50% of data below MRL		
Manganese	0.05	0		> 50% of data below MRL		
Mercury	0.0005	0		> 50% of data below MRL		
Nickel	0.1	0		> 50% of data below MRL		
Selenium	0.005	1		>50% of data below MRL		
Silver	0.001	0		> 50% of data below MRL		
Thallium	0.005	0		> 50% of data below MRL		
Zinc	0.05	3		> 50% of data below MRL		
Radiochemical Constituents						
Radon*	Varies	2		> 50% of data below MRL		
Gross Alpha*	Varies	3		> 50% of data below MRL		
Gross Beta*	Varies	2		> 50% of data below MRL		
Ra-226*	Varies	1		> 50% of data below MRL		
Ra-228*	Varies	0		> 50% of data below MRL		
Uranium**	Varies	1		> 50% of data below MRL		

All units mg/L except * = pCi/L and ** = F g/L
 *** = Only 3 sites sampled for ammonia and aluminum

GROUNDWATER COMPOSITION

General Summary

Groundwater in the Meadview basin is *slightly alkaline, fresh, and moderately hard-to-very hard* as indicated by pH values, TDS, and hardness concentrations. Levels of pH were *slightly alkaline* (above 7 SU) at the 6 sites measured.¹⁴ TDS concentrations were considered *fresh* (below 1,000 mg/L) all 8 sites.¹⁴ Hardness concentrations (Map 2) were divided into *soft* (0 sites), *moderately hard* (1 site), *hard* (3 sites), and *very hard* (4 sites).¹¹

Nutrient concentrations were generally low. Only nitrate was detected at more than 50 percent of the sites. Nitrate (as nitrogen) concentrations were divided into natural background (2 sites < 0.2 mg/L), may or may not indicate human influence (2 sites between 0.2 - 3.0 mg/L), may result from human activities (4 sites between 3.0 - 10 mg/L), and probably result from human activities (0 sites > 10 mg/L).²⁰

Most trace elements such as aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, and zinc were rarely--if ever--detected. Only boron and fluoride were detected at more than 50 percent of the sites.

Groundwater Chemistry

The chemical composition of sampled sites is illustrated using Piper trilinear diagrams.

- The cation triangle diagram (lower left in Figure 7) shows that the dominant (> 50 percent) cation is calcium at 2 sites, sodium at 0 sites, magnesium at 1 site, and mixed at 5 sites.
- The anion triangle diagram (lower right in Figure 7) shows that the dominant anion (>

50 percent) is bicarbonate at 6 sites, sulfate at 0 sites, chloride at 0 sites, and mixed at 2 sites).

- The cation-anion diamond diagram (in center of Figure 7) shows that the groundwater chemistry is calcium-bicarbonate at 1 site, calcium-mixed at 1 site, magnesium-bicarbonate at 1 site, mixed-bicarbonate at 4 sites, and mixed-mixed at 1 site.

Constituent Co-variation

The co-variation of constituent concentrations was determined to scrutinize the strength of the association. 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.

Many significant correlations occurred among the 8 Meadview basin sites (Pearson Correlation Coefficient test, $p \# 0.05$). Positive correlations occurred among TDS, SC, hardness, calcium, and magnesium. Other positive correlations were: pH-field – bicarbonate and chloride – oxygen-18/deuterium. Negative correlations occurred between potassium and TDS, calcium, and bicarbonate. Other negative correlations were: temperature – sulfate, pH-field – nitrate, and fluoride – nitrate. TDS concentrations are best predicted among cations by magnesium concentrations while among anions, bicarbonate is the best predictor (multiple regression analysis, $p\# 0.01$).

