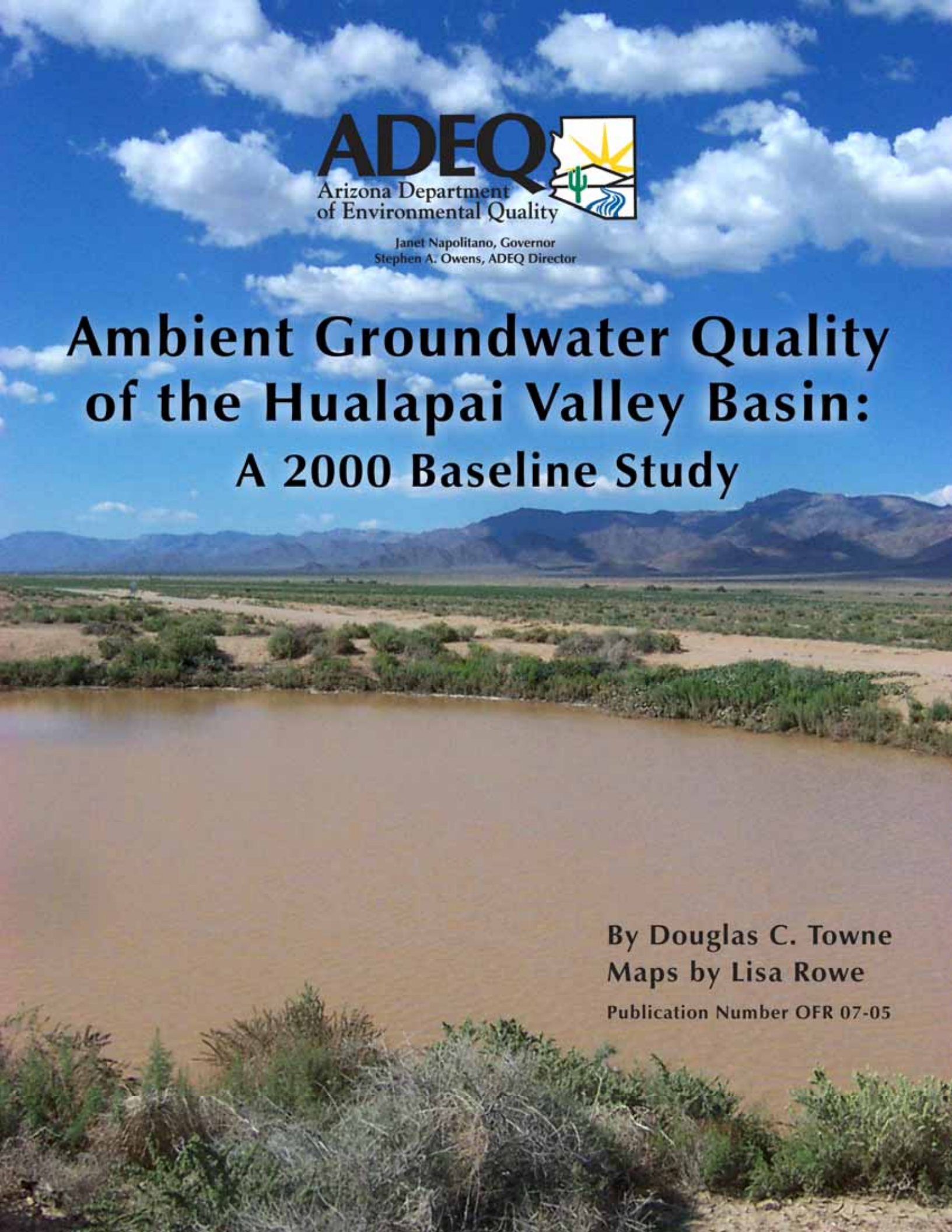

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Arizona Department of Environmental Quality

Janet Napolitano, Governor
Stephen A. Owens, ADEQ Director

Ambient Groundwater Quality of the Hualapai Valley Basin:
A 2000 Baseline Study

By Douglas C. Towne
Maps by Lisa Rowe

Publication Number OFR 07-05

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Arizona Department of Environmental Quality
Open File Report 07-05

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

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Photo Credits:	Douglas Towne

Report Cover: Recent monsoon rains diverted from Truxton Wash filled this small stock tank. Below the tank, the channel becomes heavily braided before flowing into Red Lake, a large playa located in the center of the Hualapai Valley basin. Drainages such as Truxton Wash become poorly defined farther from the mountain fronts owing to the lack of streamflow.[1] The background vista of Hualapai Valley and the Music Mountains captures the undeveloped conditions found in much of the basin.

Other Publications of the ADEQ Ambient Groundwater Monitoring Program

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

Big Sandy Basin	OFR 06-09, October 2006, 66 p.
Lake Mohave Basin	OFR 05-08, October 2005, 66 p.
Meadview Basin	OFR 05-01, January 2005, 29 p.
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 Fact sheets (FS):

Hualapai Valley Basin	FS 07-10, 2006, 4 p.
Big Sandy Basin	FS 06-24 October, 2006, 4 p.
Lake Mohave Basin	FS 05-21, October 2005, 4 p.
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.

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

ADEQ Ambient Monitoring Program Studies

October 2006

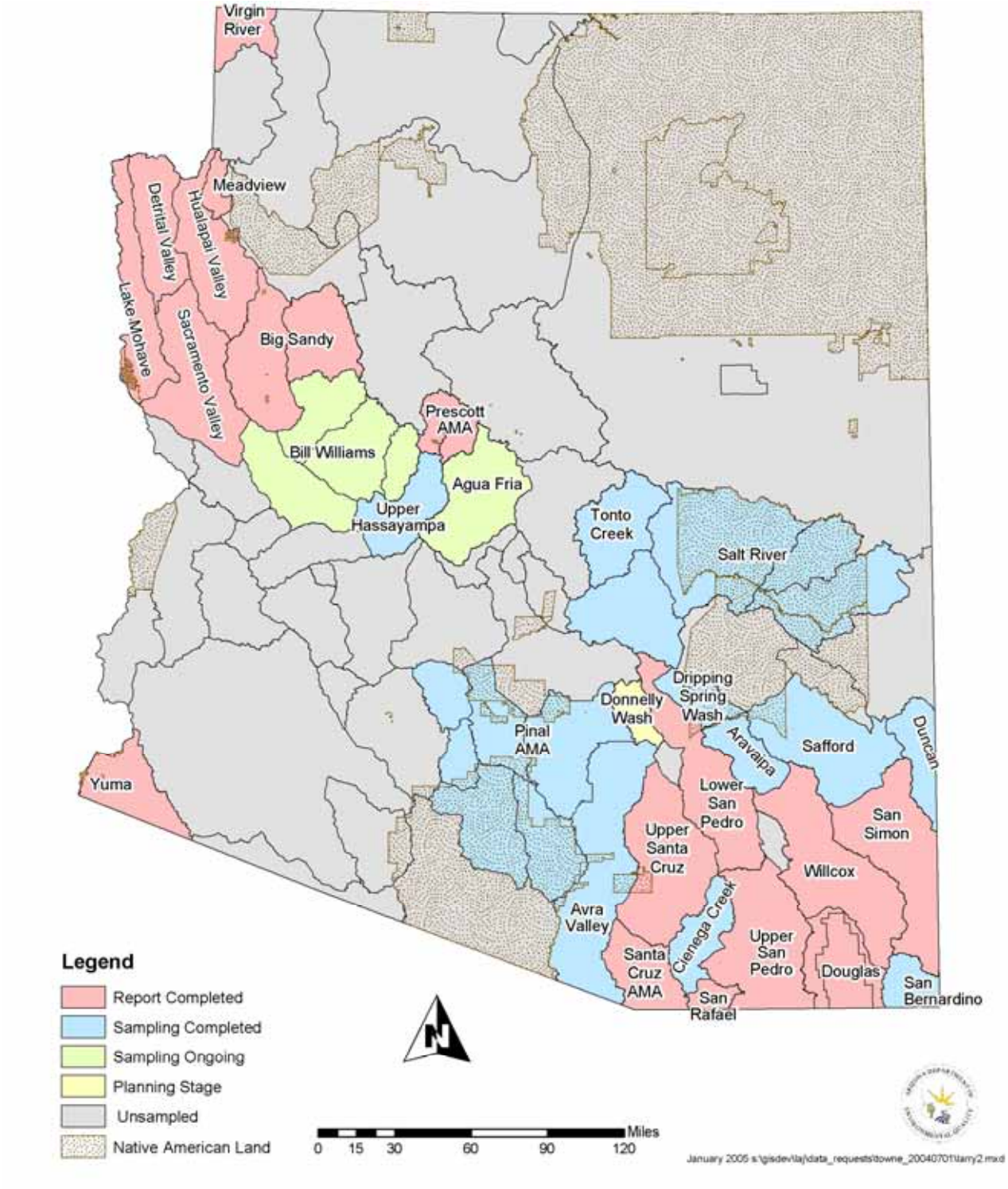


Table of Contents

Maps

Tables

Figures

Abbreviations

amsl	above mean sea level
ac-ft	acre-feet
af/yr	acre-feet per year
ADEQ	Arizona Department of Environmental Quality
ADHS	Arizona Department of Health Services
ADWR	Arizona Department of Water Resources
ARRA	Arizona Radiation Regulatory Agency
AZGS	Arizona Geological Survey
As	arsenic
bls	below land surface
BLM	U.S. Department of the Interior Bureau of Land Management
^{o}C	degrees Celsius
$CI_{0.95}$	95 percent Confidence Interval
Cl	chloride
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
gpm	gallons per minute
GWPL	Groundwater Protection List pesticide
HCl	hydrochloric acid
HUA	Hualapai Valley groundwater basin
LLD	Lower Limit of Detection
Mn	manganese
MCL	Maximum Contaminant Level
ml	milliliter
msl	mean sea level
ug/L	micrograms per liter
um	micron
uS/cm	microsiemens per centimeter at 25° Celsius
mg/L	milligrams per liter
MRL	Minimum Reporting Level
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
*	significant at $p \leq 0.05$ or 95% confidence level
**	significant at $p \leq 0.01$ or 99% confidence level
***	for information only, statistical test for this constituent invalid because detections fewer than 50 percent

"When Lt. Joseph Christmas Ives in 1854 sought the head of navigation of the Colorado River, he named this peak Music Mountain because the exposed strata appeared similar to a huge sheet of music or a musical staff. The name was placed on his map, but as the mountain was not conspicuous, it was overlooked by pioneers. Later the name was misapplied to another and more conspicuous peak ten miles west. It is the latter Music Mountain to which Capt. George M. Wheeler refers in his report of his expedition in the early 1870's. The Music Mountain area was a stronghold of the Hualapais and it was a good prospecting ground for miners."

Byrd Howell Granger
Arizona's Names: X Marks the Place [20]

Ambient Groundwater Quality of the Hualapai Valley Basin: A 2000 Baseline Study

By Douglas Towne

Abstract - The Hualapai Valley groundwater basin (HUA) trends north-northwest and is roughly 60 miles long and varying from 15 to 25 miles wide in northwestern Arizona. The basin covers 1,820 square miles in Mohave County stretching from Hualapai Peak just south of the City of Kingman to Lake Mead to the north.[27] The basin is composed of lands federally managed by the Bureau of Land Management, the National Park Service (as part of the Lake Mead National Recreation Area), private, State Trust and Hualapai Indian Nation lands.[6] Land use is mainly rangeland and recreation, with private lands near Kingman, increasingly developed for residential housing.

There are no perennial streams in the HUA basin.[7] The southern portion of the basin is drained by an ephemeral watercourse, Truxton Wash, which flows north and debouches after heavy precipitation into the normally dry Red Lake Playa. The other major ephemeral watercourse, Hualapai Wash, runs north of Red Lake Playa after heavy precipitation and debouches into Lake Mead. [7] Although the Colorado River, impounded in Lake Mead, forms the northern boundary of the basin, it is not a significant water supply within the HUA basin.[1]

Groundwater is the major source of water in the HUA.[27] It occurs in both the extensive older alluvium deposits found in Hualapai Valley and, to a lesser degree, the fractured rock and thin alluvium deposits of the Hualapai, Peacock, Music, and Cerbat Mountains.[17, 27] Historically, low-yield wells and springs located in or near mountain areas provided the main source of water for the minimal needs of the local economy that was based on ranching. Now, deep, high-yield alluvial wells, often exceeding 1,000 feet in depth, are the main supply source for major water users in the basin including the City of Kingman and outlying housing developments.[11]

In 2000, ADEQ conducted a baseline groundwater quality study of the HUA, sampling 26 sites for inorganic constituents. Also collected at selected sites were volatile organic compounds (VOCs)(21 samples), radiochemistry (16 samples) and radon (8 samples). Groundwater sites consisted of 20 relatively shallow, domestic or stock wells and/or springs in bedrock mountain areas and 6 deep wells in the valley alluvium. [28]

Of the 26 sites sampled, 9 sites (35 percent) had concentrations of at least one constituent that exceeded a health-based, federal or State water-quality standard. 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.[4, 36, 38] Health-based exceedances included arsenic (3 sites), fluoride (2 sites), gross alpha (3 sites), nitrate (3 sites), radium 226/228 (1 site), and uranium (2 sites). At 17 sites (65 percent), 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.[36] Aesthetics-based exceedances included chloride (2 sites), fluoride (11 sites), iron (2 sites), manganese (3 sites), pH-field (2 sites), sulfate (2 sites), and total dissolved solids or TDS (11 sites). There was one VOC detection of toluene (at 4.7 micrograms per Liter) in one of the 21 VOC samples collected.

Analytical results indicate that groundwater in the HUA is generally *slightly alkaline*, *fresh*, and *hard* to *very hard* based on pH values and TDS and hardness concentrations. [13, 20] The chemistry of groundwater samples varied widely with mixed-mixed and mixed-bicarbonate the most common compositions. Among trace elements, only boron, fluoride, selenium and zinc were detected at more than 20 percent of sample sites. Nitrate concentrations were sometimes elevated, with 11 sites (42 percent) having concentrations that may be from human activities. [25]

Statistically-significant patterns in water-quality data were found among groundwater sources (ANOVA, $p \leq 0.05$).[22] Temperature (field-measured), pH (field-measured), and fluoride were significantly higher at sites in the alluvium than at sites in hardrock. In contrast, calcium, magnesium and hardness were significantly higher at sites in hardrock than in alluvium. TDS ($p = 0.11$) and bicarbonate ($p = 0.08$) were also higher at sites in hardrock than in alluvium but failed to meet the statistical confidence level (ANOVA, $p \leq 0.05$). The limited sampling conducted in wells tapping the older alluvium—the aquifer that holds the majority of water reserves in the HUA—revealed generally acceptable groundwater quality with fluoride generally the only constituent of concern. Fluoride exceeded health based standards in one well and aesthetics based standards in four other wells; otherwise pH-field and TDS were the only aesthetic standards exceeded in one well apiece. The elevated fluoride concentrations are believed to occur naturally and are controlled by pH values that also increase downgradient through silicate hydrolysis reactions.[30]

INTRODUCTION

Purpose and Scope

The Hualapai Valley groundwater basin (HUA) is located in northwestern Arizona within Mohave County. The basin, as defined by the Arizona Department of Water Resources (ADWR) is a north-northwesterly trending trough roughly 60 miles long and varies from 15 to 25 miles wide, covering approximately 1,820 square miles (Map 1). [7] Groundwater is the primary source for domestic, public water supply, and stock uses as well as the limited irrigation, and mining water uses that occur in the HUA. The basin was selected for study to characterize groundwater quality conditions in this rapidly developing area of the state.

The ADEQ Ambient Groundwater Monitoring Program designed a study to characterize the current (2000) groundwater quality conditions in the HUA. Sampling by this ADEQ program 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*." [4]

This study sought to:

- Provide information on baseline groundwater quality conditions in the HUA in preparation for potential large population increases which will rely upon this resource as a municipal or domestic source.

- 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.[36]

- Examine water quality differences among different aquifers within the basin.

- Continue the assessment of the groundwater quality of the Upper Colorado River Planning Area that has culminated in ADEQ hydrology reports on the following basins: Sacramento Valley (2000),[31] Detrital Valley (2003),[32] Meadview (2004),[33] Lake Mohave (2005), [34] and Big Sandy (2006)[35].

- Support the Rural Watershed Initiatives investigation of the hydrogeology of the Detrital, Hualapai, and Sacramento Valleys.[1]

ADEQ collected samples from 26 sites for this groundwater quality assessment of the HUA. Types and numbers of samples collected and analyzed include inorganic constituents (physical parameters, major ions, nutrients, and trace elements); (26 sites), volatile organic compounds or VOCs (21 sites), radiochemistry (unstable elements, such as uranium, thorium, or radium that release radioactivity in the form of alpha, beta and gamma radiation) at 16 sites, and radon at 8 sites.