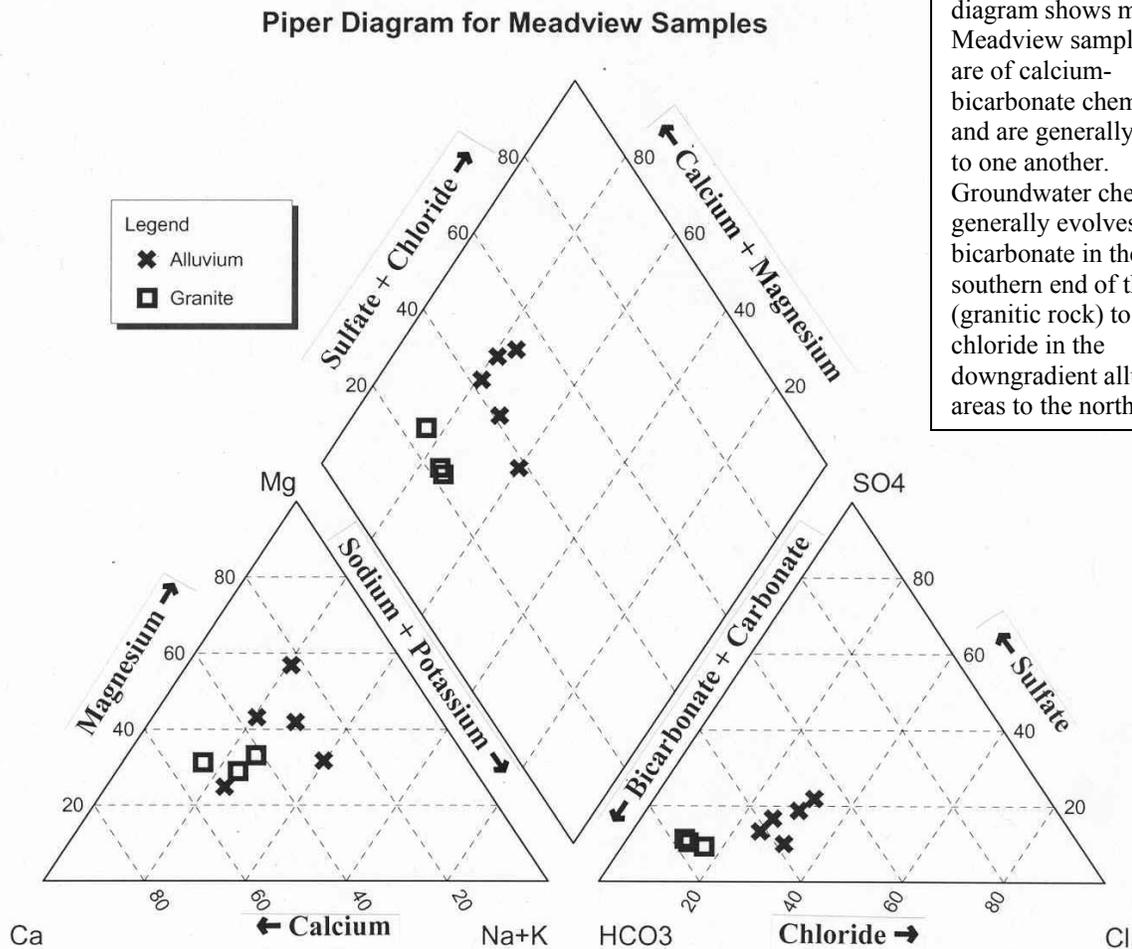


Figure 7 – The piper diagram shows most Meadview sample sites are of calcium-bicarbonate chemistry and are generally similar to one another. Groundwater chemistry generally evolves from bicarbonate in the southern end of the basin (granitic rock) to more chloride in the downgradient alluvium areas to the north.

Spatial Variation

For water quality comparison purposes, the MEA samples can be divided into two geologic areas: a southern area of granite and, to the north, alluvium/sedimentary rock.⁴ Analytical results were compared between these two areas to identify significant differences in concentrations of groundwater quality constituents as groundwater evolves during its movement from south to north.²¹ Significant concentration differences were found with only four constituents: bicarbonate and calcium were higher in sites situated in granite rock than in sites located to the north in alluvium; the opposite pattern was found with chloride and nitrate (ANOVA test, ≤ 0.01 for nitrate, 0.05 for other constituents). The nitrate pattern is illustrated in Figure 8.

Isotope Comparison

Groundwater characterizations using oxygen and hydrogen isotope data may be made with respect to the climate and/or elevation where the water originated, residence time within the aquifer, and whether or not the water was exposed to extensive evaporation prior to collection.⁹ These characterizations are made by comparing oxygen-18 isotopes (^{18}O) and deuterium (^2H), an isotope of hydrogen, to the Global Meteoric Water Line (GMWL). The GMWL is described by the linear equation: $^2\text{H} = 8^{18}\text{O} + 10$ where ^2H is deuterium in parts per thousand (per mil, ‰), 8 is the slope of the line, ^{18}O is oxygen-18 ‰, and 10 is the y-intercept.⁹ The GMWL is the standard by which water samples are compared and represents the best fit isotopic analysis of numerous water samples, worldwide.

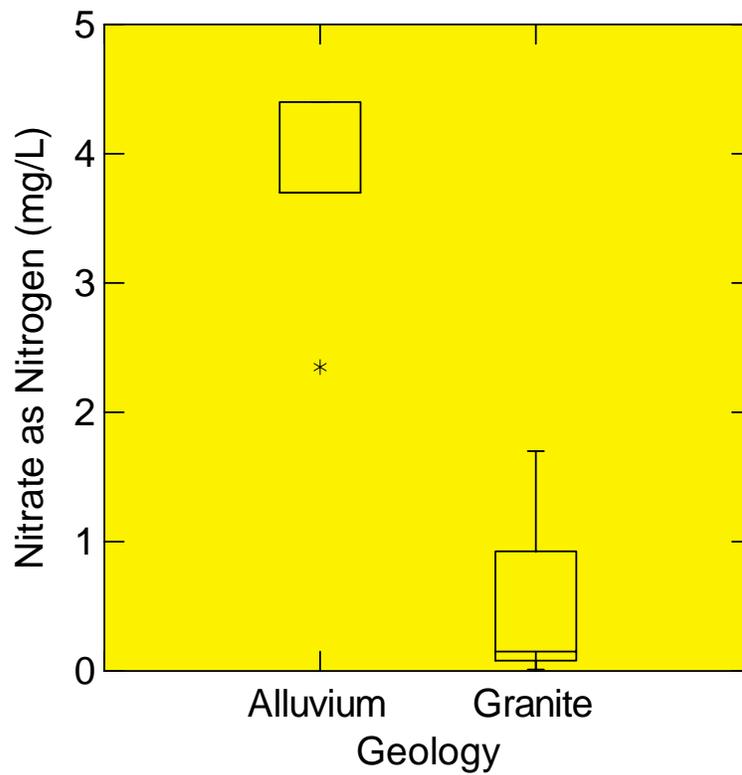


Figure 8 – This boxplot illustrates the statistical determination that nitrate (as nitrogen) concentrations are significantly higher in sample sites located in alluvium than in sample sites located in or influenced by granite (ANOVA, $p \leq 0.01$). However, none of the nitrate concentrations approach the health based water quality standard of 10 mg/L. The source of nitrate is likely from natural soil organic matter based on results from nearby basins. These conclusions were based on the depths to groundwater and nitrogen isotope results.²⁶