Benefits of Study – This study, which utilizes accepted sampling techniques and quantitative analyses, is designed to provide the following benefits:

- 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 and identifies areas with impaired conditions.[21]

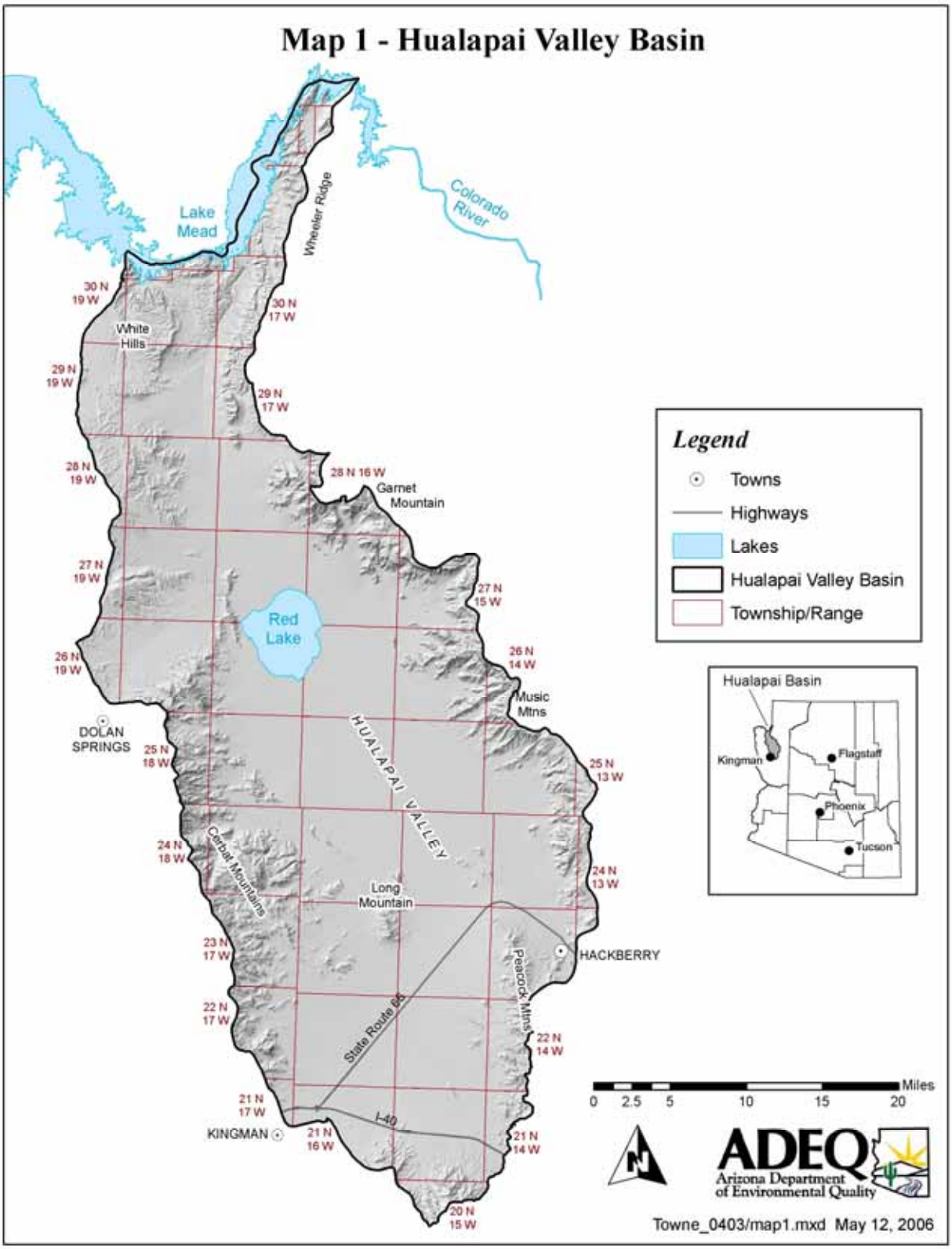
- A process for evaluating potential groundwater quality impacts arising from a variety of sources including mineralization, mining, agriculture, livestock, septic tanks, and poor well construction.

- A guide for identifying future locations of public supply wells.

- Determining where further water-quality investigation is needed?

Physical and Cultural Characteristics

Geography – The HUA is located adjacent to the Colorado Plateau within the Basin and Range physiographic province which consists of northwest-trending alluvial basins separated by elongated fault-block mountain ranges.[7] Hualapai Valley is an intermountain basin filled with alluvial deposits and volcanic rocks to depths of more than 10,000 feet.[11] The basin is bounded on the west by the Cerbat Mountains and White Hills, on the north by Lake


Map 1 - Hualapai Valley Basin
Lake Mead
Colorado River
Wheeler Ridge
White Hills
Garnet Mountain
Red Lake
HUALAPAI VALLEY
Music Mtns
DOLAN SPRINGS
Cerbat Mountains
Long Mountain
HACKBERRY
Peacock Mtns
State Route 66
I-40
KINGMAN
30 N 19 W
30 N 17 W
29 N 19 W
29 N 17 W
28 N 19 W
28 N 16 W
27 N 19 W
27 N 15 W
26 N 19 W
26 N 14 W
25 N 18 W
25 N 13 W
24 N 18 W
24 N 13 W
23 N 17 W
22 N 17 W
22 N 14 W
21 N 17 W
21 N 16 W
21 N 14 W
20 N 15 W
Legend
Towns
Highways
Lakes
Hualapai Valley Basin
Township/Range
Hualapai Basin
Kingman
Flagstaff
Phoenix
Tucson
Miles
0 2.5 5 10 15 20
ADEQ
Arizona Department of Environmental Quality
Towne_0403/map1.mxd May 12, 2006

Mead, on the east by Wheeler Ridge, Garnet Mountain, the Music Mountains, and the Grand Wash Cliffs and on the south by the Peacock and Hualapai Mountains (Map 1). Within Hualapai Valley lies Long Mountain and a few other isolated bedrock outcrops of metamorphic and volcanic origin. [28]

Mountain elevations range from 7,150 feet above mean sea level (amsl) in the Cerbat Mountains and 6,500 feet amsl along the Grand Wash Cliffs Elevations along the valley floor range from approximately 4,000 feet amsl at the basin's southern end and descend to 400 feet amsl where Hualapai Wash debouches into Lake Mead. [8]

In a previous Arizona Department of Water Resources (ADWR) report, a much larger "Hualapai Basin" was defined that consisted of five sub-basins: Kingman-Red Lake, Meadview, Hackberry, Truxton Lake, and Nelson. [27] This report covers only the Kingman-Red Lake sub-basin which is currently considered by the ADWR to be the Hualapai Valley basin. [7] In contrast, a smaller "Hualapai Basin" that ends just north of Red Lake Playa is delineated in an earlier USGS report. [17]

The land in the basin is privately owned, federally managed by the U.S. Bureau of Land Management (BLM), federally managed by the National Park Service as part of the Lake Mead National Recreation Area, State Trust lands or part of the Hualapai Indian Reservation (Map 2).[6]

Although the rapidly growing City of Kingman lies partially within the basin's boundaries, the HUA is otherwise lightly populated with scattered residential developments and homes, particularly in the southwest portion near Kingman. Located along Interstate 40, U.S. Highway 93 and the main Burlington Northern-Santa Fe railroad, Kingman has become a major service, trade and transportation center for northwest Arizona.

Climate and Vegetation - The climate of the HUA is semiarid, characterized by hot summers and mild winters. Precipitation varies with elevation; the highest reaches of the Hualapai Mountains average almost 20 inches annually. In contrast, Kingman averages 9 inches annually while Red Lake, a playa located in the middle of Hualapai Valley averages 6 inches. The low amount of precipitation combined with high temperatures and low humidity cause high evaporation rates in the region.[17]

Precipitation occurs in the late summer from July to September as high intensity thunderstorms of short duration; winter precipitation occurs from December to March and typically consists of gentle, long-lasting rains or snow produced by low-intensity storms. [7]

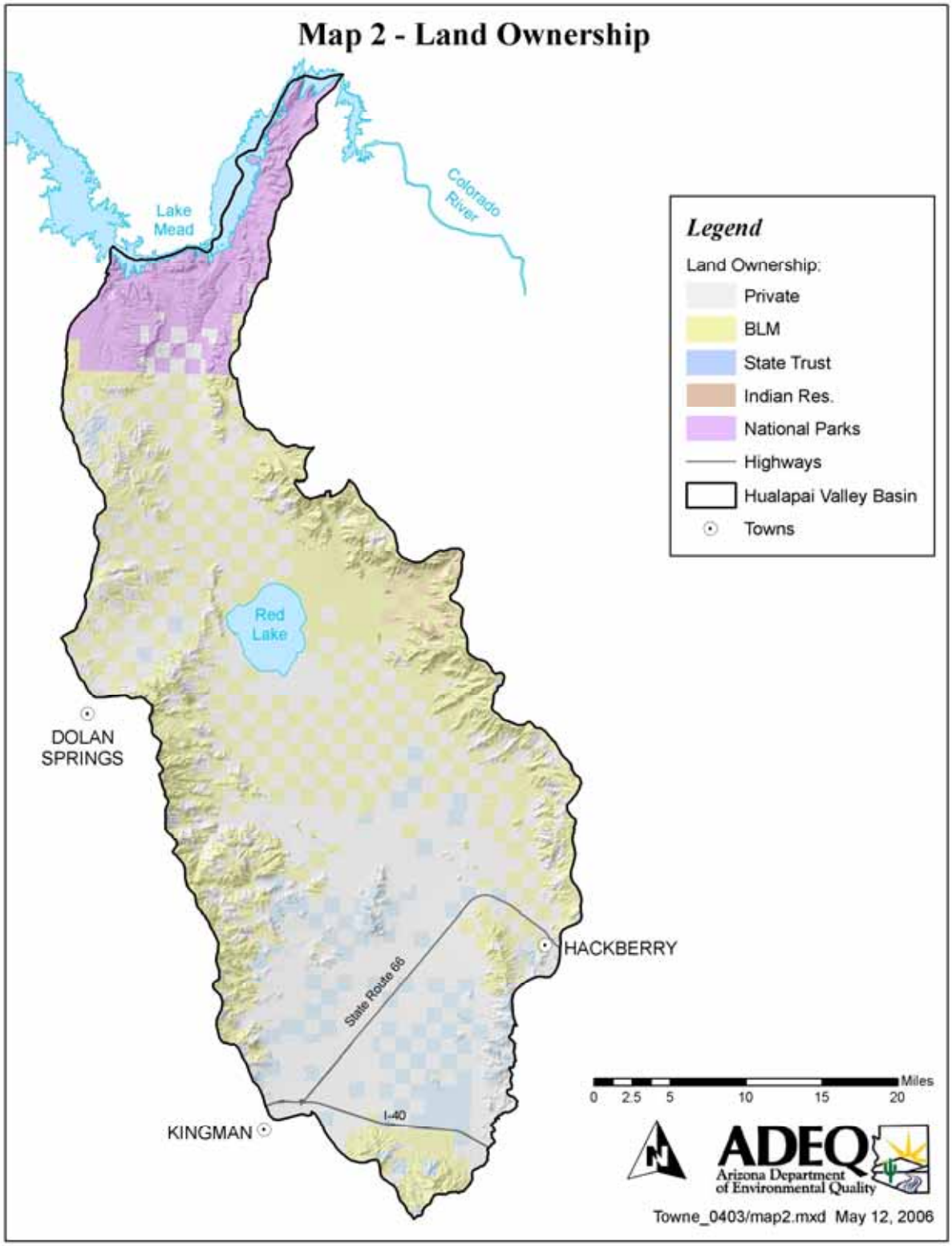
Vegetation at lower altitudes is characterized by various cacti, yucca, Joshua trees, and desert shrubs such as creosote bush, mesquite, ocotillo, and crucifixion thorn. Grass is sparse on the valley floors and lower slopes of the surrounding mountains. Juniper, pinion pine, and scrub oak grow at intermediate elevations and ponderosa pine is found above 6,500 feet. [16]

Surface Water –There are no perennial streams in the basin although intermittent stream flow occurs in the mountains as a result of major precipitation events.[7] Because of infiltration and evaporation, these flows rarely reach Truxton Wash which drains most of the southern portion of the basin and eventually debouches into the 22-square mile Red Lake, the second largest playa in Arizona. Most of the inflow to the lake eventually evaporates. [27] A drainage divide north of Red Lake causes the central and southern parts of the basin to be topographically closed to surface drainage. Groundwater, however flows under this divide and drains to the Colorado River. [27]

The northern portion of the basin is drained by Hualapai Wash, an intermittent stream that runs after heavy precipitation north of Red Lake Playa and flows 20 miles before debouching into Lake Mead. [27] Before the construction of Hoover Dam, there was a large spring near the mouth of Hualapai Wash that has since been submerged by Lake Mead. [27]

Although the Colorado River forms a small part of the northern perimeter of the basin, it is not a significant water supply within the HUA.[1] The HUA is within the Upper Colorado River Watershed. The ADEQ 303 (d) Listing Report for impaired surface water found no citations in the basin.[5]

Groundwater Development – Historically, springs and shallow wells located in and near the mountains throughout the HUA were the primary source of water for domestic, stock and mining uses. [27] The annual amount of groundwater pumped was estimated to be about 20 acre-feet per year.[11] In 1960, deep wells were drilled in Hualapai Valley near Kingman when the city established a


Map 2 - Land Ownership
Lake Mead
Colorado River
Red Lake
DOLAN SPRINGS
HACKBERRY
KINGMAN
State Route 66
I-40
Legend
Land Ownership:
Private
BLM
State Trust
Indian Res.
National Parks
Highways
Hualapai Valley Basin
Towns
0 2.5 5 10 15 20
Miles
ADEQ
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municipal well field. Kingman pumped approximately 1,000 acre-feet by 1962 and 3,600 acre-feet by 1967.[11] By 1990, Kingman had 15 wells that pumped an estimated 6,000 acre-feet and is now the largest water user in the basin.[7]

HYDROGEOLOGY

Hualapai Valley is an intermountain basin filled with alluvium, evaporites, and volcanic rocks to depths in excess of 10,000 feet. [11] Over most of the basin, bedrock drops off steeply from the peripheral mountain fronts, achieving depths in excess of 800 feet in relatively short distances. [11] The area around Red Lake Playa is the thickest part of the basin and is partially separated from the southern portion of the basin by a ridge of granite-gneiss bedrock whose surface expression is Long Mountain. [11]

The Hualapai Valley basin-fill sediments can be divided into three main units: younger alluvium, intermediate alluvium, and older alluvium (Figure 1).[17]

Younger Alluvium – Streambed deposits in Hualapai Valley and in mountain canyons seldom exceed 50 feet in thickness. [27] In the central part of the valley, the younger alluvium is found above the water table. This unit yields small amounts of water for domestic and stock wells in mountain canyons. [17]

Two subgroups compose the younger alluvium: piedmont, stream and playa.[17] Piedmont deposits are up to 50 feet thick and consist of poorly consolidated conglomerate and silt interspersed with caliche layers. Stream deposits are thinner and consist of unconsolidated sand and gravels. Playa deposits are composed of unconsolidated silt, clay, sand, and fine gravel. [11]

Intermediate Alluvium – These deposits of weak-to-moderately consolidated granite, schist, gneiss and volcanic fragments are typically 200 to 500 feet thick and are located above the water table in the central part of the valley.[17] Intermediate alluvium is only a dependable aquifer along the valley margins where the unit intersects the water table. [27] Well yields from this unit range up to 500 gallons per minute.[17]

Older Alluvium – This is the principal aquifer in the basin and also the deepest stratigraphic deposit. The older alluvium is composed of moderately consolidated granite, schist, gneiss, and volcanic conglomerate eroded from the surrounding mountains.[11] Sediment grain size and sorting are a function of distance from the source mountains. Clastics tend to be larger and more unsorted close to the base of the mountains and finer and more uniformly sorted nearer the center of the valley. This oldest alluvial deposit overlies Precambrian basement rocks such as granite, gneiss, and schist that do not yield groundwater except along fractures and weathered zones. In the southern end of the basin, volcanic rocks are interbedded with the older alluvium.[7] The older alluvium can store and transmit large amounts of water; well yields up to 1,500 gallons per minute have been reported.[27]

Bedrock – The bedrock is relatively impermeable compared with the basin fill, and forms barriers to groundwater movement in the basin-fill aquifer.[1, 17] The igneous, metamorphic, volcanic and sedimentary rocks found in the surrounding mountains are generally non-water bearing (Map 3). However, fractured and weathered zones in these rocks do provide some water to low-yielding wells and springs. [27]

A large halite salt body is located about 1,400 feet bls near Red Lake and extends to at least 6,000 feet bls based on drill cores. Subsequent seismic surveys show the salt deposit as wedge shaped with the thickest portion (about 7,000 feet) lying at the fault boundary on the eastern edge of the Hualapai Valley basin and thinning toward the west. The salt body is believed to be caused by basin evaporites.[11]

Groundwater Characteristics

Groundwater generally moves from the mountain fronts towards the center of the valley, then flows north and exits the basin as underflow to Lake Mead.[17] Estimates of the annual sub-surface outflow from the HUA range from 2,000 to 5,000 acre-feet. [17, 27]

Groundwater inflow to the HUA formerly occurred in the Hackberry area as groundwater moved northward over a shallow bedrock barrier. Groundwater pumping in this area has lowered water levels so that little or no groundwater now flows into Hualapai Valley. [17]

Groundwater gradients are remarkably flat in Hualapai Valley, with depths to groundwater varying almost solely as a function of surface elevation. The only exception is at the northeast-trending buried ridge of granite-gneiss bedrock whose surface expression is Long Mountain. This ridge impedes groundwater movement towards Red Lake resulting in a higher gradient required to move groundwater through the area. [11]