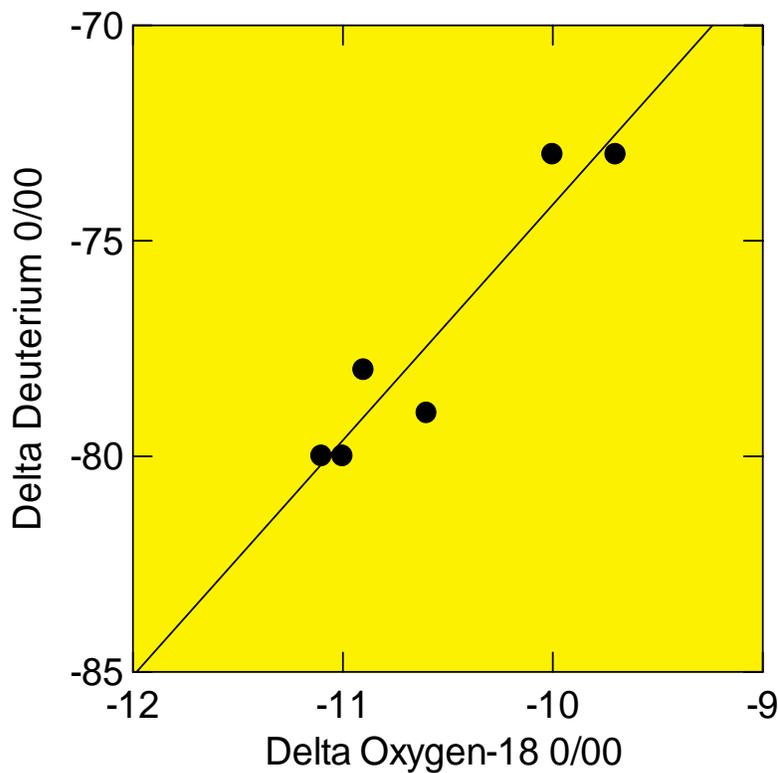


Figure 9 – Isotope samples were collected at six of the eight Meadview sites. The two springs in the north (Grapevine & Unnamed Springs) are slightly more enriched than wells in the alluvium and springs located to the south in hard rock. These results are similar to those in the “Deep Wells and Springs” cluster in the Detrital Valley basin.²⁵ These sites were considered to represent the oldest water in the basin, recharged during a cooler climate.²⁵

Regional isotopic data may be plotted to create a Local Meteoric Water Line (LMWL), which is affected by local climatic and geographic factors. When the LMWL is compared to the GMWL, inferences may be made about the origin or history of the local water.⁹ The LMWL created by $\delta^{18}\text{O}$ and δD values for samples collected at sites in the MEA were compared to the GMWL. The δD and $\delta^{18}\text{O}$ data lie to the right of the GMWL (Figure 9). Meteoric waters exposed to evaporation characteristically plot below and to the right of the GMWL. Evaporation tends to preferentially remove the lighter isotopes in the vapor phase; the water that remains behind is isotopically heavier.⁹

Groundwater from arid environments is typically subject to evaporation which enriches δD and $\delta^{18}\text{O}$. This results in a lower slope value (usually between 3 and 6), compared to the slope of 8 associated with the GMWL.⁹ Data for the arid MEA conform to this theory, having a slope of 5.47 (Figure 9).

The LMWL is described by the linear equation:

$$\delta\text{D} = 5.47\delta^{18}\text{O} - 19.48$$

This LMWL is similar to others determined for nearby basins such as Detrital Valley (5.15) and Sacramento Valley (5.5).^{25, 26}

Although the isotope results illustrate that all the MEA sites have a similar isotopic signature, the two northernmost springs, Grapevine Spring and a much smaller, unnamed spring were slightly more enriched.

CONCLUSIONS

Based on the results of ADEQ sampling, groundwater in most areas of the MEA appears generally to be suitable for domestic use. The findings of this study agrees with the findings of a 1981 ADWR study which indicated TDS concentrations ranged from 240 to 420 mg/L and fluoride concentrations ranged from 0.9 to 3.4 mg/L.²¹ However, this previous ADWR study did not collect radiochemistry samples, the concentrations of which appear to be the major limitation to using groundwater in the MEA for domestic use. Radiochemistry concentrations often exceeded health-based water quality standards in the bedrock geology of the southern part of the basin. Specific groundwater quality concerns will be addressed by geologic area.

Southern Basin – Granitic Geology

The granitic setting affected three sampled springs in southern part of the MEA. Of particular concern are radiochemistry samples collected at two springs, Diamond Bar Spring (HV-33) and Iron Spring (MEA-6). Both exceeded health-based water quality standards for gross alpha. The Diamond Bar Spring also exceeded the health-based water quality standard for uranium. Both sample sites are located in the northern flanks of the Garnet Mountains, within or near an occurrence of granite. Groundwater associated with granite frequently has elevated radiochemistry.^{19, 22} Because of these results ADEQ strongly recommends that any domestic water sources in this area be tested for radiochemistry constituents.

Aesthetics-based water quality standards were exceeded at three of the four sites for fluoride and at one site for TDS. The elevated fluoride concentrations may also be influenced by the area's geology. Groundwater in granite has been found to have twice the fluoride concentration of those measured in other rock types.²⁹ Similar elevated fluoride concentrations were found along the predominantly granitic rock of the west flank of the Hualapai Mountains in the nearby Sacramento Valley basin.²⁵

The groundwater in this southern area tends to be *hard to very hard*.¹¹ Bicarbonate and calcium concentrations are significantly higher in samples collected at sites in bedrock than at northern sites in alluvium (ANOVA, $p \leq 0.05$). This finding supports the assertion that the basin's higher elevations provide most of the groundwater recharge.⁴ Elevated bicarbonate and calcium concentrations are typical of recharge areas.²⁴ All the samples consisted of *fresh* water as indicated by TDS concentrations. Nitrate concentrations were also low.