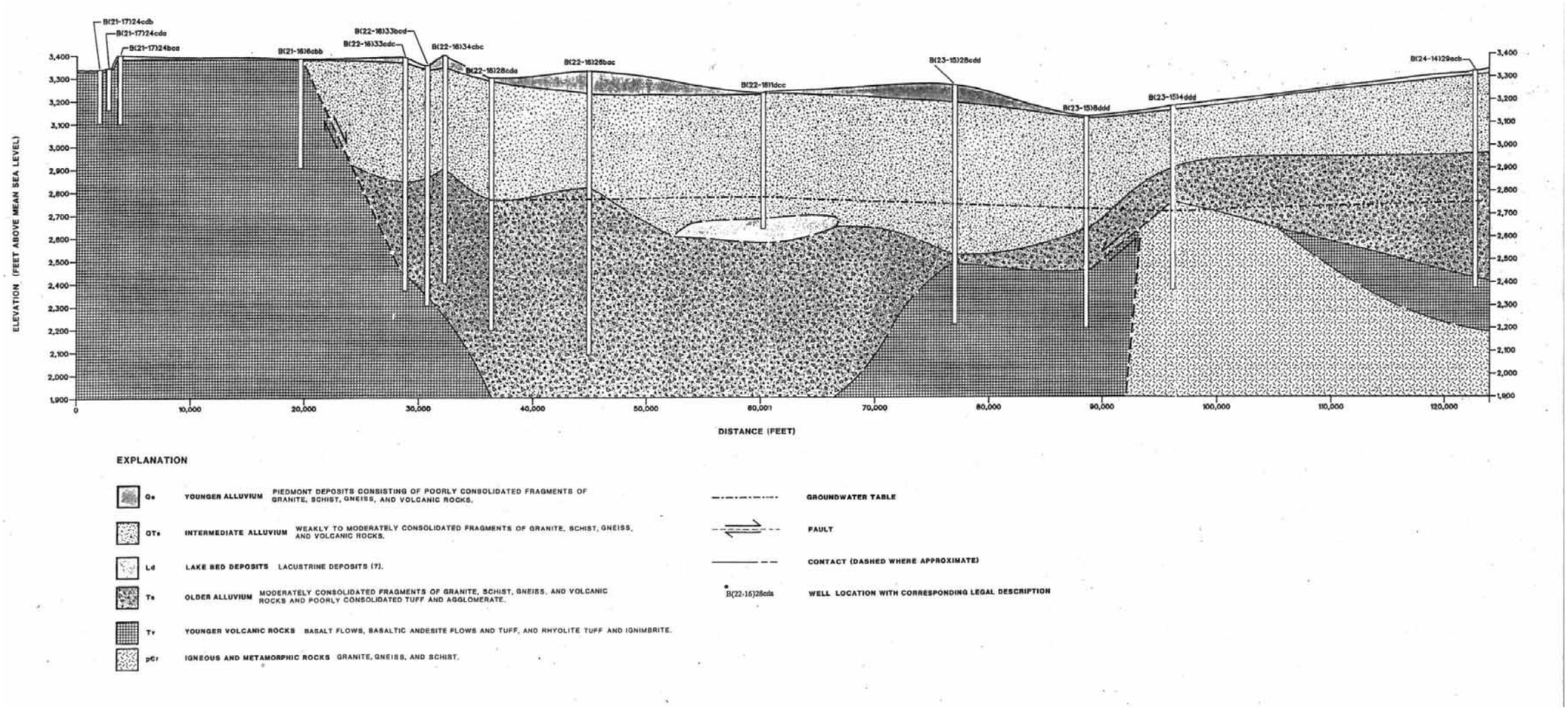
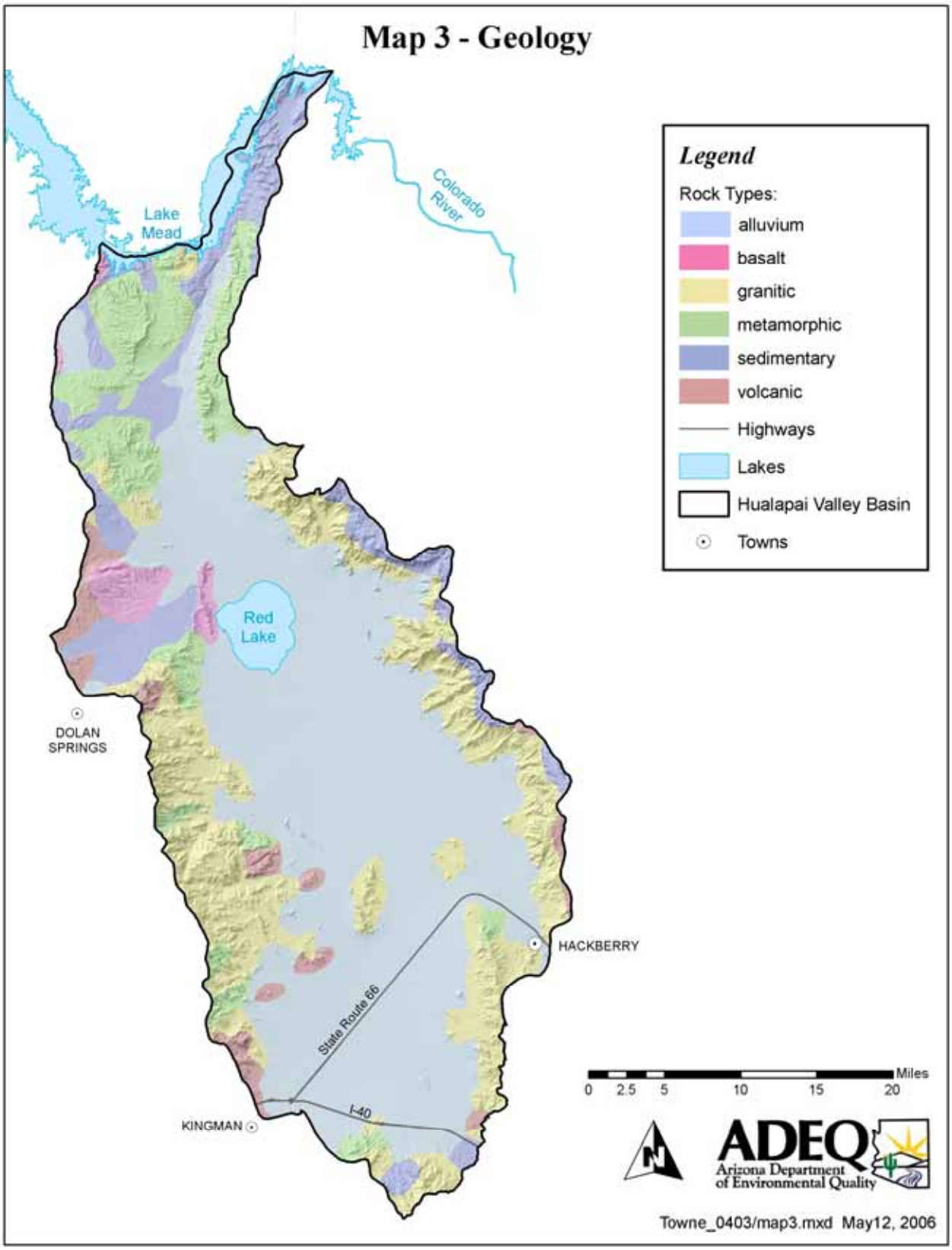


Figure 1. Geologic cross-section of Hualapai Valley from Kingman (SW) to Peacock Mtns (NE). [11]


Map 3 - Geology
Legend
Rock Types:
alluvium
basalt
granitic
metamorphic
sedimentary
volcanic
Highways
Lakes
Hualapai Valley Basin
Towns
Lake Mead
Colorado River
Red Lake
DOLAN SPRINGS
HACKBERRY
State Route 66
I-40
KINGMAN
0 2.5 5 10 15 20 Miles
ADEQ
Arizona Department of Environmental Quality
Towne_0403/map3.mxd May12, 2006

Recharge to the basin is mainly from streambed infiltration near the apexes of dissected alluvial fans which extend into the mountain canyons. Recharge from precipitation on the valley floor is considered negligible due to evapo-transpiration.[11] Total recharge to the basin is estimated at 3,000 acre-feet per year. [7]

Groundwater depths range from 500 to 900 feet below land surface (bls) northeast of Kingman, to 300 feet bls south of Red Lake to 650 feet bls north of Red Lake at Pierce Ferry Road. [27] Groundwater levels have been largely static in the basin, except for decreases noted around the City of Kingman's well fields near Hackberry and the municipal airport.[11]

HUA groundwater reserves are estimated to be 5 million acre-feet to a depth of 1,200 feet bls; another estimate ranges from 10.5-21 million acre-feet. [7, 17] In a 1990 study, the HUA basin was divided into three areas by quantifying available groundwater: generally south of Long Mountain contained 2.6 million acre-feet, from Long Mountain to south of Red Lake contained 4.7 million acre-feet, and the area around Red Lake and to the north contained almost 2 million acre-feet. [11]

INVESTIGATION METHODS

Various groundwater sites were sampled by the ADEQ Ambient Groundwater Monitoring Program to characterize regional groundwater quality in the HUA. Samples were collected at all sites for inorganic constituents (physical parameters, major ions, nutrients, and trace elements) and VOCs at most sites. At select sites, samples were also collected for radiochemistry and radon 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.[19]

Sampling Strategy

This study focused on regional groundwater quality conditions that are large in scale and persistent in time. This research is designed to identify large-scale 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.[22]

Sampling in the HUA 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.[22] 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 both stock and domestic purposes 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.[8] Other factors such as casing access to determine groundwater depth and construction information were preferred but not essential.

If wells registered with ADWR 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.[22]

Twenty-six (26) groundwater sites were sampled for the study. The various types and numbers of samples collected and analyzed were: inorganic (26 samples), VOC (21samples), radiochemistry (16 samples) and radon (8 samples).

Sample Collection

The sample collection methods for this study conformed to the Quality Assurance Project Plan (QAPP)[3] and the Field Manual For Water Quality Sampling.[8] While these sources should be consulted as references to specific sampling questions, a brief synopsis of the procedures involved in collecting a groundwater sample is provided.

After obtaining permission from the owner to sample the well, the volume of water needed to purge the well three bore-hole volumes was calculated from well log and on-site information. Physical parameters—temperature, pH, and specific conductivity—were monitored at least every five minutes using an YSI multi-parameter instrument. Typically to assure obtaining fresh water from the aquifer, after three bore volumes had been pumped and physical parameter measurements were stable, 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. VOCs
2. Radon
3. Inorganic
4. Radiochemistry

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

Radon samples were collected in two unpreserved, 40-ml clear glass vials. Radon samples were carefully filled and sealed so that no headspace remained.[13]

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 preserved with 2 ml sulfuric acid (95.5 percent). Samples to be analyzed for other parameters were unpreserved.[29]

Radiochemistry samples were collected in two collapsible 4-liter plastic containers and preserved with 5 ml nitric acid to reduce the pH below 2.5 su. [15]

All samples were kept at 4°C with ice in an insulated cooler, with the exception of the radiochemistry samples. Chain of custody procedures were followed in sample handling. Samples for this study were collected during eight field trips between February 1999 and December 2002.

Laboratory Methods

The inorganic and VOC analyses for this study were conducted by the Arizona Department of Health Services (ADHS) Laboratory in Phoenix, Arizona. Inorganic sample splits analyses were conducted by Del Mar Laboratory in Phoenix, Arizona. A complete listing of inorganic parameters, including laboratory method, EPA water method and Minimum Reporting Level (MRL) for each laboratory is provided in Table 1. The analyte list for the VOC samples is provided in Table 2.

Radon samples were analyzed by Radiation Safety Engineering, Inc. Laboratory in Chandler, Arizona.

Radiochemistry samples were analyzed by either the Radiation Safety Engineering, Inc. Laboratory or the Arizona Radiation Agency Laboratory in Phoenix. The following EPA SDW protocols were used: 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. [15]

Table 1. ADHS/Del Mar/ARRA Laboratory Water Methods and Minimum Reporting Levels Used for the Hualapai Valley Basin 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 (uS/cm)	Electrometric	EPA 120.1/ SM2510B	-- / 1
Hardness	Titrimetric, EDTA	EPA 130.2 / SM2340B	10 / 1
Hardness	Calculation	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	1 / 2
Magnesium	ICP-AES	EPA 200.7	1 / 0.5
Sodium	ICP-AES	EPA 200.7 / EPA 273.1	1 / 5
Potassium	Flame AA	EPA 200.7 / EPA 258.1	0.5 / 1
Bicarbonate	Calculation	Calculation	2
Carbonate	Calculation	Calculation	2
Chloride	Potentiometric Titration	EPA 300.0	0.5 / 0.5
Sulfate	Colorimetric	EPA 300.0	1 / 0.5
Nutrients			
Nitrate as N	Colorimetric	EPA 353.2	0.02 / 0.1
Nitrite as N	Colorimetric	EPA 353.2	0.02 / 0.1
Ammonia	Colorimetric	EPA 350.1/ EPA 350.3	0.02 / 0.5
TKN	Colorimetric	EPA 351.2 / 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 [14, 29]

Table 1. ADHS/Del Mar/ARRA Laboratory Water Methods and Minimum Reporting Levels Used for the Hualapai Valley Basin Study--Continued

Constituent	Instrumentation	ADHS / Del Mar Water Method	ADHS / Del Mar Minimum Reporting Level
Trace Elements			
Aluminum	ICP-AES	EPA 200.7	-- / 0.5
Antimony	Graphite Furnace AA	EPA 200.9	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 200.7 / EPA 200.9	0.01 / 0.004
Fluoride	Ion Selective Electrode	EPA 300.0	0.05 / 0.1
Iron	ICP-AES	EPA 200.7	0.1 / 0.2
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 200.7	0.001 / 0.005
Thallium	Graphite Furnace AA	EPA 200.9	0.002
Zinc	ICP-AES	EPA 200.7	0.05
Radiochemicals			
Gross alpha beta	Gas flow proportional counter	EPA 900.0	varies
Co-Precipitation	Gas flow proportional counter	EPA 00.02	varies
Radium 226	Gas flow proportional counter	EPA 903.0	varies
Radium 228	Gas flow proportional counter	EPA 904.0	varies
Uranium	Kinnetic phosphorimeter	EPA Laser Phosphorimetry	varies

All units are mg/L
Source [14, 15, 29]

Table 2. Volatile Organic Compounds (VOCs) Analyte List for the Hualapai Valley Study

Benzene*	1,2-Dichloroethane*	Trichloroethylene*
Bromozene	1,1-Dichloroethene*	Trichlorofluoromethane*
Bromochloromethane	cis-1,2-Dichloroethene*	1,2,3-Trichloropropane
Bromodichloromethane*	trans-1,2-Dichloroethene*	1,2,4-Trimethylbenzene
Bromoform*	1,2-Dichloropropane*	1,3,5-Trimethylbenzene
Bromomethane*	1,3-Dichloropropane	Vinyl chloride*
n-Butylbenzene	2,2-Dichloropropane	Total xylenes*
sec-Butylbenzene	1,1-Dichloropropene	Methyl-t-butyl ether (MTBE)*
tert-Butylbenzene	cis-Dichloropropene*	
Carbon Tetrachloride*	trans-Dichloropropene*	
Chlorobenzene*	Ethylbenzene*	
Chloroethane*	Hexachlorobutadiene	
Chloroform*	Isopropylbenzene	
Chloromethane*	p-Isopropyltoluene	
2-Chlorotoluene	Methylene chloride*	
4-Chlorotoluene	Naphthalene	
Dibromochloromethane*	n-Propylbenzene	
1,2-Dibromo-3-chloropropane	Styrene	
1,2-Dibromoethane	1,1,1,2-Tetrachloroethane*	
Dibromomethane	Tetrachloroethylene*	
1,2-Dichlorobenzene*	Toluene*	
1,3-Dichlorobenzene*	1,2,3-Trichlorobenzene	
1,4-Dichlorobenzene*	1,2,4-Trichlorobenzene	
Dichlorodifluormethane*	1,1,1-Trichlorobenzene*	
1,1-Dichloroethane*	1,1,2-Trichloroethane	

VOC suite for samples HUA-1 through HUA-3, * = VOC suite for samples HUA-4 through HUA-36

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 HUA study. The design of the QA/QC plan was based on recommendations included in the *Quality Assurance Project Plan* (*QAPP*) and *the Field Manual For Water Quality Sampling*. [3, 8] Types and numbers of QC samples collected for this study are as follows:

Inorganic: (3 duplicates, 5 partial duplicates, 2 splits, 3 blanks).

VOCs: (5 travel blanks).

Radiochemical: (no QC samples).

Radon: (1 duplicate).

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.[7]

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.[22] The equipment blanks contained SC-lab and turbidity contamination at levels expected due to impurities in the source water used for the samples. The blank results, however, did not indicate systematic contamination.

SC and turbidity were detected in all three equipment blanks.

For SC, equipment blanks had a mean (2.3 uS/cm) which was less than 1 percent of the SC mean concentration 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 uS/cm, and carbon dioxide from the air can dissolve in de-ionized water with the resulting bicarbonate and hydrogen ions imparting the observed conductivity.[29]

Similarly for turbidity, equipment blanks had a mean level (0.06 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.[29]

In one blank (HUA-28), hardness (22 mg/L) and calcium (7.4 mg/L) were detected; however, in the partial lab filtered blank (HUA-28D), calcium was not detected. These results did not appear to significantly impact sampling results.

The five VOC travel blanks revealed no contamination issues.

Duplicate Samples - Duplicate samples are identical sets of samples collected from the same source at the same time and submitted to the same laboratory. Data from duplicate samples provide a measure of variability from the combined effects of field and laboratory procedures.[8]

Duplicate samples were collected from sampling sites that were believed to have elevated constituent concentrations as judged by field SC values. Three duplicate samples and five partial duplicate samples were collected in this study (Table 3).

Analytical results indicate that of the 22 constituents that had concentrations above the MRL, the maximum variation between duplicates was less than 5 percent (Table 2). The only exceptions were selenium (11%), calcium (12%), nitrate (17%), turbidity (26%), and TKN (30%). The median variation between duplicates was less than 5 percent except with turbidity (7%) and TKN (30%).

Analytical results of the one duplicate radon sample submitted to Del Mar Laboratory revealed less than one percent difference.

Table 3. Summary Results of HUA Duplicate Samples from the ADHS Laboratory

Parameter	Number	Difference in Percent			Difference in Concentrations		
		Minimum	Maximum	Median	Minimum	Maximum	Median
Physical Parameters and General Mineral Characteristics							
Alk., Total	3	0 %	1 %	0 %	0	1	0
SC (uS/cm)	3	0 %	0 %	0 %	0	0	0
Hardness	3	0 %	1 %	0 %	0	20	0
pH (su)	3	0 %	3 %	1 %	0	0.5	0.01
TDS	3	1 %	3 %	1 %	20	50	20
Turb. (ntu)	3	7 %	26 %	7 %	0.02	0.14	0.05
Major Ions							
Bicarbonate	3	0 %	4 %	0 %	0	10	0
Calcium	8	0 %	12 %	1 %	0	6	2
Magnesium	8	0 %	5 %	3 %	0	11	1
Sodium	8	0 %	5 %	2 %	0	8	2
Potassium	8	0 %	5 %	1 %	0	0.7	0.1
Chloride	3	0 %	0 %	0 %	0	0	0
Sulfate	3	0 %	2 %	2 %	0	10	10
Nutrients							
Nitrate (as N)	2	5 %	17 %	-	0.01	6	-
TKN	1	30 %	30 %	30 %	0.16	0.16	0.16
Trace Elements							
Arsenic	3	1 %	3 %	1 %	0.001	0.002	0.001
Boron	8	0 %	4 %	0 %	0	0.01	0
Chromium	2	1 %	2 %	-	0.001	0.002	-
Fluoride	3	1 %	4 %	3 %	0.01	0.2	0.2
Manganese	1	1 %	1 %	1 %	0.001	0.001	0.001
Selenium	3	0 %	11 %	4 %	0	0.0015	0.0005
Zinc	2	0 %	4 %	-	0	0.02	-

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

***** Antimony (one sample), TKN (two samples), and total phosphorus (two samples) were detected in the one duplicate sample and not detected in the other duplicate sample.

Split Samples - Split samples are identical sets of samples collected from the same source at the same time that are submitted to two different laboratories to check for laboratory differences.[8] Two inorganic split samples were 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 19 had concentrations above MRLs for both ADHS and Del Mar laboratories (Table 4). The maximum difference between split constituent only exceeded 20 percent for phenolphthalein alkalinity (23%), selenium (41%) and TKN (77%).

Split samples were also evaluated using the non-parametric Sign test to determine if there were any significant ($p \leq 0.05$) differences between ADHS laboratory and Del Mar laboratory analytical results.[22] Results of the Sign test showed no significant differences between constituent concentrations reported by the ADHS laboratory and those reported by Del Mar laboratory.

Split results reported by Del Mar laboratory detected ammonia in one sample at concentrations above ADHS laboratory MRLs that was reported as non-detect by the latter laboratory. The opposite pattern occurred in one sample with the ADHS laboratory detecting total phosphorus at concentrations above Del Mar laboratory MRL that was reported as non-detect by the latter laboratory.

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.

Data Validation

The analytical work for this study was subjected to the following five QA/QC correlations. [21, 23]

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.[23]

Overall, cation/anion meq/L balances of HUA samples were significantly correlated (regression analysis, $p \leq 0.01$) and were within acceptable limits (90 - 110 percent) except for HUA-16, which at 113 percent, barely exceeded the acceptable limit.

SC/TDS - The SC and TDS concentrations measured by contract laboratories were significantly correlated as were field-SC and TDS concentrations (regression analysis, $p \leq 0.01$). Typically, the TDS concentration in mg/L should be from 0.55 to 0.75 times the SC in µS/cm for groundwater up to several thousand TDS mg/L.[23] 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 factor. The relationship of TDS to SC becomes undefined for groundwater with very high or low concentrations of dissolved solids.[23]

Hardness - Concentrations of laboratory-measured and calculated values of hardness were significantly correlated (regression analysis, $p \leq 0.01$). Hardness concentrations were calculated using the following formula: [(Calcium x 2.497) + (Magnesium x 4.118)]. [23]

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, $p \leq 0.01$).

pH - The pH value is closely related to the environment of the water and is likely to be altered by sampling and storage.[23] Even so, the pH values measured in the field using a YSI meter at the time of sampling were significantly correlated with laboratory pH values (regression analysis, $p \leq 0.01$).

Temperature/GW Depth/Well Depth – Groundwater temperature measured in the field was compared to groundwater depth and well depth to examine the relationship that exists between temperature and depth. Groundwater temperature should increase with depth, approximately 3 degrees Celsius with every 100 meters or 328 feet.[9]

Temperature was significantly correlated (regression analysis, $p \leq 0.01$) with both groundwater depth and well depth.

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

Table 4. Summary Results of Hualapai Valley Basin Split Samples From ADHS/Del Mar Labs

Constituents	Number	Difference in Percent		Difference in Levels		Significance
		Minimum	Maximum	Minimum	Maximum	
Physical Parameters and General Mineral Characteristics						
Alkalinity, total	2	0 %	5 %	0	20	ns
Alkalinity, phen.	1	23 %	23 %	6	6	ns
SC (uS/cm)	2	0 %	1 %	0	10	ns
Hardness	2	4 %	11 %	10	30	ns
pH (su)	2	1 %	1 %	0.09	0.13	ns
TDS	2	1 %	14 %	10	160	ns
Turbidity (ntu)	2	5 %	7 %	2	2	ns
Major Ions						
Calcium	2	5 %	12 %	7.7	8	ns
Magnesium	2	3 %	5 %	0.5	2	ns
Sodium	2	2 %	2 %	1	10	ns
Potassium	2	3 %	7 %	0.2	1.1	ns
Chloride	2	0 %	2 %	0	4	ns
Sulfate	2	1 %	2 %	1	3	ns
Nutrients						
Nitrate as N	1	0 %	0 %	0	0	ns
TKN	1	77 %	77 %	0.77	0.77	ns
Trace Elements						
Arsenic	1	12 %	12 %	0.023	0.023	ns
Fluoride	2	4 %	16 %	0.1	0.17	ns
Selenium	1	41 %	41 %	0.0058	0.0058	ns
Zinc#	1	8 %	8 %	0.016	0.016	ns

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

* Ammonia (in one split sample) was detected in the Del Mar sample near the MRL and not detected in the ADHS sample; the opposite pattern occurred with total phosphorus (in one split sample). Total phosphorus was detected in the ADHS sample near the MRL and not detected in the ADHS sample.

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.[39]

Data Normality: Data associated with 25 constituents were tested for non-transformed normality using the Kolmogorov-Smirnov one-sample test with the Lilliefors option.[10] Results of this test revealed that 6 of the 25 constituents (or 24 percent) examined (temperature, calcium, magnesium, total alkalinity, bicarbonate, and fluoride) were normally distributed.

Results of the log-transformed test revealed that 18 of the 25 constituents (or 68 percent) examined (temperature, pH-field, SC-field, SC-lab, TDS, hardness, turbidity, calcium, sodium, potassium, bicarbonate, chloride, sulfate, fluoride, radon, gross alpha, and gross beta) were normally distributed. Thus, log-transformed data were used for the remainder of the statistical analyses.

Spatial Relationships: The parametric analysis of variance (ANOVA) test using log-transformed data was applied to investigate the hypothesis that constituent concentrations from groundwater sites having different sources of water 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.[39] 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 water sources (basin-fill and bedrock).

The ANOVA test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.[22] The ANOVA test was applied to selenium even though the result was not considered statistically valid in order to highlight possible significant differences. Highlights of these statistical tests are summarized in the groundwater quality section. The ANOVA test was not calculated for trace parameters or nutrients rarely detected, such as ammonia, antimony, arsenic, barium, beryllium, cadmium, carbonate, chromium, copper, iron, lead, manganese, mercury, nickel, nitrite, phenolphthalein alkalinity, radium, selenium, silver, thallium, total phosphorus, and uranium.

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.[39] The Pearson test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.[22] Consequently, Pearson Correlation Coefficients were not calculated for the same constituents as in spatial relationships.

Figure 2. This 400-foot domestic well (HUA-1) shows the preferred sampling location of a faucet located near the wellhead.

Figure 3. The Hualapai Basin ends at Lake Mead, created in 1936 with the impoundment of the Colorado River by Hoover Dam.

Figure 4. From the foothills of the Hualapai Mountains, Long Mountain can be seen in the sunlight rising up from Hualapai Valley with the Music Mountains in the background to the right, the Cerbat Mountains to the left.

Figure 5. The sample from Thompson Windmill, located in the foothills of the Cerbat Mountains southwest of Red Lake, met all water quality standards except iron and manganese.

Figure 6. Most of the groundwater samples collected in Hualapai Valley were from stock or domestic wells such as this well Maureen Freark is sampling.

Figure 7. Some wells in the Hualapai Valley basin are capable of producing upwards of 1,000 gallons per minute, such as this irrigation well off Route 66 between Kingman and Hackberry. This well was 1,059 feet deep and the sample (HUA-27) met all health-based water quality standards.

Figure 8. The groundwater sample (HUA-22/23) from this 405-foot deep domestic well in the Music Mountains had water quality exceedances for arsenic, gross alpha, radium 226+228, sulfate and TDS. The well is located in granite, a rock type which is often linked with elevated radiochemistry concentrations, especially in combination with mining operations that expose more rock surface material. [24] The other constituents that exceeded water quality standards, particularly sulfate, are also commonly associated with mining activities. It is not known if any mining had occurred in the vicinity.

Figure 9. The largest water user in the Hualapai Valley Basin is the City of Kingman, which withdrew 6,000 acre-feet in 1989. [7] Kingman has several high production wells near the municipal airport; this well is located between the Burlington Northern Santa Fe railroad line and Route 66. The City of Kingman is also supplied by wells located to the west in the Sacramento Valley Basin.

Figure 10. Mohave County is experiencing rapid population growth, marked by the construction of numerous housing developments. The area northeast of Kingman between the Cerbat and Peacock Mountains is where many such developments are being built including the "The Ranch at Long Mountain". There is relatively little residential development in the northern part of Hualapai Valley, especially in the area between Red Lake and Lake Mead.

Figure 11. The mural on the Mohave County Historical Museum building shows the famous two-lane highway that runs through the basin. Route 66 was not only a famous song and TV show but was also featured in the novel, *The Grapes of Wrath*.

Figure 12. Contrary to the art found on this well driller's sign in Kingman, no artesian wells were located during this water quality study of the Hualapai Valley basin.

Figure 13. An ephemeral drainage, Truxton Wash, shown here looking south towards its headwaters in the Peacock Mountains, is the main drainage in the southern part of the basin. Truxton Wash flows north until becoming braided and debouching into Red Lake Playa. North of the playa, another ephemeral drainage, Hualapai Wash, forms the main drainage and debouches into Lake Mead. [7]

GROUNDWATER SAMPLING RESULTS

To characterize the regional groundwater quality of the HUA basin, ADEQ personnel sampled 26 groundwater sites consisting of 23 wells and 3 springs. The wells were equipped with submersible pumps except for four windmills, and used for domestic and/or stock use. The springs were used for livestock watering. Information on these groundwater sample sites is provided in Appendix A.

At the 26 sites, the following types of samples were collected: inorganic suites at 26 sites, Volatile Organic Compounds (VOCs) at 21 sites, radiochemistry (unstable elements such as uranium, thorium, or radium that release radioactivity in the form of alpha, beta and gamma radiation) at 16 sites, radon at 8 sites.

Water Quality Standards/Guidelines

The ADEQ ambient groundwater monitoring program characterizes regional groundwater quality. An important determination ADEQ makes concerning the collected samples is how the analytical results compare to various drinking water quality standards. ADEQ used three sets of drinking water standards to evaluate the suitability of groundwater in the basin for drinking water use. These standards reflect the best current scientific and technical judgment available on the suitability of water for drinking water use:

- Federal Safe Drinking Water (SDW) Primary Maximum Contaminant Levels (MCLs). These enforceable health-based standards establish the maximum concentration of a constituent allowed in water supplied by public systems.[36]

- State of Arizona Aquifer Water Quality Standards. These apply to aquifers that are classified for drinking water protected use.[4] All aquifers within Arizona are currently classified and protected for drinking water use unless otherwise reclassified. To date no aquifers have been reclassified. 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 effects on the water.[36]

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

HUA Sites - Of the 26 sites sampled for the HUA study, 9 (35 percent) met all SDW Primary and Secondary MCLs.

Health-based Primary MCL water quality standards and State aquifer water quality standards were exceeded at 9 of 26 sites (35 percent; Map 4; Table 5). Constituents exceeding Primary MCLs include arsenic (3 sites), fluoride (2 sites), gross alpha (3 sites), nitrate (3 sites), radium 226/228 (1 site), and uranium (2 sites). Potential health effects of these chronic Primary MCL exceedances are provided in Table 5.[36, 38]

Aesthetics-based Secondary MCL water quality guidelines were exceeded at 17 of 26 sites (65 percent; Map 4; Table 6). Constituents above Secondary MCLs include chloride (2 sites), fluoride (11 sites), iron (2 sites), manganese (3 sites), pH (2 sites), sulfate (2 sites), and TDS (11 sites). Potential impacts of these Secondary MCL exceedances are provided in Table 5.[36, 38]

Radon is a naturally occurring, intermediate breakdown product from the radioactive decay of uranium-238 to lead-206.[12] 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 piC/L.[12] Of the 8 sites sampled for radon, 7 sites exceeded the proposed 300 pCi/L standard; 1 site exceeded the proposed 4,000 pCi/L standard.

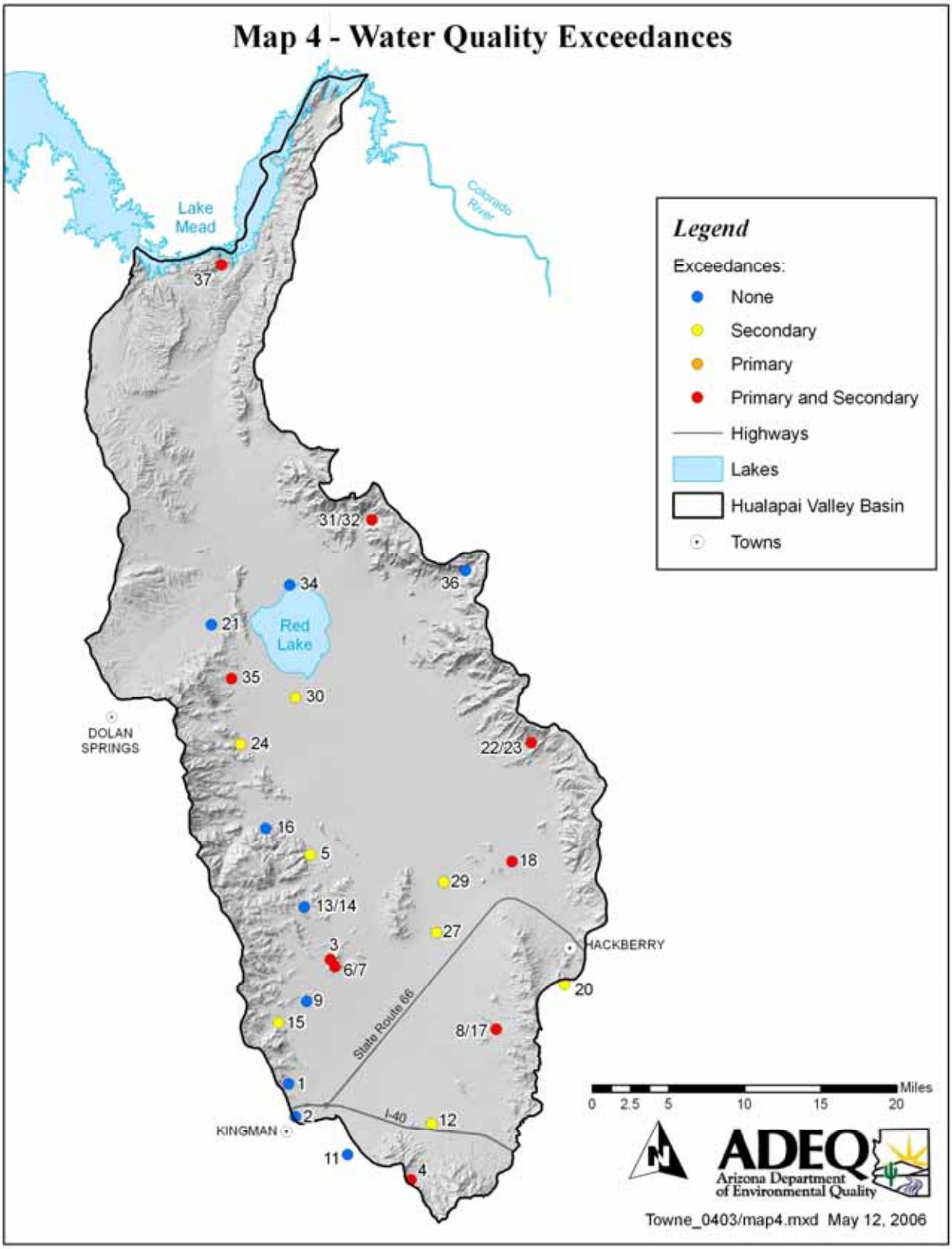

Map 4 - Water Quality Exceedances
Lake Mead
Colorado River
Red Lake
DOLAN SPRINGS
KINGMAN
HACKBERRY
State Route 66
I-40
37
31/32
36
34
21
35
30
24
22/23
16
5
18
29
13/14
27
3
6/7
20
9
15
8/17
1
2
12
11
4
Legend
Exceedances:
None
Secondary
Primary
Primary and Secondary
Highways
Lakes
Hualapai Valley Basin
Towns
Miles
0 2.5 5 10 15 20
ADEQ
Arizona Department of Environmental Quality
Towne_0403/map4.mxd May 12, 2006

Table 5. HUA Sites Exceeding Health-Based Water Quality Standards (Primary MCLs)

Constituent	Primary MCL	Number of 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	**3**	10 – 15	Methemoglobinemia
Trace Elements				
Antimony (Sb)	0.006	0	-	
Arsenic (As)	0.01	**3**	0.019 – 0.0985	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	**2**	4.1 – 5.0	Skeletal damage
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	**3**	29 – 34	Cancer
Ra-226+Ra-228	5	**1**	8.8	Bone cancer
Uranium	30	**2**	38 – 66	Cancer and kidney toxicity

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

* Health-based drinking water quality standards are based on a lifetime consumption of two liters of water per day over a 70-year life span.[36, 38]

Table 6. HUA Sites Exceeding Aesthetics-Based Water Quality Standards (Secondary MCLs)

Constituents	Secondary MCL	Number of Sites Exceeding Secondary MCLs	Concentration Range of Exceedances	Aesthetic Effects of MCL Exceedances
Physical Parameters				
pH - field	6.5 to 8.5	2	8.7 – 9.2	Corrosive water
General Mineral Characteristics				
TDS	500	**11**	550 – 1,800	Unpleasant taste
Major Ions				
Chloride (Cl)	250	**2**	360 – 710	Salty taste
Sulfate (SO_4)	250	**2**	265 – 270	Rotten-egg odor, unpleasant taste and laxative effect
Trace Elements				
Fluoride (F)	2.0	**11**	2.1 – 5.0	Mottling of teeth enamel
Iron (Fe)	0.3	**2**	0.30 – 1.7	Rusty color, reddish stains and metallic tastes
Manganese(Mn)	0.05	**3**	0.072 – 0.15	Black stains and bitter taste
Silver (Ag)	0.1	0	-	-
Zinc (Zn)	5.0	0	-	-

All units mg/L except pH is in standard units (su). Source: [23, 36, 38]

Suitability for Irrigation

The groundwater at each sample site was assessed as to its suitability for irrigation use based on salinity and sodium hazards. Excessive levels of sodium are known to cause physical deterioration of the soil and vegetation.[37] Irrigation water may be classified using specific conductivity (SC) and the Sodium Adsorption Ratio (SAR) in conjunction with one another.[37] Groundwater sites in the HUA basin display a wide range of irrigation water classifications with salinity hazards generally greater than sodium hazards. The 26 sample sites are divided into the following salinity hazards: low or C1 (0), medium or C2 (11), high or C3 (14), and very high or C4 (1). The 26 sample sites are divided into the following sodium or alkali hazards: low or S1 (22), medium or S2 (3), high or S3 (1), and very high or S4 (0).