Other than the limitations imposed by radiochemistry and fluoride concentrations, groundwater in the southern basin area appears to be adequate for domestic uses.

Northern Basin, Alluvium Geology

Three deep wells and two springs were sampled in the northern part of the basin where the source rocks are alluvial or sedimentary deposits. The only health-based exceedance was arsenic.

The arsenic concentration in the sample from Grapevine Spring was 0.01 mg/L which is both the health-based, water quality standard effective in 2006 and the minimum reporting level for arsenic at the Arizona Department of Health Services laboratory.²³ Aesthetics-based water quality standards were exceeded for fluoride at one well and for TDS at one spring.

Generally, samples collected from sites in the alluvium/sedimentary rock were acceptable for domestic uses. Well samples had lower TDS concentrations than spring samples.

Well and spring samples exhibited nitrate (as nitrogen) concentrations ranging from 2.4 to 4.4 mg/L. Nitrate concentrations in sample sites in the alluvium are significantly higher than those sites in granitic geology (ANOVA, $p \leq 0.01$). Nitrate concentrations in the alluvium are elevated enough that they may be reflecting impacts from human activities.²⁰ The community of Meadview does utilize septic systems for wastewater disposal. However, similar groundwater sample results from deep wells and springs in nearby basins were hypothesized to be caused from natural soil organic matter.²⁶ This conclusion was based the great depth to groundwater as well as the nitrogen isotope results.²⁵

Study Design and Data Evaluation

The eight groundwater sample sites were generally selected using a modified grid-based, random site-selection approach. This method allowed the spatial distribution of sample sites throughout the MEA, although some areas were not sampled because of a combination of remote, rugged terrain and a corresponding lack of groundwater sample sites.

Quality assurance procedures were followed and quality control samples were collected to ensure the validity of groundwater quality data. Analysis of equipment blank samples indicated systematic contamination of SC-lab and turbidity; however, the extent of contamination by these parameters was not considered significant. Contamination of blanks by calcium and hardness on individual field trips was noted but also determined not to be significant.

Analysis of the two partial duplicate samples revealed excellent correlations of less than 10 percent. The split sample had more variability, but rarely exceeded a maximum difference of 10 percent. As usual, TKN exhibited the largest maximum difference, a pattern found in other ADEQ ambient

groundwater studies due to the difficulty in analyzing this constituent.^{25, 26}

Data validation was also examined in five QA/QC correlations that affirmed the acceptability of the groundwater quality data for further analysis. Only the field pH – lab pH correlation was not significant (regression analysis, $p \# 0.05$). The non-significance of this QA/QC correlation is likely due to the short holding time (15 minutes) associated with lab pH measurements. This holding time was exceeded with each sample.²³

Data analysis for this study was conducted using Systat software.³¹ The normality of most non-transformed data was determined using the Kolmogorov-Smirnov one-sample test with the Lilliefors option.⁷ Spatial variations in constituent concentrations were investigated using the parametric Analysis of Variance (ANOVA) test. Correlations among constituent concentrations were analyzed using the Pearson Correlation Coefficient test.

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Appendix A. Basic Data on Sample Sites, Meadview Basin

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Sample Type	Well Depth	Water Depth	Geology
1st Field Trip, March 28, 2000 – Freark & Lucci (Equipment Blank HV-28/28a)									
HV-25a/b/26	(B-29-17)26aaa submersible	35°52'47.82" 114°04'04.28"	524465	46814	Co-op Well	Inorganic, VOCs, Radon	1150'	960'	Alluvium
2nd Field Trip, April 18-19, 2000 - Freark & Lucci									
HV-33	(B-29-16)27bba spring	35°52'46.333" 113°59'26.316"	--	58660	Diamond Bar Spring	Inorganic Radiochem	--	--	Granite
3rd Field Trip, December 5, 2002 - Towne & Boettcher (Equipment Blank DET-39)									
MEA-1/2	(B-30-17)23cab submersible	35°58'26.160" 114°04'49.331"	610726	22399	Meadview Unit #4	Inorganic, Radiochem O & H isotopes	600'	--	Alluvium
4th Field Trip, January 14- 17, 2003 - Towne & Boettcher (Equipment Blank MHV-6)									
MEA-3	(B-31-16)29cad spring	36°02'59.085" 114°01'00.528"	--	22420	Grapevine Spring	Inorganic O & H isotopes	--	--	Alluvium
MEA-4	(B-30-16)07aaa spring	36°00'25.915" 114°01'53.461"	--	60534	Unnamed Spring	Inorganic O & H isotopes	--	--	Alluvium
MEA-5	(B-30-17)11aaa submersible	36°00'34.864" 114°04'04.356"	610733	22392	Meadview Unit-New	Inorganic, Radon O & H isotopes	600'	--	Alluvium
MEA-6	(B-28-16)09daa spring	35°49'45.936" 113°59'20.167"	--	48749	Iron Spring	Inorganic, Radiochem O & H isotopes	--	--	Granite
MEA-7	(B-29-16)34ddd spring	35°50'57.371" 113°58'57.972"	--	60540	Willow Spring	Inorganic O & H isotopes	--	--	Granite

Appendix B. Groundwater Quality Data, Meadview Basin

Site #	MCL Exceedances	Temp (°C)	pH-field (su)	pH-lab (su)	SC-field (F S/cm)	SC-lab (F S/cm)	T. Alk (mg/L)	P. Alk (mg/L)	TDS (mg/L)	Hardness (mg/L)	Hard (cal) (mg/L)
HV-25/26	F	28.3	7.66	<i>7.60</i>	602	645	145	ND	385	265	250
HV-33	F, Gross α , U	16.8	7.66	<i>8.0</i>	748	780	350	ND	480	360	360
MEA-1/2		25.6	8.09	<i>7.9</i>	448	470	120	ND	260	150	160
MEA-3	As	10.6	8.12	<i>8.2</i>	763	820	200	ND	460	320	330
MEA-4	TDS	-	-	<i>8.4</i>	842	940	280	5.6	600	390	400
MEA-5		20.0	8.12	<i>8.0</i>	436	460	130	ND	320	130	140
MEA-6	TDS, F, Gross α	13.4	8.27	<i>7.8</i>	778	860	350	ND	540	340	350
MEA-7		-	-	<i>7.8</i>	-	640	240	ND	410	280	290

bold = parameter level exceeds Primary or Secondary MCL

* = concentration exceeds the revised arsenic SDW Primary MCL which becomes effective in 2006

ND = not detected above minimum reporting level

italics = constituent exceeded lab holding time

Appendix B. Groundwater Quality Data, Meadview Basin--Continued

Site #	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
HV-25/26	69	20	32	6.4	180	ND	71	66.5
HV-33	89	33	51	0.86	430	ND	40	45
MEA-1/2	26.5	23	27.5	4.3	150	ND	47	20
MEA-3	61	44	38	3.1	240	ND	82	69
MEA-4	46	70	48	ND	330	6.7	87	75
MEA-5	27	18	40	4.4	160	ND	38	27
MEA-6	79	38	54	1.8	430	ND	36	49
MEA-7	73	26	24	1.6	290	ND	36	28

ND = not detected above minimum reporting level

Appendix B. Groundwater Quality Data, Meadview Basin--Continued

Site #	Nitrate-Nitrite-N (mg/L)	Nitrate - N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Phosphorus (mg/L)	Turbidity (NTU)	SAR (value)	Irrigation Quality
HV-25/26	2.35	2.35	ND	0.80	0.026	ND	2.07	0.8	C2-S1
HV-33	ND	ND	ND	ND	ND	0.097	0.02	1.2	C2-S1
MEA-1/2	3.7	3.7	ND	ND	-	0.021	0.30	1.0	C2-S1
MEA-3	4.4	4.4	ND	<i>0.081</i>	-	ND	<i>0.18</i>	0.9	C3-S1
MEA-4	4.4	4.4	ND	<i>0.27</i>	-	ND	<i>0.08</i>	1.0	C3-S1
MEA-5	3.7	3.7	ND	ND	-	ND	<i>0.57</i>	1.5	C2-S1
MEA-6	0.15	0.15	ND	<i>0.095</i>	-	ND	<i>0.20</i>	1.2	C3-S1
MEA-7	1.7	1.7	ND	ND	-	ND	<i>0.25</i>	0.6	C2-S1

ND = not detected above minimum reporting level

italics = constituent exceeded lab holding time

Irrigation Quality - C = salinity hazard, S = sodium hazard, 1 = low, 2 = medium, 3 = high, 4 = very high

Appendix B. Groundwater Quality Data, Meadview Basin—Continued

Site #	Aluminum (mg/L)	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)
HV-25/26	ND	ND	ND	ND	ND	0.105	ND	ND	ND	2.1
HV-33	ND	ND	ND	ND	ND	0.14	ND	ND	ND	2.3
MEA-1/2	-	ND	ND	0.16	ND	0.105	ND	0.0465	ND	1.5
MEA-3	-	ND	0.010 *	ND	ND	0.12	ND	ND	ND	0.83
MEA-4	-	ND	ND	ND	ND	0.17	ND	0.023	ND	1.4
MEA-5	-	ND	ND	0.12	ND	0.14	ND	0.043	ND	1.4
MEA-6	-	ND	ND	ND	ND	0.12	ND	ND	ND	3.6
MEA-7	-	ND	ND	ND	ND	ND	ND	ND	ND	1.0

bold = parameter level exceeds Primary or Secondary MCL ND = not detected above minimum reporting level
 * = concentration exceeds the revised arsenic SDWA Primary MCL of 0.01 mg/L which becomes effective in 2006

Appendix B. Groundwater Quality Data, Meadview Basin--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)
HV-25/26	ND	ND	ND	ND	ND	0.0073	ND	ND	0.051
HV-33	ND	ND	ND	ND	ND	ND	ND	ND	ND
MEA-1/2	ND	ND	ND	ND	ND	ND	ND	ND	0.0855
MEA-3	ND	ND	ND	ND	ND	ND	ND	ND	ND
MEA-4	ND	ND	ND	ND	ND	ND	ND	ND	ND
MEA-5	ND	ND	ND	ND	ND	ND	ND	ND	ND
MEA-6	ND	ND	ND	ND	ND	ND	ND	ND	0.49
MEA-7	ND	ND	ND	ND	ND	ND	ND	ND	ND

ND = not detected above minimum reporting level

Appendix B. Groundwater Quality Data, Meadview Basin--Continued

Site #	Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Ra-226 (pCi/L)	Ra-228 (pCi/L)	Uranium (ug/L)	*18 O (‰)	* D (‰)	Radon-222 (pCi/L)	Type of Chemistry
HV-25/26	-	-	-	-	-	-	-	453	calcium-mixed
HV-33	27	13	< LLD	-	30	-	-	-	mixed-bicarbonate
MEA-1/2	6.3	-	-	-	-	-10.6	-79	-	mixed-bicarbonate
MEA-3	-	-	-	-	-	-10.0	-73	-	mixed-mixed
MEA-4	-	-	-	-	-	-9.7	-73	-	magnesium-bicarbonate
MEA-5	-	-	-	-	-	-11.0	-80	724	mixed-bicarbonate
MEA-6	22	< 4.7	-	-	-	-11.1	-80	-	mixed-bicarbonate
MEA-7	-	-	-	-	-	-10.9	-78	-	calcium-bicarbonate

bold = parameter level exceeds Primary or Secondary MCL ND = not detected above minimum reporting level LLD = Lower Limit of Detection