Analytical Results

Analytical inorganic and radiochemistry results of the 26 HUA sample sites are summarized (Table 7) using the following indices: minimum reporting levels (MRLs), number of sample sites over the MRL, upper and lower 95 percent confidence intervals

($CI_{95\%}$), median, and mean. Confidence intervals are a statistical tool which indicates that 95 percent of a constituent's population lies within the stated confidence interval.[22] Specific constituent information for each groundwater site is found in Appendix B.

Table 7. Summary Statistics for Hualapai Valley Basin 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	26	21.6	22.5	23.2	24.7
pH-field (su)	N/A	26	7.48	7.55	7.68	7.88
pH-lab (su)	0.01	26	7.51	7.60	7.70	7.88
Turbidity (ntu)	0.01	26	0.18	0.30	3.22	6.26
General Mineral Characteristics						
T. Alkalinity	2.0	26	166	180	205	245
Phenol. Alk.	2.0	2		> 50% of data below MRL		
SC-field (uS/cm)	N/A	26	687	755	916	1146
SC-lab (uS/cm)	N/A	26	733	790	984	1234
Hardness-lab	10.0	26	229	295	315	402
TDS	10.0	26	437	470	583	729
Major Ions						
Calcium	5.0	26	50	67	73	96
Magnesium	1.0	26	22	24	31	41
Sodium	5.0	26	43	51	84	126
Potassium	0.5	26	3.6	3.5	4.6	5.6
Bicarbonate	2.0	26	208	220	253	298
Carbonate	2.0	2		> 50% of data below MRL		
Chloride	1.0	26	61	82	118	175
Sulfate	10.0	26	58	47	90	122
Nutrients						
Nitrate (as N)	0.02	21	0.7	2.1	5.3	9.9
Nitrite (as N)	0.02	1		> 50% of data below MRL		
Ammonia	0.02	2		> 50% of data below MRL		
TKN	0.05	14	0.05	0.06	0.07	0.10
T. Phosphorus	0.02	7		> 50% of data below MRL		

Table 7. Summary Statistics for Hualapai Valley Basin 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						
Antimony	0.005	0		> 50% of data below MRL		
Arsenic	0.01	3		> 50% of data below MRL		
Barium	0.1	2		> 50% of data below MRL		
Beryllium	0.0005	1		> 50% of data below MRL		
Boron	0.1	19	0.11	0.14	0.17	0.23
Cadmium	0.001	0		> 50% of data below MRL		
Chromium	0.01	4		> 50% of data below MRL		
Copper	0.01	3		> 50% of data below MRL		
Fluoride	0.20	26	1.24	1.35	1.76	2.28
Iron	0.1	2		> 50% of data below MRL		
Lead	0.005	2		> 50% of data below MRL		
Manganese	0.05	3		> 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	12		>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	13	0.08	0.05	0.21	0.33
Radiochemical Constituents						
Radon*	Varies	8	- 184	1049	1691	3567
Gross Alpha*	Varies	16	3.7	6.8	13.7	23.7
Gross Beta*	Varies	16	5.5	6.8	12.8	20.1
Ra-226*	Varies	2		> 50% of data below MRL		
Uranium**	Varies	0		> 50% of data below MRL		

All units mg/L except where noted or * = pCi/L, ** = ug/L, and *** = 0/00

HUA GROUNDWATER COMPOSITION

General Summary

Groundwater from the 26 sample sites (Map 5) varied widely but was typically either a mixed-mixed (7 sites) or mixed-bicarbonate (6 sites) chemistry (Figure 14). Other water chemistry types found in the basin include calcium-mixed (3 sites), sodium-mixed, calcium-bicarbonate, sodium-chloride and sodium-bicarbonate (all 2 sites) or magnesium-bicarbonate and magnesium-mixed (1 site each).

The dominant cations in the 26 sampled sites consist of sodium (6 sites), calcium (5 sites) and magnesium (2 sites). There was no dominant cation (or was mixed) at 13 of the sites (Figure 14). The dominant anions in the 26 sites consist of bicarbonate (11 sites) and chloride (2 sites). Sulfate was never the dominant anion while at 13 sites, there was no dominant (or was mixed) anion (Figure 14).

Groundwater in the Hualapai Valley basin was *slightly alkaline*, *fresh*, and *hard*-to-*very hard* as indicated by pH values and TDS and hardness concentrations. Levels of pH were *slightly alkaline* (above 7 su) at all 26 sites.[21] TDS concentrations were considered *fresh* (below 1,000 mg/L) at 23 sites and slightly saline (1,000 to 3,000 mg/L) at 3 sites (Map 6).[21] Hardness concentrations were divided into *soft* (below 75 mg/L) at 3 sites, *moderately hard* (75 – 150 mg/L) at 1 site, *hard* (150 – 300 mg/L) at 11 sites, and *very hard* (above 300 mg/L) at 11 sites.[13]

Nitrate, TKN, and total phosphorus were detected at more than 20 percent of the sites. Nitrate (as nitrogen) concentrations were divided into natural background (5 sites < 0.2 mg/L), may or may not indicate human influence (10 sites between 0.2 - 3.0 mg/L), may result from human activities (8 sites between 3.0 - 10 mg/L), and probably result from human activities (3 sites ≥ 10 mg/L).[25]

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

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.[39]

Many significant correlations occurred among the 26 sample sites (Table 8, Pearson Correlation Coefficient test, $p \leq 0.05$). Three groups of correlations were identified:

- Positive correlations occurred between calcium and TDS, magnesium, hardness, sulfate, selenium, TKN, gross alpha, gross beta; negative correlations occurred with temperature and pH-field.

- Positive correlations occurred between sodium and pH-field, pH-lab, TDS, chloride, sulfate, fluoride and boron.

- Positive correlations occurred between bicarbonate and hardness, magnesium, and sulfate; negative correlations occurred with temperature, pH-field (Figure 15), pH-lab, and nitrate.

TDS concentrations are best predicted among major ions (and cations) by sodium concentrations while among anions, chloride (Figure 16) is the best predictor (multiple regression analysis, $p \leq 0.01$).

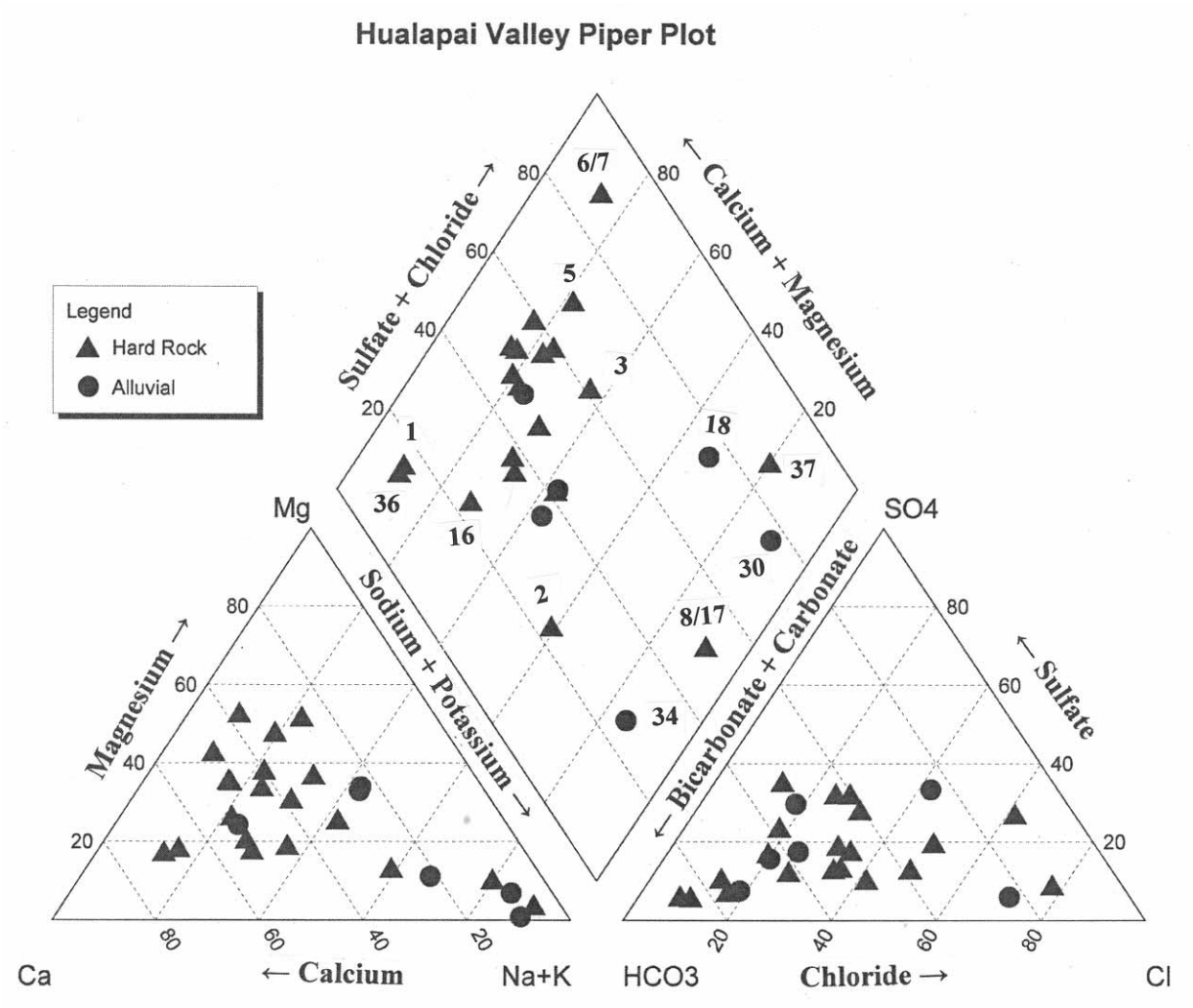
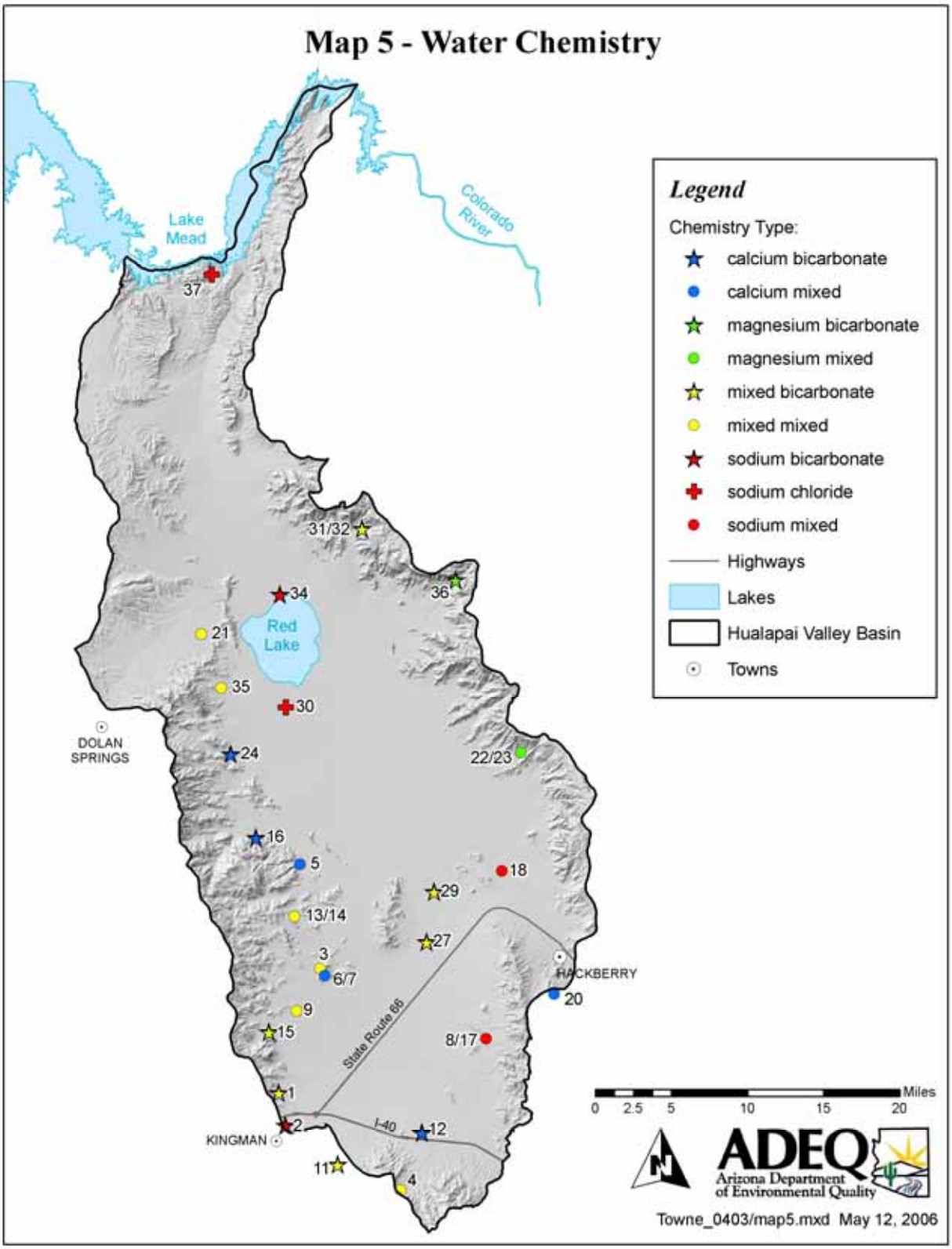


Figure 14. The Piper trilinear diagram above shows sample sites in the Hualapai Valley basin vary widely in water chemistry (top diamond diagram). In most samples, calcium/magnesium is a larger cation component of the water than sodium/potassium. In contrast bicarbonate/carbonate and sulfate/chloride each are the largest anion component in roughly half the samples apiece. The outliers don't appear to follow any geographic pattern with samples HUA-18, 30 and 37 having a sodium/potassium – sulfate/chloride chemistry; HUA-2 and 34 have a sodium/potassium-bicarbonate/carbonate chemistry and HUA-8/17 situated between the two groups on the diagram. The other outlier at the top of the diagram is HUA-6/7 which shows a strong calcium/magnesium – sulfate/chloride chemistry.


Map 5 - Water Chemistry
Lake Mead
Colorado River
Red Lake
DOLAN SPRINGS
KINGMAN
HACKBERRY
State Route 66
I-40
37
31/32
36
34
21
35
30
24
22/23
16
5
18
29
13/14
27
3
6/7
20
9
15
8/17
1
2
12
11
4
Legend
Chemistry Type:
calcium bicarbonate
calcium mixed
magnesium bicarbonate
magnesium mixed
mixed bicarbonate
mixed mixed
sodium bicarbonate
sodium chloride
sodium mixed
Highways
Lakes
Hualapai Valley Basin
Towns
Miles
0 2.5 5 10 15 20
ADEQ
Arizona Department of Environmental Quality
Towne_0403/map5.mxd May 12, 2006

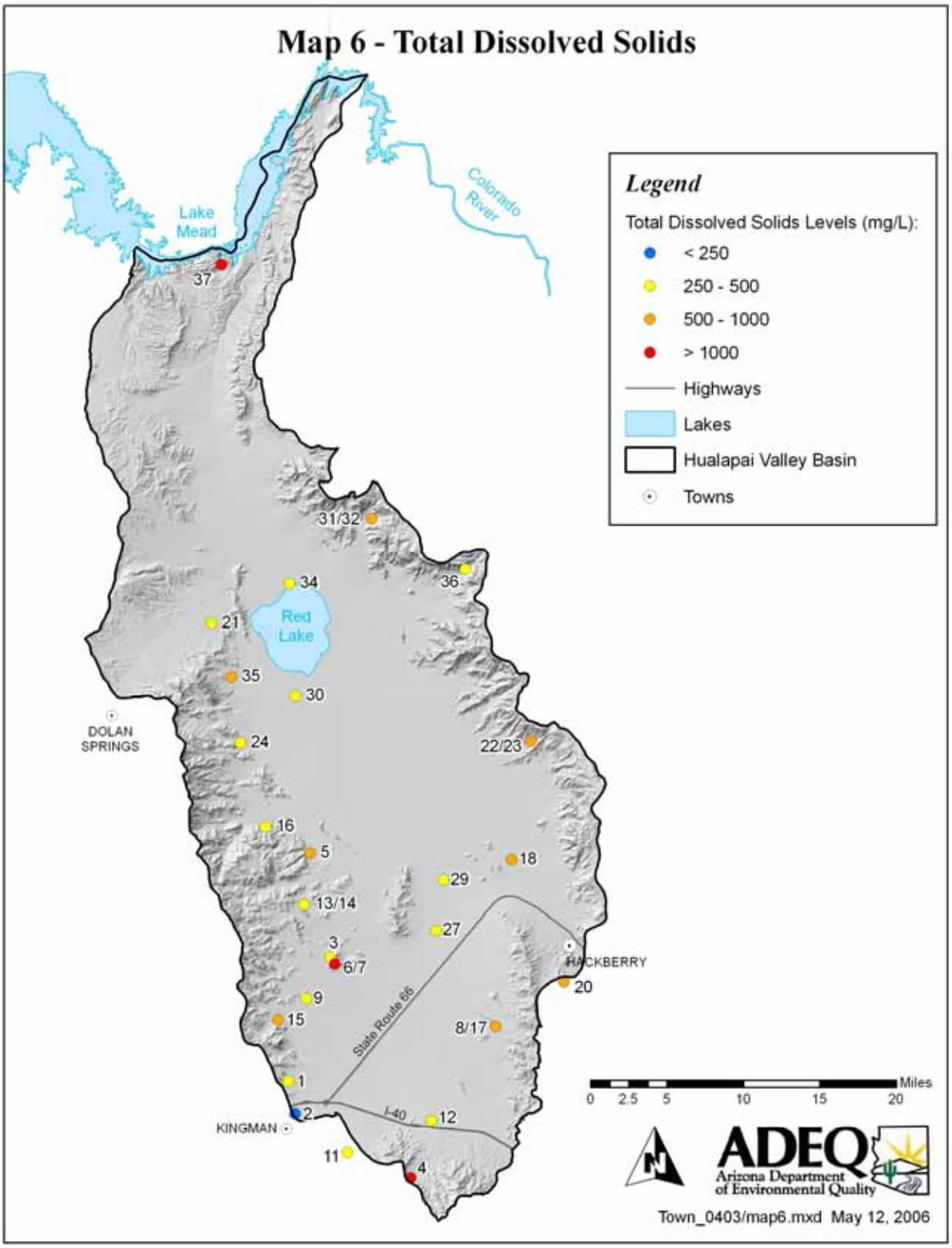

Map 6 - Total Dissolved Solids
Lake Mead
Colorado River
Red Lake
DOLAN SPRINGS
KINGMAN
HACKBERRY
State Route 66
I-40
37
31/32
36
34
21
35
30
24
22/23
16
5
18
29
13/14
27
3
6/7
20
9
15
8/17
1
2
12
11
4
Legend
Total Dissolved Solids Levels (mg/L):
< 250
250 - 500
500 - 1000
> 1000
Highways
Lakes
Hualapai Valley Basin
Towns
Miles
0 2.5 5 10 15 20
ADEQ
Arizona Department of Environmental Quality
Town_0403/map6.mxd May 12, 2006

Table 8. Correlation Among HUA Groundwater Quality Constituent Concentrations Using Pearson Correlation Probabilities

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

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

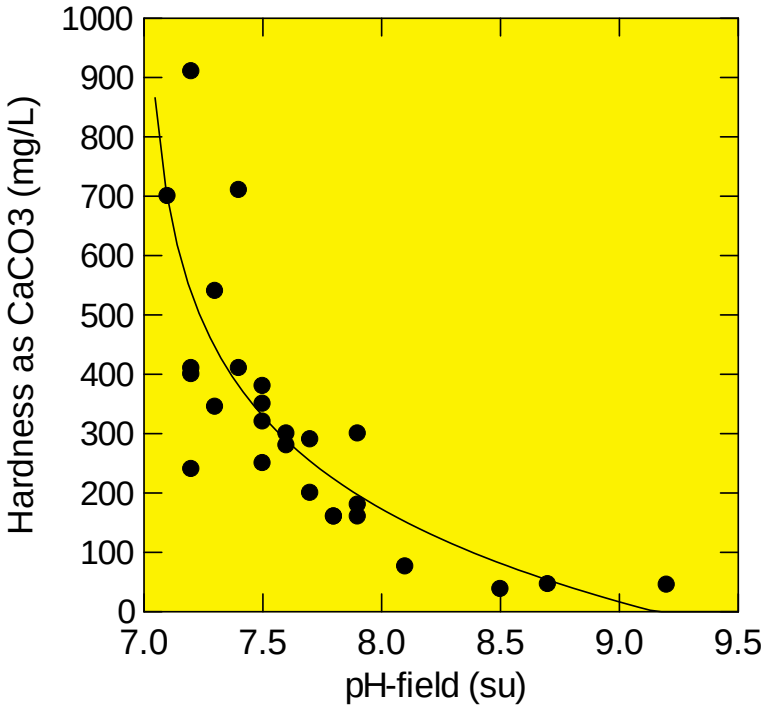


Figure 15. The graph to the left illustrates a negative correlation between two constituents: as pH-field values increase, hardness concentrations tend to decrease. This relationship was found to be statistically significant ($p \leq 0.01$). The pH – hardness relationship has been found in other Arizona groundwater basins and is likely related to precipitation of calcite in response to increases in pH.[30]

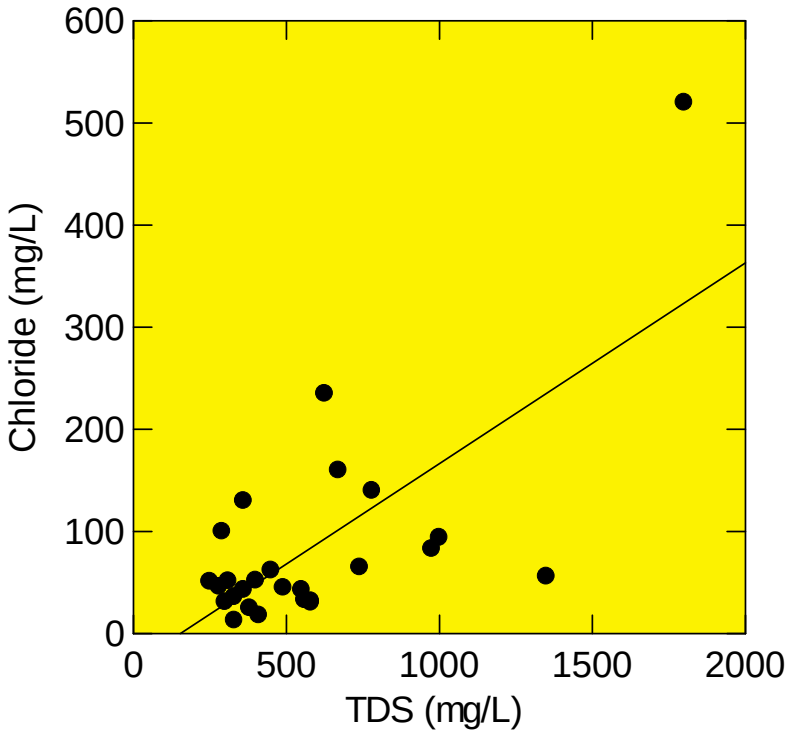


Figure 16. The graph to the left illustrates the positive relationship between two constituents: as TDS concentrations increase chloride concentrations also increase (regression analysis, $y = 0.35x - 86.9$, $n = 26$, $r = 0.96$). This relationship was found to be statistically significant ($p \leq 0.01$). Although recharge areas in the mountains usually contain low concentrations of chloride, this constituent is frequently the dominant cation in down-gradient areas in the valley alluvium in Arizona.[30]

Lithologic Variation

The HUA was separated into spatial divisions by water source. Analytical results were compared between groundwater samples collected in the two water sources (alluvial and hard rock). Sample sites were placed into these two lithologic categories based on well logs obtained through ADWR. Well logs were available for the 18 of the 23 wells sampled which also provided the perforation interval found in the last column of Appendix A. The remaining 5 wells and 3 spring sample sites were placed into lithologic categories as delineated by the geologic map produced by the Arizona Geological Survey.[28]

Significant concentration differences were found with six constituents (Table 9). Calcium, magnesium and hardness (Figure 17) were higher in hard rock than in alluvium samples; temperature-field, pH-field (Figure 18) and fluoride (Figure 19 and Map 7) were higher in alluvium than in hard rock (ANOVA test, $p \leq 0.01$ except fluoride, $p \leq 0.05$). For constituents having significantly different concentrations between sub-basins, 95 percent confidence intervals are provided in Table 10.

Although not statistically significant, most groundwater quality constituents were higher in hard rock than in alluvium. These included SC-field, SC-lab, TDS, potassium, bicarbonate (Figure 20), chloride, sulfate, nitrate, TKN, boron, selenium, and zinc. Only pH-lab and sodium had the opposite pattern, higher in alluvium than in hard rock.

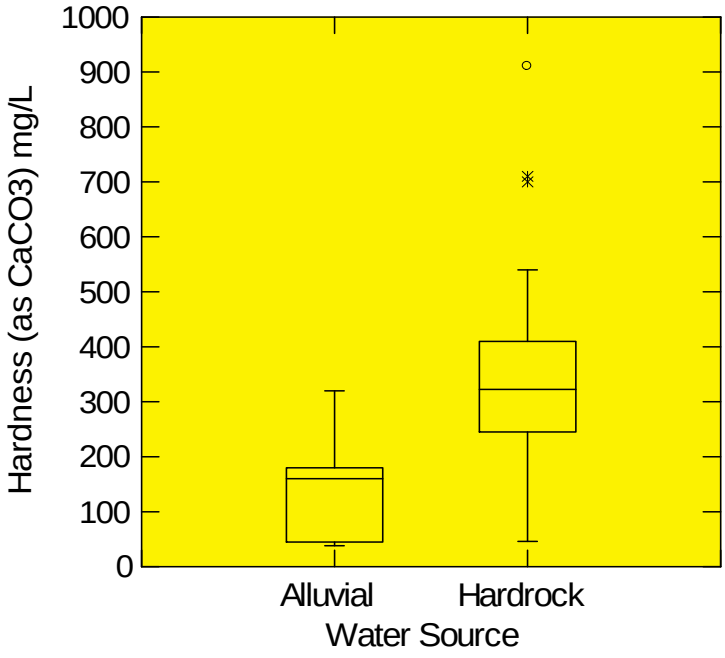


Figure 17. Hardness concentrations in the Hualapai Valley basin are significantly higher in hardrock than in alluvium (ANOVA test, $p \leq 0.01$). Groundwater generally varies from *soft* to *hard* in the alluvial and from *hard* to *very hard* in hardrock. This spatial difference in hardness concentrations is probably due to several factors: the impact of recharge which generally occur at or near the mountain fronts and consists of calcium-dominated water as well as the natural softening that occurs along a groundwater flowpath in downgradient areas such as the valley's alluvium. [30]

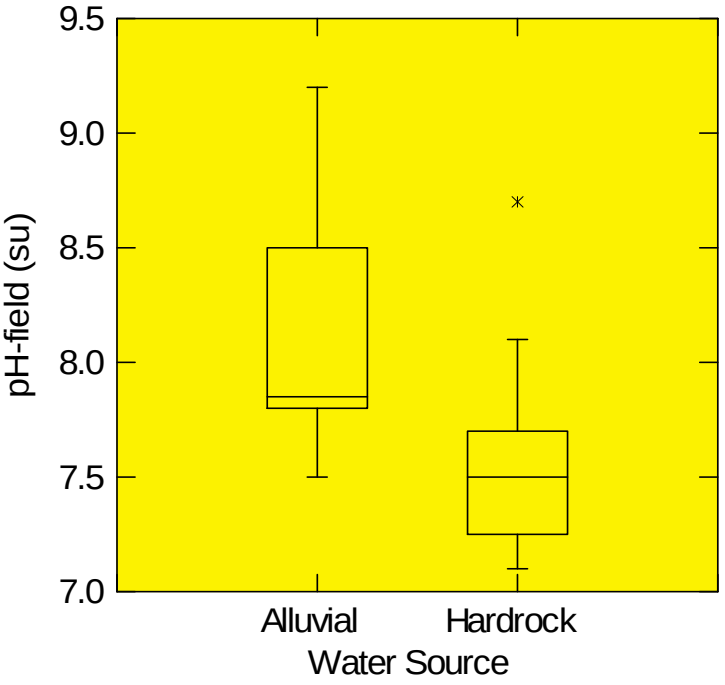


Figure 18. Levels of pH (field-sampled) in the Hualapai Valley basin are significantly higher in the alluvium than in hardrock (ANOVA test, $p \leq 0.01$). Although all the groundwater samples in the study were alkaline in nature (> 7 su), the samples collected from low-yield wells or springs in hardrock were overwhelmingly lower which is probably due to acidic precipitation averaging 5.8 su that percolates into rock fractures and the shallow alluvium found in the mountains. This recharged groundwater gradually increases in pH with downgradient flow through silicate hydrolysis reactions. [30]

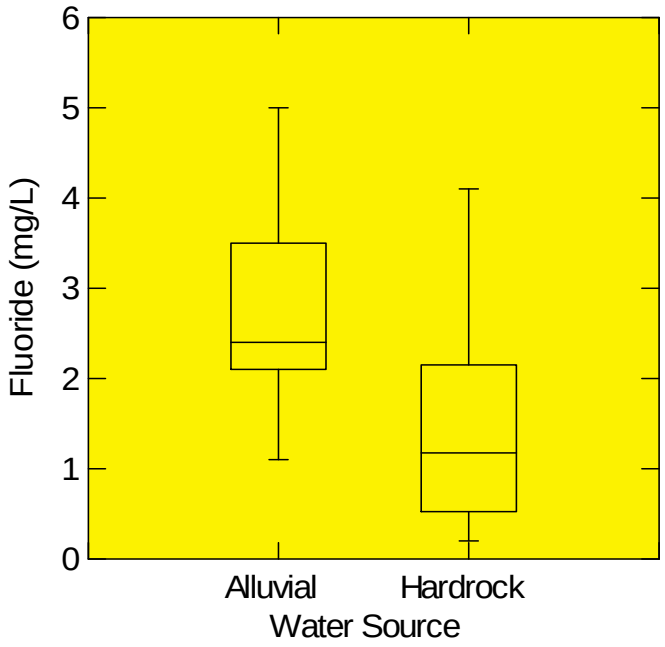


Figure 19. Fluoride concentrations in the Hualapai Valley basin are significantly higher in the alluvium than in hardrock (ANOVA test, $p \leq 0.05$). Water quality exceedances for fluoride (Secondary MCL is 2 mg/L, Primary MCL is 4 mg/L) occur much more frequently in the alluvium. Fluoride concentrations are frequently low in recharge areas and increase along a flowpath with pH in downgradient valley areas.[30] Although calcium can be an important control on fluoride, fluoride's relatively low concentrations (≤ 5 mg/L) suggest hydroxyl ion exchange or sorption/de-sorption reactions are the fluoride controls in the study area.[30]

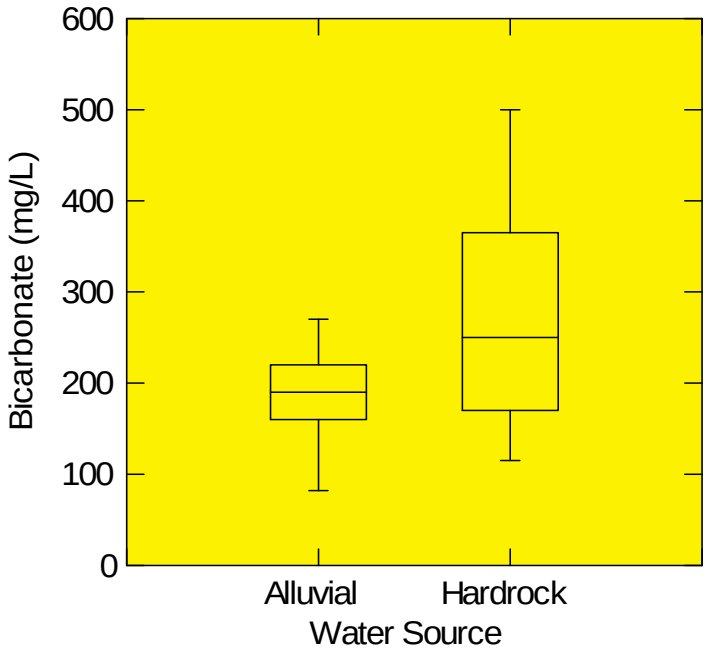


Figure 20. Although bicarbonate concentrations in the Hualapai Valley basin are higher in the hardrock than in alluvium, this pattern is not significantly higher ($p = 0.078$) as this relationship narrowly missed statistical significance (ANOVA test, $p \leq 0.05$). Bicarbonate concentrations are frequently high in recharge areas and decrease in downgradient valley areas.[30] Statistically significant alluvial-hardrock bicarbonate patterns have been found in other Arizona groundwater basins including the nearby Sacramento Valley and Detrital Valley basins.[31, 32]

Table 9. Variation in Groundwater Quality Constituent Concentrations Between Two Hualapai Valley Basin Water Sources Using Transformed Data with ANOVA Test.