APPENDIX C. INVESTIGATION METHODS

Groundwater sites were sampled by the ADEQ Groundwater Monitoring Program to characterize regional groundwater quality in the MEA. Samples were collected at all sites for inorganic (physical parameters, major ions, nutrients, and trace elements) analyses and at select sites for hydrogen and oxygen isotopes, radiochemistry, radon, and VOC analyses. 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.¹³

Sampling Strategy

This study focused on regional groundwater quality conditions that are large in scale and persistent over time. This research was designed to identify regional degradation of groundwater quality such as occurs from non-point sources of pollution or a high density of point sources. The quantitative estimation of regional groundwater quality conditions requires the selection of sampling locations that follow scientific principles for probability sampling.¹⁵

Sampling in the MEA followed a systematic stratified random site-selection approach. This is an efficient method because it requires sampling relatively few sites to make valid statistical statements about the conditions of large areas. This systematic element requires that the selected wells be spatially distributed while the random element ensures that every well within a cell has an equal chance of being sampled. This strategy also reduces the possibility of biased well selection and assures adequate spatial coverage throughout the study area.¹⁵ The main benefit of a statistically-designed sampling plan is that it allows for greater groundwater quality assumptions than would be allowable with a non-statistical approach.

Wells pumping groundwater for a variety of purposes - domestic, stock, and industrial - were sampled for this study, provided each individual well met ADEQ requirements. A well was considered suitable for sampling if the well owner gave permission to sample, if a sampling point existed near the wellhead, and if the well casing and surface seal appeared to be intact and undamaged.⁵ Other factors such as casing access to determine groundwater depth and construction information were preferred but not essential.

If registered wells were unavailable for sampling, springs or unregistered wells were randomly selected for sampling. Springs were considered adequate for

sampling if they had a constant flow through a clearly-defined point of egress, and if the sample point had minimal surface impacts. Well information compiled from the ADWR well registry and spring data are found in Appendix A.

Several factors were considered to determine sample size for this study. Aside from administrative limitations on funding and personnel, this decision was based on three factors related to the conditions in the area:

- Amount of groundwater quality data already available;
- Extent to which impacted groundwater is known or believed likely to occur; and
- Hydrologic complexity and variability of the basin.¹⁵

Sample Collection

The personnel who designed the MEA study were also responsible for the collection and interpretation of the data. This protocol helps ensure that consistently high quality data are collected, from which are drawn relevant and meaningful interpretations. The sample collection methods for this study conformed to the Quality Assurance Project Plan (QAPP)¹ and the Field Manual For Water Quality Sampling.⁵ While these sources should be consulted as references to specific sampling questions, a brief synopsis of the procedures involved in collecting a groundwater sample is provided.

After obtaining permission from the owner to sample the well, the water level was measured with a sounder if the casing had access for a probe. The volume of water needed to purge the well three bore-hole volumes was calculated from well log and on-site information. Physical parameters - temperature, pH, and specific conductivity - were monitored at least every five minutes using a YSI multi-parameter instrument. To assure obtaining fresh water from the aquifer, typically after three bore volumes had been pumped and the physical parameters were 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. Inorganic

4. Radiochemistry
5. Isotope

Radon samples were collected in two unpreserved, 40-ml clear glass vials. Radon samples were carefully filled and sealed so that no headspace remained.¹²

VOC samples were collected in two, 40-ml amber glass vials which contained 10 drops 1:1 hydrochloric (HCl) acid preservative prepared by the laboratory. Before sealing the vials with Teflon caps, litmus paper was used to make certain the pH of the sample was below 2 su; additional HCl was added if necessary. VOC samples were also checked to make sure there was no headspace.¹²

The inorganic constituents were collected in three, 1-liter polyethylene bottles:

- Samples to be analyzed for dissolved metals were filtered into bottles and preserved with 5 ml nitric acid (70 percent). An on-site positive pressure filtering apparatus with a 0.45 micron (μm) pore size groundwater capsule filter was used.
- Samples to be analyzed for nutrients were collected in bottles and preserved with 2 ml sulfuric acid (95.5 percent).
- Samples to be analyzed for other parameters were unpreserved.²⁷

Radiochemistry samples were collected in two collapsible 1-liter plastic containers and preserved with 5 ml nitric acid to reduce the pH below 2.5 su.

Hydrogen and oxygen isotope samples were collected in a single 500 ml plastic bottle and were not preserved.

Samples were kept at 4⁰C with ice in an insulated cooler, with the exception of the isotope and radiochemistry samples. Chain of custody procedures were followed in sample handling. Samples for this study were collected in March-April 2000, December 2002, and January 2003.

Laboratory Methods

The inorganic analyses for this study were conducted by the Arizona Department of Health Services (ADHS) Laboratory and Del Mar Laboratory, both in Phoenix, Arizona. A complete listing of inorganic parameters, including laboratory method, EPA water method, and Minimum Reporting Level (MRL) is provided in Table 4. VOC sample analyses were also conducted by the ADHS Laboratory.

The radon samples were analyzed by Radiation Safety Engineering, Inc. Laboratory in Chandler, AZ.

The analysis of radiochemistry samples was performed by either the Radiation Safety Engineering, Inc. Laboratory or the Arizona Radiation Agency Laboratory in Phoenix according to the following EPA SDW protocols: Gross alpha was analyzed, and if levels exceeded 5 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.

Hydrogen and oxygen isotope samples were analyzed by the University of Arizona, Laboratory of Isotope Geochemistry in Tucson.

Sample Numbers

Eight (8) groundwater sites were sampled for the study. Various numbers and types of samples were collected and analyzed:

- < 8 - inorganic
- < 6 - hydrogen and oxygen isotopes
- < 2 - radiochemistry
- < 2 - radon
- < 1 - VOCs

Table 4. ADHS/Del Mar Laboratory Methods Used for the Meadview Study

Constituent	Instrumentation	ADHS / Del Mar Water Method	ADHS / Del Mar Minimum Reporting Level
Physical Parameters and General Mineral Characteristics			
Alkalinity	Electrometric Titration	SM232OB	2 / 5
SC (FS/cm)	Electrometric	EPA 120.1/ SM2510B	1 / 2
Hardness	Titrimetric, EDTA	EPA 130.2 / SM2340B	10 / 1
Hardness - Calc.	Calculation	--	--
pH (su)	Electrometric	EPA 150.1	0.1
TDS	Gravimetric	EPA 160.1 / SM2540C	10 / 20
Turbidity (NTU)	Nephelometric	EPA 180.1	0.01 / 1
Major Ions			
Calcium	ICP-AES	EPA 200.7	5 / 2
Magnesium	ICP-AES	EPA 200.7	1 / 0.5
Sodium	ICP-AES	EPA 200.7 / EPA 273.1	5
Potassium	Flame AA	EPA 258.1	0.5 / 1
Bicarbonate	Calculation	--	2
Carbonate	Calculation	--	2
Chloride	Potentiometric Titration	SM 4500 CLD / EPA 300.0	1 / 5
Sulfate	Colorimetric	EPA 375.2 / EPA 300.0	10 / 5
Nutrients			
Nitrate as N	Colorimetric	EPA 353.2	0.02 / 0.50
Nitrite as N	Colorimetric	EPA 353.2	0.02
Ammonia	Colorimetric	EPA 350.1/ EPA 350.3	0.02 / 0.5
TKN	Colorimetric	EPA 351.2 / SM4500	0.05 / 0.5
Total Phosphorus	Colorimetric	EPA 365.4 / EPA 365.3	0.02 / 0.05

All units are mg/L except as noted
Source ^{12, 23}

Table 4. ADHS/Del Mar Laboratory Methods Used for the Meadview Study--Continued

Constituent	Instrumentation	ADHS / Del Mar Water Method	ADHS / Del Mar Minimum Reporting Level
Trace Elements			
Antimony	Graphite Furnace AA	EPA 200.9	0.005 / 0.004
Arsenic	Graphite Furnace AA	EPA 200.9	0.01 / 0.003
Barium	ICP-AES	EPA 200.7	0.1 / 0.01
Beryllium	Graphite Furnace AA	EPA 200.9	0.0005
Boron	ICP-AES	EPA 200.7	0.1 / 0.5
Cadmium	Graphite Furnace AA	EPA 200.9	0.001 / 0.0005
Chromium	Graphite Furnace AA	EPA 200.9	0.01 / 0.004
Copper	Graphite Furnace AA	EPA 200.9	0.01 / 0.004
Fluoride	Ion Selective Electrode	SM 4500 F-C	0.2 / 0.1
Iron	ICP-AES	EPA 200.7	0.1
Lead	Graphite Furnace AA	EPA 200.9	0.005 / 0.002
Manganese	ICP-AES	EPA 200.7	0.05 / 0.02
Mercury	Cold Vapor AA	SM 3112 B / EPA 245.1	0.0005 / 0.0002
Nickel	ICP-AES	EPA 200.7	0.1 / 0.05
Selenium	Graphite Furnace AA	EPA 200.9	0.005 / 0.004
Silver	Graphite Furnace AA	EPA 200.9 / EPA 273.1	0.001 / 0.005
Thallium	Graphite Furnace AA	EPA 200.9	0.002
Zinc	ICP-AES	EPA 200.7	0.05

All units are mg/L
Source ^{12, 23}

APPENDIX D. 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 MEA study. The design of the QA/QC plan was based on recommendations included in the *Quality Assurance Project Plan (QAPP)*¹ and the *Field Manual For Water Quality Sampling*.⁵ The types and numbers of QC samples collected for this study are as follows:

- Inorganic: (2 partial filter duplicate, 1 split, 3 full blanks and 1 partial filter blank).

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

Blanks - Equipment blanks for inorganic analyses were collected to ensure adequate decontamination of sampling equipment, and that the filter apparatus and/or de-ionized water were not impacting the groundwater quality sampling.⁵ Equipment blank samples for major ion and nutrient analyses were collected by filling unpreserved and sulfuric acid preserved bottles with de-ionized water. Equipment blank samples for trace element analyses were collected with de-ionized water that had been filtered into nitric acid preserved bottles.

Systematic contamination was judged to occur if more than 50 percent of the equipment blank samples contained measurable quantities of a particular groundwater quality constituent.²⁶ As such, SC-lab and turbidity were considered to be affected by systematic contamination; however, the extent of contamination was not considered significant.