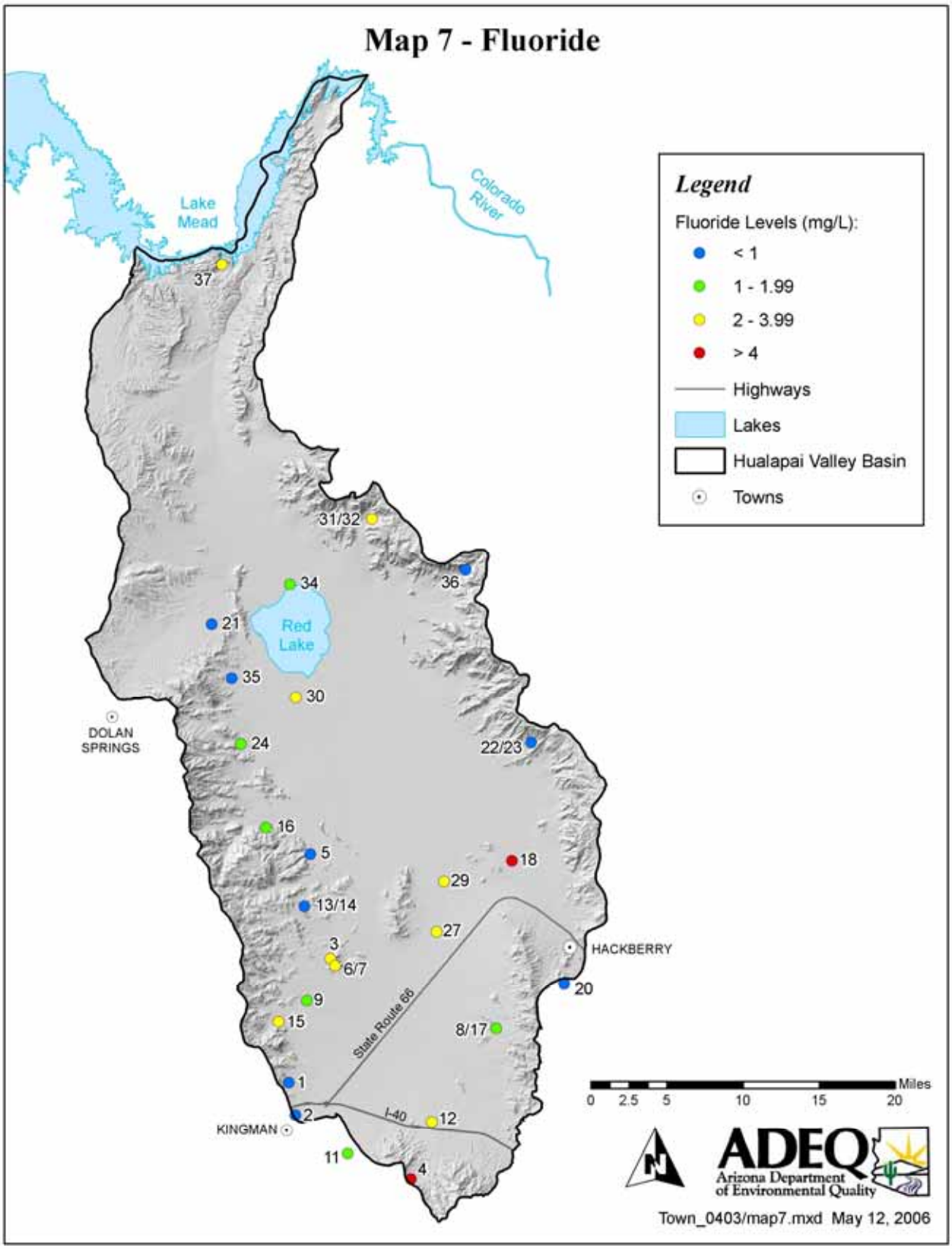
Constituent	Significance	Differences Among Water Sources
Temperature - f	**	Alluvial > Hard rock
pH – field	**	Alluvial > Hard rock
pH – lab	ns	-
SC - field	ns	-
SC - lab	ns	-
Turbidity	ns	-
TDS	ns	-
Hardness	**	Hard rock > Alluvial
Calcium	**	Hard rock > Alluvial
Magnesium	**	Hard rock > Alluvial
Sodium	ns	-
Potassium	ns	-
Bicarbonate	ns	-
Chloride	ns	-
Sulfate	ns	-
Fluoride	*	Alluvial > Hard rock
Nitrate (as N)	ns	-
TKN	ns	-
Boron	ns	-
Selenium ***	ns	-
Zinc	ns	-
Gross Alpha	ns	-
Gross Beta	ns	-
Radon	ns	-

ns = not significant
* = significant at $p \leq 0.05$ or 95% confidence level
** = significant at $p \leq 0.01$ or 99% confidence level
*** = for information only, statistical test not valid because of the large number of non-detects

Table 10. Summary Statistics (95% Confidence Intervals) for Groundwater Quality Constituents With Significant Concentration Differences Between Two Hualapai Valley Basin Water Sources

Constituent	Significant Differences	Alluvial	Hard Rock
Temperature – field (C)	**	23.1 to 31.0	20.5 to 23.5
pH – field (su)	**	7.46 to 8.77	7.37 to 7.73
pH – lab (su)	ns	-	-
SC – field (uS/cm)	ns	-	-
SC – lab (uS/cm)	ns	-	-
TDS	ns	-	-
Turbidity (ntu)	ns	-	-
Hardness	**	42 to 259	265 to 465
Calcium	**	3 to 66	57 to 112
Magnesium	**	4 to 25	25 to 50
Sodium	ns	-	-
Potassium	ns	-	-
Bicarbonate	ns	-	-
Chloride	ns	-	-
Sulfate	ns	-	-
Fluoride	*	1.3 to 4.2	0.9 to 2.0
Nitrate (as N)	ns	-	-
TKN	ns	-	-
Boron	ns	-	-
Selenium ***	ns	-	-
Zinc	ns	-	-
Gross Alpha (pCi/L)	ns	-	-
Gross Beta (pCi/L)	ns	-	-
Radon (pCi/L)	ns	-	-

All units in milligrams per liter (mg/L) unless otherwise noted
ns = not significant
* = significant at $p \leq 0.05$ or 95% confidence level
** = significant at $p \leq 0.01$ or 99% confidence level
*** = for information only, statistical test not valid because of the large number of non-detects


Map 7 - Fluoride
Lake Mead
Colorado River
Red Lake
DOLAN SPRINGS
KINGMAN
HACKBERRY
State Route 66
I-40
37
31/32
36
34
21
35
30
24
22/23
16
5
18
29
13/14
27
3
6/7
20
9
15
8/17
1
2
12
11
4
Legend
Fluoride Levels (mg/L):
< 1
1 - 1.99
2 - 3.99
> 4
Highways
Lakes
Hualapai Valley Basin
Towns
Miles
0 2.5 5 10 15 20
N
ADEQ
Arizona Department of Environmental Quality
Town_0403/map7.mxd May 12, 2006

CONCLUSIONS

Groundwater Characteristics

Groundwater in the HUA is generally *slightly alkaline*, *fresh*, and *hard* to *very hard* based on pH values, TDS, and hardness concentrations.[13, 21] These groundwater characteristics were also found in previous studies.[11, 18] The chemistry of groundwater sample sites varied widely, with *mixed-mixed* and *mixed-bicarbonate* the most common compositions. Among trace elements, only boron, fluoride, selenium and zinc were detected at more than 20 percent of sample sites.

Water Quality Standards

Of the 26 samples collected in the HUA, about one-third (9 samples or 31 percent of samples) met all health and aesthetic water quality standards. Constituents exceeding health-based standards were arsenic, nitrate, gross alpha, fluoride, uranium and radium-226/228. TDS and fluoride most commonly exceeded the aesthetics-based standards. These water quality exceedances appear, with the possible exception of nitrate, to be the result of naturally occurring geochemical processes because of the relatively remote and undeveloped nature of the basin. Other nearby groundwater basins such as Sacramento Valley, Detrital Valley and Big Sandy have similar constituent exceedances.[31, 32, 35]

Nitrate concentrations were sometimes elevated, with 11 sites (42 percent) having concentrations (over 3 mg/L) that are possibly related to human activities. [25] Nitrate concentrations were generally higher in shallow wells in or near the mountains compared to deep wells in the valley alluvium, though this trend was not significant (ANOVA test, $p \leq 0.05$). Nonetheless, these results suggest that the nitrate source could be septic systems in soil types marginal suited for wastewater disposal.

Groundwater Patterns Related to Lithology

Statistically-significant patterns were found among groundwater water sources (ANOVA, $p \leq 0.05$).[22] Temperature (field-measured), pH (field-measured), and fluoride were significantly higher at sites in the alluvium than at sites in hardrock. In contrast, calcium, magnesium and hardness were significantly higher at sites in hardrock than in alluvium. TDS and bicarbonate were also higher at sites in hardrock than in alluvium but just missed the statistical confidence level (ANOVA, $p \leq 0.05$).

These patterns largely support earlier studies that indicated groundwater generally meets water quality standards but in some areas usually near the edge of the older alluvium or within the fractured or weathered crystalline rocks or the thin patches of alluvium in the mountains, the water can be highly mineralized.[11, 18]

Several factors may contribute to this water quality difference. The older alluvium main source of recharge is from streambed infiltration near the apexes of dissected alluvial fans which extend into the mountain canyons.[11] The recharge should be relatively dilute, high quality water since it travels only a short distance percolating from the stream channels to the underlying aquifer—and therefore, has little opportunity to dissolve and transport minerals.[18] Recharge moving through fractured bedrock aquifers in the mountains is likely to have higher concentrations of dissolved minerals because of the greater distance traveled through weathered, mineralized zones—especially where mining areas expose ores to oxidation and subsequent contact with percolating groundwater.[18] The older alluvium near the peripheries of Hualapai Valley may also receive significant quantities of water recharged via this pathway.

Older Alluvium Water Quality Characteristics

The limited sampling of wells tapping the older alluvium—the aquifer that holds the majority of water reserves in the HUA—revealed mostly acceptable groundwater quality. This finding supports an earlier study that found groundwater in the central alluvium of Hualapai Valley is generally of good chemical quality. [11, 18]

Fluoride appears to be the only constituent of concern in the deep alluvium of Hualapai Valley. Fluoride exceeded health based standards in one well and aesthetics based standards in four other wells; otherwise only pH-field and TDS were aesthetic standards exceeded in one well apiece. The elevated fluoride concentrations are believed to occur naturally and are controlled by pH values that also increase downgradient through silicate hydrolysis reactions. [30]

In previous groundwater quality studies, chromium had been reported in excess of water quality standards (0.10 mg/L) in five City of Kingman wells, with one sample as high as 0.15 mg/L.[11] Originally thought to be the result of industrial pollution, the high chromium concentrations are now believed to be naturally occurring. [11] Four of 26 sites had positive

detections of total chromium, including 3 of the 6 sites from deep alluvial wells. However, 0.063 mg/L was the highest concentration, well below the Primary MCL of 0.01 mg/L.

A previous groundwater study noted that as groundwater moves northward through HUA, the TDS increased and the type of water changed from sodium/calcium-bicarbonate to sodium chloride. Evaporite deposits were cited as the source of the TDS increase and sodium chloride chemistry near Red Lake.[11] Although evaporites are the likely source of high TDS concentrations found in samples collected for previous studies near Red Lake, the sampling conducted for this ADEQ study found no consistent TDS concentrations or groundwater chemistry evolution trends.

REFERENCES

[1] Anning, D.W., Flynn, M.E. and Truini, M., 2006, Hydrogeologic investigation of the Detrital, Hualapai, and Sacramento Valleys of northwestern Arizona: U.S. Geological Survey Fact Sheet 2006-3008, 4 p.

[2] Arizona Corporation Commission Website, 2006, www.cc.state.az.us/news/pr11-26-01.htm , accessed 5/15/06.

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

[4] Arizona Department of Environmental Quality, 2002-2003, Arizona Laws Relating to Environmental Quality: St. Paul, Minnesota, West Group Publishing, §49-221-224, p 134-137.

[5] Arizona Department of Environmental Quality, 2004, The status of water quality in Arizona—2004: Arizona's 2004 integrated 305(b) assessment and 303(d) listing report, 249 p.

[6] Arizona State Land Department, 1997, "Land Ownership - Arizona" GIS coverage: Arizona Land Resource Information Systems, downloaded, 4/7/04.

[7] Arizona Department of Water Resources, 1994, Arizona Water Resources Assessment – Volume II, Hydrologic Summary, Hydrology Division, pp. 62-63.

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

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

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

[11] Cella Barr Associates, 1990, Geohydrologic study for the Kingman-Red Lake sub-area of the Hualapai basin: Unpublished consultants report to the City of Kingman, Arizona, CBA #41503-01, 64 p.

[12] Cordy, G.E., Sanger, H.W., and Gellenbeck,, D.J., 2000, Radon in ground water in central and southern Arizona: A Cause for Concern?: Arizona Hydrologic Society, Annual Symposium, Phoenix, Arizona, September 20-23, 2000, p. 79-81.

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

[14] Del Mar Laboratory, 2006, Personal communication from Del Mar staff.

[15] Freeland, Gary, 2006, Personal communication from ARRA staff.

[16] Gillespie, J.B., Bentley, C.B., and Kam, William, 1966, Basic hydrologic data of the Hualapai, Sacramento, and Big Sandy Valleys, Mohave County, Arizona: Water-Resources Report Number 26, 39 p.

[17] Gillespie, J.B. and Bentley, C.B, 1971, Geohydrology of Hualapai and Sacramento Valleys, Mohave County, Arizona: U.S. Geological Survey Water-Supply Paper 1899-H, 37 p, two sheets, scale 1:125,000.

[18] Geo/Resources Consultants, Inc, 1982, Groundwater resources and water quality of Detrital and Hualapai basins, Mohave County, Arizona. Unpublished consultants report for the Bureau of Land Management, 263-1H, 84 p.

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

[20] Granger, Byrd Howell, 1983, *Arizona's names: X marks the spot*: Tucson: Falconer Publishing, 824 p.

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

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

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

[24] Lowry, J.D. and Lowry, S.B., 1988, Radionuclides in drinking water. Journal American Water Works Association, 80 (July), pp. 50-64.

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

[26] Manera, P.A., 1972, Hydrologic investigation of the Hualapai Valley between the Peacock Mountains and Long Mountain, Mohave County, Arizona. Unpublished consultants report for the Queen Creek Land and Cattle Corporation, 44 p.

[27] Remick, W.H., 1981, Map showing ground-water conditions in the Hualapai Basin area, Mohave, Coconino and Yavapai Counties, Arizona—1980, Arizona Department of Water Resources, Hydrologic Map Series Report Number 4, 1 sheet, scale 1:250,000.

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

[29] Roberts, Isaac, 2006, Personal communication from ADHS staff.

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

[31] Towne, D.C., and Freark, M.C., 2001, Ambient groundwater quality of the Sacramento Valley basin: A 1999 baseline study: Arizona Department of Environmental Quality Open File Report 01-04, 78 p.

[33]

[32] Towne, D.C., 2003, Ambient groundwater quality of the Detrital Valley basin: A 2002 baseline study: Arizona Department of Environmental Quality Open File Report 03-03, 65 p.

[33] Towne, D.C., 2005, Ambient groundwater quality of the Meadview basin: A 2000-2003 baseline study: Arizona Department of Environmental Quality Open File Report 05-01, 32 p.

[34] Towne, D.C., 2005, Ambient groundwater quality of the Lake Mohave basin: A 2003 baseline study: Arizona Department of Environmental Quality Open File Report 05-08, 66 p.

[35] Towne, D.C., 2006, Ambient groundwater quality of the Big Sandy basin: A 2003-2004 baseline study: Arizona Department of Environmental Quality Open File Report 06-09, 66 p.

[36] U.S. Environmental Protection Agency, 1993, A pocket guide to the requirements for the operators of small water systems: U.S. Environmental Protection Agency Region 9, 3rd edition, 47 p.

[37] U.S. Salinity Laboratory, 1954, Diagnosis and improvement of saline and alkali soils: U.S. Department of Agriculture, Agricultural Research Service, Agriculture Handbook No. 60, 160 p. [reprinted, 1969].

[38] Water Quality Association website, 2006, www.wqa.org, accessed 5/15/06.

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

Appendix A. Data for Sample Sites, Hualapai Valley, 2000

Site #	Cadastral / Pump Type	Latitude – Long. NAD 27	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Perforation / Aquifer
1st Field Trip, February 4, 1999 – Towne & Freark (Equipment Blank, SV-?)									
HUA-1	B(21-17)01cbc submersible	35°14'13.186" 114°03'19.276"	565029	57748	Orr Well	Inorganic & VOCs	400'	171'	- hard rock
2nd Field Trip, February 16-17, 1999 – Towne & Freark (Equipment Blank, SV-?)									
HUA-2	B(21-17)13acc submersible	35°12'22.100" 114°02'47.488"	-	21725	Arnold Well	Inorganic & VOCs Radiochem	585'	150'	- hard rock
HUA-3	B(23-16)19ddd submersible	35°21'21.500" 114°00'41.300"	541211	57780	Stout Well	Inorganic & VOCs Radiochem	680'	350'	600-680' hard rock
3rd Field Trip, January 12-14, 2000 – Freark & Lucci (Equipment Blank, HUA-10)									
HUA-4	B(20-15)06bdb submersible	35°08'53.999" 113°54'37.423"	-	58247	Mulley Well	Inorganic, VOCs Radiochem	175'	100'	100-175' hard rock
HUA-5	B(24-16)19bca submersible	35°27'16.920" 114°02'18.249"	549705	58248	Lossing Well	Inorganic, VOCs Radiochem	450'	370'	380-450' hard rock
HUA-6/7	B(23-16)29bdd submersible	35°20'57.979" 114°00'20.433"	562768	58249	Gebbia Well	Inorganic, VOCs Radon	440'	340'	340-440' hard rock
HUA-9	B(22-16)06cbb submersible	35°18'55.418" 114°02'13.691"	543531	58250	Drewry Well	Inorganic, VOCs Radon	620'	475'	560-620' hard rock
HUA-11	B(21-16)28caa submersible	35°10'15.765" 113°59'04.207"	526138	58251	Schritter Well	Inorganic Radiochem	660'	525'	460-680' hard rock
HUA-12	B(21-15)17adb submersible	35°12'10.982" 113°53'17.715"	541923	58252	Shields Well	Inorganic, VOCs Radon	663'	520'	560-660' alluvial
HUA-13/14	B(23-17)01ddb submersible	35°24'18.034" 114°02'35.171"	545813	58253	Carley Well	Inorganic, VOCs Radiochem	295'	100'	145-285' hard rock
4th Field Trip, February 14-16, 2000 – Freark & Lucci (Equipment Blank, HUA-19)									
HUA-8/17	B(22-15)13aad windmill	35°17'38.677" 113°49'00.251"	527480	58373	Upton Well	Inorganic, VOCs Radiochem	345'	205'	200-320' hard rock
HUA-15	B(22-17)14cad submersible	35°17'40.581" 114°04'08.530"	562299	58374	Graham Well	Inorganic Radiochem	225'	90'	90-225' hard rock
HUA-16	B(24-17)10ccb spring	35°28'42.874" 114°05'27.126"	-	58375	Corral Ranch Spr	Inorganic Radiochem	-	-	- hard rock
HUA-18	B(24-14)19abd submersible	35°27'14.570" 113°48'13.635"	535306	58376	Lang Well	Inorganic, VOCs Radon	1020'	750'	820-1020' alluvial
HUA-20	B(23-14)35bab submersible	35°20'19.489" 113°44'20.639"	552350	58377	Trahan Well	Inorganic, VOCs Radiochem	424'	280'	304-404' hard rock
5th Field Trip, March 27-28, 2000 – Freark & Lucci (Equipment Blank, HUA-28/28D)									
HUA-21/21D	B(26-18)01bdc submersible	35°40'13.392" 114°09'41.246"	556106	58604	Gode Well	Inorganic, VOCs Radiochem	831'	642'	738-818' hard rock
HUA-22/23	B(25-14)09caa submersible	35°34'01.945" 113°47'07.365"	553193	58605	Kerr Well	Inorganic, VOCs Radiochem	405'	95'	175-215' hard rock
HUA-24	B(25-18)13aac windmill	35°33'26.231" 114°07'23.966"	-	58606	Thompson Windmill	Inorganic, VOCs Radiochem	210'	100'	- hard rock
HUA-27/27D	B(23-15)08ddd submersible	35°23'04.667" 113°53'21.149"	624999	22014	Neal Well	Inorganic, VOCs Radon	1059'	400'	475-675' alluvial
HUA-29/29D	B(24-15)28cb submersible	35°25'56.668" 113°52'55.225"	577910	58607	Mack Well	Inorganic, VOCs Radon	728'	640'	628-728' alluvial
HUA-30	B(26-17)35aaa windmill	35°36'12.637" 114°03'39.138"	600500	22254	Valley Well	Inorganic Radon	700'	274'	400-700' alluvial
6th Field Trip, April 18-19, 2000 – Freark & Lucci									
HUA-31/32	B(28-16)34bda submersible	35°46'30.672" 113°58'41.975"	-	58659	Tenney Well	Inorganic, VOCs Radiochem	982'	225'	- hard rock