SC and turbidity were detected in all three full equipment blanks. SC had a 1.9 F S/cm mean, which was less than 1 percent of the SC mean level for the study. The SC detections may be explained in two ways: water passed through a de-ionizing exchange unit will normally have an SC value of at least 1 F S/cm, and carbon dioxide from the air can dissolve in de-ionized water with the resulting bicarbonate and hydrogen ions imparting the observed conductivity.²³ Similarly, turbidity had a mean level of 0.033 ntu, less than

1 percent of the turbidity median level for the study. 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.²³

Two other constituents were detected in the one blank but none appeared to significantly impact sampling results. Hardness was detected at 22 mg/l and calcium was detected at 7.4 mg/L in HV-28; calcium was not detected in HV-28a, the laboratory filter blank duplicate

Duplicate Samples - Duplicate samples are identical sets of samples collected from the same source at the same time and submitted to the same laboratory. Data from duplicate samples provide a measure of variability from the combined effects of field and laboratory procedures.⁵ Duplicate samples were collected from sampling sites that were believed to have elevated constituent concentrations as judged by field SC values. Only two partial filter duplicate samples were collected in this study. An extra duplicate sample was collected in an unpreserved container. Upon submission to the ADHS laboratory, this sample water would be filtered and preserved with nitric acid. As such, only metal concentrations were analyzed in the duplicate.

Analytical results indicate that of the 21 constituents examined, 8 (boron, calcium, chromium, magnesium, potassium, selenium, sodium, and zinc) had concentrations above the MRL. In each case, the variation between duplicates was less than 10 percent. The only exception was barium which was not detected in the field duplicate (MRL = 0.1 mg/L) and was detected in the lab duplicate at 0.22 mg/L.

Split Samples - Split samples are identical sets of samples collected from the same source at the same time that are submitted to two different laboratories to check for laboratory differences.⁵ One inorganic split sample was collected and analytical results were evaluated by examining the variability in constituent concentrations in terms of absolute levels and as the percent difference.

Analytical results indicate that of the 36 constituents examined, only 15 (calcium, chloride, fluoride, hardness, magnesium, nitrate, pH, potassium, SC, sodium, sulfate, total alkalinity, TDS, TKN, and turbidity) had concentrations above MRLs for both ADHS and

Del Mar laboratories. The maximum difference between split constituents rarely exceeded 10 percent. As usual, TKN exhibited the largest maximum difference, a pattern which has been found in other ADEQ ambient groundwater studies and is due to the difficulty in analyzing this constituent.^{12,23} TKN was detected in the Del Mar laboratory sample (1.7 mg/L) but not in the ADHS sample (MRL = 0.1 mg/L).

Based on the results of blanks, duplicates and the split sample collected for this study, no significant QA/QC problems were apparent with the groundwater quality collected for this study. This conclusion is supported by the acceptable QA/QC results for other groundwater basins sampled concurrently with Meadview (2000-2003) including Hualapai Valley (2000), Detrital Valley (2002)²⁶, and Lake Mohave (2003).

Data Validation

The analytical work for this study was subjected to the following five QA/QC correlations.

Cation/Anion Balances - In theory, water samples exhibit electrical neutrality. Therefore, the sum of milliequivalents per liter (meq/L) of cations must 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.¹⁶

Overall, cation/anion balances of MEA samples were significantly correlated (regression analysis, p # 0.01) and were within acceptable limits (90 - 110 percent).

SC/TDS - The SC and TDS concentrations measured by contract laboratories were significantly correlated as were field-SC and TDS concentrations (regression analysis, p # 0.01). Typically, the TDS concentration in mg/L should be from 0.55 to 0.75 times the SC in F S/cm for groundwater up to several thousand mg/L.¹⁶ Groundwater in which the ions are mostly bicarbonate and chloride will have a multiplication factor near the lower end of this range and groundwater high in sulfate may reach or even exceed the higher number. The relationship of TDS to SC becomes undefined for groundwater either with very high and low concentrations of dissolved solids.¹⁶

Hardness - Concentrations of laboratory-measured and calculated values were significantly correlated (regression analysis, p # 0.01). Hardness concentrations were calculated using the following formula: [(Calcium x 2.497) + (Magnesium x 4.118)].

SC - The SC measured in the field using a YSI meter at the time of sampling was significantly correlated with the SC measured by contract laboratories (regression analysis, p # 0.01).

pH - The pH value is closely related to the environment of the water and is likely to be altered by sampling and storage.¹⁶ As such, 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, p # 0.05).

The analytical work conducted for this study was considered valid based on the quality control samples and the QA/QC correlations.

Statistical Considerations

Various methods were used to complete the statistical analyses for the groundwater quality data of this study. All statistical tests were conducted on a personal computer using SYSTAT software.³¹

Data Normality: Data associated with 22 constituents were tested for non-transformed normality using the Kolmogorov-Smirnov one-sample test with the Lilliefors option.⁷ Results of this test revealed that 20 of the 22 constituents (all except for sulfate and turbidity) were normally distributed.

Spatial Relationships: The parametric analysis of variance (ANOVA) test was applied to investigate the hypothesis that constituent concentrations from groundwater sites in different aquifers or rock types, of the MEA were the same. The ANOVA tests the equality of two or more means in experiments involving one continuous dependent variable and one categorical independent variable.³¹ 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. Comparisons conducted using the ANOVA test include physiographic areas aquifers (Grapevine Mesa and Grapevine Valley).⁴

The ANOVA test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.¹⁵ Consequently, they were not calculated for trace parameters such as antimony, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, total phosphorus, TKN, thallium, zinc, phenolphthalein alkalinity, carbonate, nitrite, and ammonia. Highlights of these statistical tests are summarized in the groundwater quality section.

Correlation Between Constituent

Concentrations: In order to assess the strength of association between constituents, their concentrations were compared to each other using the Pearson Correlation Coefficient test.

The Pearson correlation coefficient varies between -1 and +1, with a value of +1 indicating that a variable can be predicted perfectly by a positive linear function of the other, and vice versa. A value of -1 indicates a perfect inverse or negative relationship. The results of the Pearson Correlation Coefficient test were then subjected to a probability test to determine which of the individual pair wise correlations were significant.³¹ The Pearson test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.¹⁵ Consequently, Pearson Correlation Coefficients were not calculated for the same constituents as in spatial relationships.