Appendix A. Data for Sample Sites, Hualapai Valley, 2000

Site #	Cadastral / Pump Type	Latitude - Long. NAD 27	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Perforation / Aquifer
7th Field Trip, May 15-16, 2000 – Freark & Lucci									
HUA-34	B(27-17)23aab submersible	35°42'38.352" 114°04'18.942"	640651	22311	Kelly Well #1	Inorganic, VOCs Radon	700’	-	- alluvial
HUA-35	B(26-17)19ddd windmill	35°37'12.008" 114°08'10.784"	-	22246	Kelly Well #2	Inorganic, VOCs Radiochem	185’	140’	60-180 hard rock
HUA-36	B(27-15)15adb spring	35°38'08.785" 113°54'42.598"	-	22304	Clay Spring	Inorganic, VOCs Radiochem	-	-	- hard rock
8th Field Trip, December 2, 2002 – Towne & Boettcher (Equipment Blank, DET-39)									
HUA-37	B(30-18)1dcb spring	36°00'44.665" 114°09'46.802"	-	22408	Burro Spring	Inorganic	-	-	- hard rock

Appendix B. Groundwater Quality Data, Hualapai Valley, 2000

Site #	MCL Exceedances	Temp (°C)	pH-field (su)	pH-lab (su)	SC-field (µS/cm)	SC-lab (µS/cm)	TDS (mg/L)	Hard (mg/L)	Hard - cal (mg/L)	Turb (ntu)
HUA-1	-	21.7	7.6	*7.3*	560	520	330	280	286	*0.03*
HUA-2	-	25.9	8.1	*8.0*	397	340	250	76	81	*0.07*
HUA-3	NO_3, F	25.8	7.5	*6.9*	880	770	450	250	249	*0.06*
HUA-4	TDS, SO_4, **F**, Mn, gross α, U	16.5	7.1	*7.4*	1475	1700	**1000**	700	680	*1.8*
HUA-5	TDS	22.8	7.5	7.6	908	1000	**550**	380	380	0.05
HUA-6/7	TDS, Cl, NO_3, F	20.1	7.2	7.5	1940	2200	**1350**	910	900	0.09
HUA-8/17	pH, TDS, As, Fe	20.4	**8.7**	**8.7**	1030	1100	**625**	46	62	14
HUA-9	-	28.5	7.7	7.6	532	590	330	200	190	0.02
HUA-11	-	18.5	7.9	8.1	418	460	300	160	160	0.09
HUA-12	F	22.5	7.5	7.5	750	810	490	320	320	0.35
HUA-13/14		21.3	7.3	7.6	761	845	490	345	360	19
HUA-15	TDS, F	18.7	7.2	7.5	1203	1300	**780**	410	420	0.24
HUA-16	-	17.9	7.2	7.5	568	620	360	240	260	0.65
HUA-18	TDS, **F**	27.6	7.8	7.9	1106	1200	**670**	160	170	0.2
HUA-20	TDS	20.2	7.2	7.4	894	980	**560**	400	410	1.5
HUA-21/21D	-	26.4	7.7	7.4	598	660	380	290	260	0.06
HUA-22/23	TDS, SO_4, As gross α, Ra-226/8	22.4	7.4	7.5	1409	1500	**975**	710	645	1.02
HUA-24	Fe, Mn	20.8	7.6	7.3	686	760	400	300	280	33
HUA-27/27D	F	30.7	7.9	7.3	498	540	310	180	160	0.06
HUA-29/29D	F, Mn	27.0	7.8	7.8	437	440	280	160	140	3.1
HUA-30	pH, F	23.0	**9.2**	**9.1**	645	740	360	45	30	3.3
HUA-31/32	TDS, F Gross α, U	19.9	7.3	7.6	1061	1100	**740**	540	540	0.14
HUA-34	-	31.6	8.5	8.2	466	510	290	38	39	0.07
HUA-35	TDS, NO_3	24.7	7.4	7.6	882	940	**580**	410	400	1.1
HUA-36	-	25.2	7.5	7.8	690	750	410	350	350	3.2
HUA-37	TDS, Cl, As, F	21.8	7.9	8.0	3027	3200	**1800**	300	290	0.56

bold = constituent level exceeds Primary or Secondary MCL *italics* = constituent exceeded holding time

Appendix B. Groundwater Quality Data, Hualapai Valley, 2000--Continued

Site #	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	T. Alk (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Chloride (mg/L)	Sulfate (mg/L)
HUA-1	60	33	13	2.0	240	290	ND	20	16
HUA-2	22	6.3	51	3.4	130	160	ND	20	12
HUA-3	70	18	62	3.4	120	150	ND	110	40
HUA-4	150	73	94	2.8	350	430	ND	170	**270**
HUA-5	100	31	43	7.4	140	170	ND	160	86
HUA-6/7	290	44	56	10	94.5	115	ND	**360**	215
HUA-8/17	12	5.25	235	7.6	280	320	14	120	97.5
HUA-9	43	21	36	6.0	140	170	ND	63	33
HUA-11	29	21	31	5.6	140	170	ND	30	36
HUA-12	89	25	45	2.8	220	270	ND	55	120
HUA-13/14	80	36	30.5	3.0	200	230	ND	98	67.5
HUA-15	93	45	140	1.6	410	500	ND	91	160
HUA-16	75	18	43	3.4	240	290	ND	30	32
HUA-18	46	14	160	5.7	130	160	ND	160	170
HUA-20	130	22	33	2.2	220	270	ND	135	46
HUA-21/21D	42.5	37.5	25	5.55	150	180	ND	71	37
HUA-22/23	88	107	83	6.5	370	450	ND	150	**265**
HUA-24	82	17	52	2.3	250	300	ND	72	47
HUA-27/27D	26	22.5	51.5	3.75	160	200	ND	50	47
HUA-29/29D	24	19.5	46	3.65	150	180	ND	33	34
HUA-30	12	ND	130	1.9	89	82	13	145	16
HUA-31/32	110	64	65	7.35	340	410	ND	60	220
HUA-34	8.6	4.2	100	2.7	180	220	ND	32	17
HUA-35	93	42	32	7.2	180	220	ND	99	120
HUA-36	63	54	18	1.7	350	430	ND	23	24
HUA-37	57	36	520	10	170	210	ND	**710**	110

bold = constituent level exceeds Primary or Secondary MCL

Appendix B. Groundwater Quality Data, Hualapai Valley, 2000--Continued

Site #	Nitrate-Nitrite-N (mg/L)	Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	T. Phosphorus (mg/L)	SAR (value)	Irrigation Quality
HUA-1	3.4	3.4	*ND*	ND	ND	0.039	0.3	C2-S1
HUA-2	2.9	2.9	*ND*	ND	ND	ND	2.5	C2-S1
HUA-3	**15**	**15**	*ND*	ND	ND	ND	1.7	C3-S1
HUA-4	0.91	0.91	*ND*	0.12	ND	ND	1.6	C3-S1
HUA-5	7.4	7.4	ND	0.10	ND	ND	1.0	C3-S1
HUA-6/7	**58**	**58**	ND	0.27	ND	ND	0.8	C3-S1
HUA-8/17	ND	ND	ND	0.067	ND	0.041	12.6	C3-S2
HUA-9	5.8	5.8	ND	0.080	ND	ND	1.1	C2-S1
HUA-11	0.54	0.54	*ND*	ND	ND	ND	1.1	C2-S1
HUA-12	ND	ND	*ND*	ND	ND	ND	1.1	C3-S1
HUA-13/14	4.6	4.6	*ND*	ND	ND	0.056	0.7	C3-S1
HUA-15	0.36	0.36	ND	0.13	ND	ND	3.0	C3-S1
HUA-16	0.70	0.70	ND	0.091	ND	ND	1.2	C2-S1
HUA-18	5.4	5.4	*ND*	0.12	ND	ND	5.3	C3-S1
HUA-20	3.4	3.4	ND	0.11	ND	ND	0.7	C3-S1
HUA-21/21D	9.3	9.3	ND	0.12	ND	0.042	0.7	C3-S1
HUA-22/23	ND	ND	*ND*	ND	ND	ND	1.4	C3-S1
HUA-24	ND	ND	0.034	0.088	0.047	ND	1.4	C2-S1
HUA-27/27D	2.2	2.2	ND	ND	ND	ND	1.7	C2-S1
HUA-29/29D	1.8	1.8	ND	ND	0.034	ND	1.7	C2-S1
HUA-30	ND	ND	*ND*	0.058	ND	ND	10.3	C2-S2
HUA-31/32	0.029	0.029	*ND*	ND	ND	ND	1.2	C3-S1
HUA-34	1.9	1.9	ND	ND	ND	0.05	7.0	C2-S2
HUA-35	**10**	**10**	ND	0.066	ND	0.023	0.7	C3-S1
HUA-36	1.1	1.1	ND	0.14	ND	0.076	0.4	C2-S1
HUA-37	3.4	3.4	*ND*	ND	-	ND	13.3	C4-S3

bold = constituent level exceeds Primary or Secondary MCL *italics* = constituent exceeded holding time

Appendix B. Groundwater Quality Data, Hualapai Valley, 2000--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)
HUA-1	ND	ND	ND	ND	ND	ND	ND	ND	0.10
HUA-2	ND	ND	ND	ND	ND	ND	ND	ND	ND
HUA-3	ND	ND	ND	0.12	ND	0.11	ND	ND	ND
HUA-4	ND	ND	ND	ND	0.00091	0.18	ND	ND	0.051
HUA-5	ND	ND	ND	ND	ND	0.17	ND	ND	ND
HUA-6/7	ND	ND	ND	ND	ND	0.16	ND	ND	ND
HUA-8/17	ND	ND	**0.0985**	ND	ND	0.34	ND	ND	ND
HUA-9	ND	ND	ND	ND	ND	0.17	ND	ND	ND
HUA-11	ND	ND	ND	ND	ND	0.13	ND	ND	ND
HUA-12	ND	ND	ND	ND	ND	ND	ND	ND	ND
HUA-13/14	ND	ND	ND	ND	ND	0.12	ND	ND	ND
HUA-15	ND	ND	ND	ND	ND	0.27	ND	ND	ND
HUA-16	ND	ND	ND	ND	ND	0.13	ND	ND	ND
HUA-18	ND	ND	ND	ND	ND	0.51	ND	ND	ND
HUA-20	ND	ND	ND	0.11	ND	ND	ND	ND	ND
HUA-21/21D	ND	ND	ND	ND	ND	0.135	ND	ND	ND
HUA-22/23	ND	ND	**0.039**	ND	ND	0.22	ND	ND	ND
HUA-24	ND	ND	ND	ND	ND	ND	ND	ND	ND
HUA-27/27D	ND	ND	ND	ND	ND	0.185	ND	0.063	ND
HUA-29/29D	ND	ND	ND	ND	ND	0.15	ND	0.0345	ND
HUA-30	ND	ND	ND	ND	ND	ND	ND	ND	ND
HUA-31/32	ND	ND	ND	ND	ND	0.22	ND	ND	ND
HUA-34	ND	ND	ND	ND	ND	ND	ND	0.030	ND
HUA-35	ND	ND	ND	ND	ND	0.15	ND	ND	0.014
HUA-36	ND	ND	ND	ND	ND	0.10	ND	ND	ND
HUA-37	ND	ND	**0.019**	ND	ND	0.67	ND	0.013	ND

bold = constituent level exceeds Primary or Secondary MCL

Appendix B. Groundwater Quality Data, Hualapai Valley, 2000--Continued

Site #	Fluoride (mg/L)	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)
HUA-1	0.39	ND	ND	ND	ND	ND	ND	ND	ND	ND
HUA-2	0.39	ND	0.0050	ND	ND	ND	ND	ND	ND	0.086
HUA-3	**2.9**	ND	ND	ND	ND	ND	0.0096	ND	ND	0.36
HUA-4	**4.1**	ND	ND	**0.072**	ND	ND	0.0063	ND	ND	ND
HUA-5	0.77	ND	ND	ND	ND	ND	0.0080	ND	ND	1.2
HUA-6/7	**2.3**	ND	ND	ND	ND	ND	0.025	ND	ND	0.23
HUA-8/17	1.25	**0.30**	ND	ND	ND	ND	ND	ND	ND	0.104
HUA-9	1.6	ND	ND	ND	ND	ND	ND	ND	ND	0.50
HUA-11	1.3	ND	ND	ND	ND	ND	ND	ND	ND	0.15
HUA-12	**2.1**	ND	ND	ND	ND	ND	0.0058	ND	ND	0.67
HUA-13/14	0.56	ND	ND	ND	ND	ND	0.0071	ND	ND	ND
HUA-15	**2.9**	ND	ND	ND	ND	ND	0.010	ND	ND	ND
HUA-16	1.1	ND	ND	ND	ND	ND	ND	ND	ND	ND
HUA-18	**5.0**	ND	ND	ND	ND	ND	0.0058	ND	ND	0.21
HUA-20	0.69	ND	0.019	ND	ND	ND	0.011	ND	ND	1.0
HUA-21/21D	0.49	ND	ND	ND	ND	ND	0.00595	ND	ND	0.25
HUA-22/22D/23/23D	0.885	ND	ND	ND	ND	ND	ND	ND	ND	ND
HUA-24	1.4	**1.7**	ND	**0.15**	ND	ND	ND	ND	ND	0.079
HUA-27/27D	**2.1**	ND	ND	ND	ND	ND	ND	ND	ND	ND
HUA-29/29D	**2.7**	ND	ND	**0.0505**	ND	ND	ND	ND	ND	ND
HUA-30	**3.5**	ND	ND	ND	ND	ND	ND	ND	ND	ND
HUA-31/32	**3.5**	ND	ND	ND	ND	ND	0.00665	ND	ND	ND
HUA-34	1.1	ND	ND	ND	ND	ND	ND	ND	ND	ND
HUA-35	0.45	ND	ND	ND	ND	ND	0.0078	ND	ND	0.24
HUA-36	0.20	ND	ND	ND	ND	ND	ND	ND	ND	ND
HUA-37	**2.0**	ND	ND	ND	ND	ND	ND	ND	ND	ND

bold = constituent level exceeds Primary or Secondary MCL

Appendix B. Groundwater Quality Data, Hualapai Valley, 2000--Continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Ra-226+228 (pCi/L)	Uranium (µg/L)	VOCs (µg/L)	Type of Chemistry
HUA-1	-	-	-	-	-	ND	mixed-bicarbonate
HUA-2	-	4.8	3.8	-	-	ND	sodium-bicarbonate
HUA-3	-	11	6.7	< LLD	-	ND	mixed-mixed
HUA-4*	-	**74**	56	2.8	**66**	ND	mixed-mixed
HUA-5	-	9.3	16	< LLD	-	ND	calcium-mixed
HUA-6/7	1690	-	-	-	-	ND	calcium-mixed
HUA-8/17	-	1.2	6.3	-	-	ND	sodium-mixed
HUA-9	2130	-	-	-	-	ND	mixed-mixed
HUA-11	-	5.6	6.1	-	-	ND	mixed-bicarbonate
HUA-12	630	-	-	-	-	ND	calcium-bicarbonate
HUA-13/14	-	2.5	9.6	-	-	Toluene – 4.7 ug/L	mixed-mixed
HUA-15	-	14	8	-	-	ND	mixed-bicarbonate
HUA-16	-	13	11	-	-	ND	mixed-bicarbonate
HUA-18	6925	-	-	-	-	ND	sodium-mixed
HUA-20	-	7.9	5.8	< LLD	-	ND	calcium-mixed
HUA-21/21D	-	1.7	6.9	-	-	ND	mixed-mixed
HUA-22/23	-	**35**	30	**8.8**	21	ND	magnesium-mixed
HUA-24	-	5.1	3.1	< LLD	-	ND	calcium-bicarbonate
HUA-27/27D	1468	-	-	-	-	ND	mixed-bicarbonate
HUA-29/29D	305	-	-	-	-	ND	mixed-bicarbonate
HUA-30	<18	-	-	-	-	ND	sodium-chloride
HUA-31/32	-	**29**	24	< LLD	**38**	ND	mixed-mixed
HUA-34	363	-	-	-	-	ND	sodium-bicarbonate
HUA-35	-	1.1	6.3	-	-	ND	mixed-mixed
HUA-36	-	3.7	4.7	-	-	ND	magnesium-bicarbonate
HUA-37	-	-	-	-	-	ND	sodium-chloride

bold = Primary MCL Exceedance
LLD = Lower Limit of Detection
italics = constituent exceeded holding time
Additional HUA-4 radiochem results: Ba-140, Co-58, Co-60, Cs-134, Cs-137, Fe-59, I-131, K-40, La-140, Mn-54, Nb-95, Zn-65 and Zr-95 all < LLD