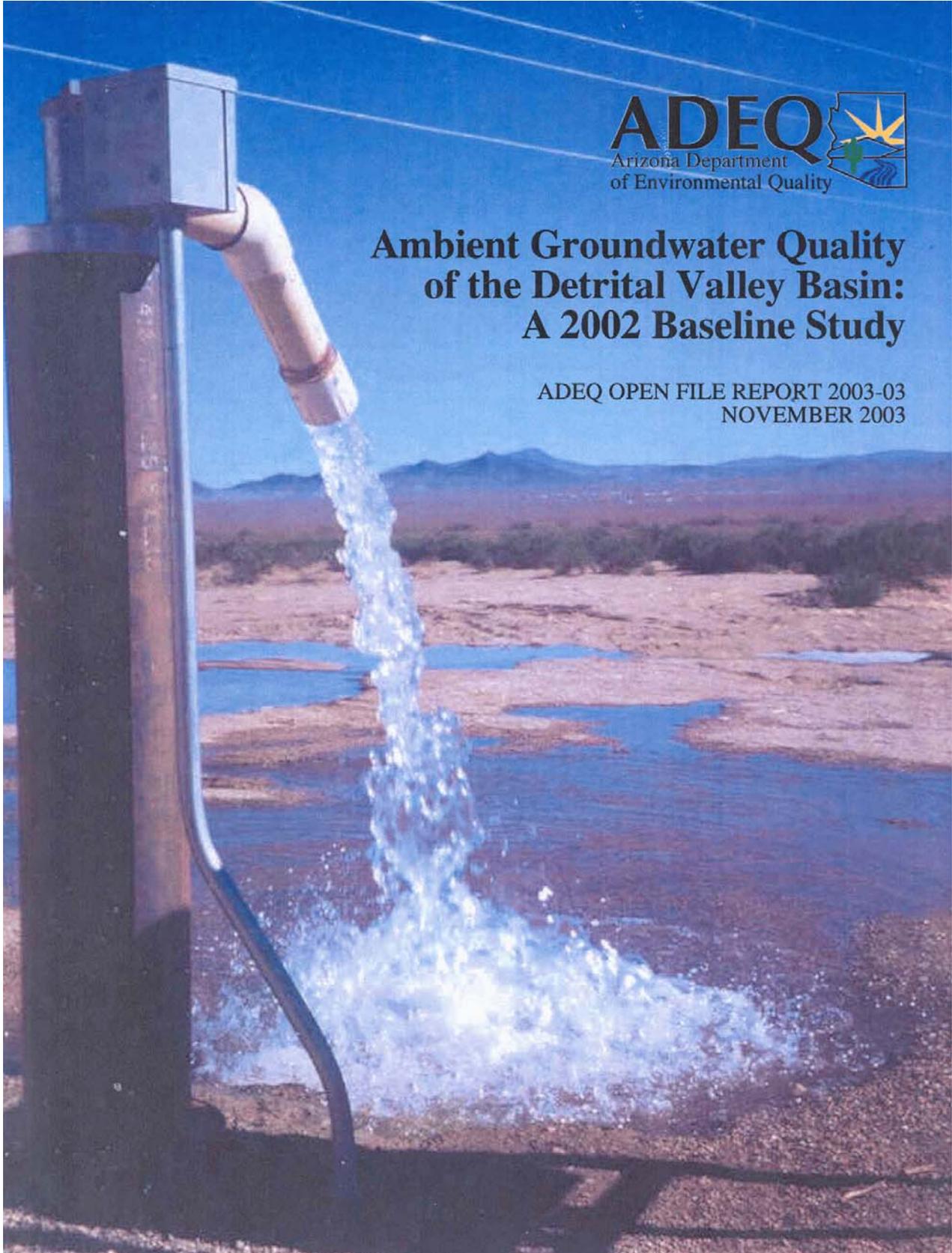




Ambient Groundwater Quality of the Detrital Valley Basin: A 2002 Baseline Study

ADEQ OPEN FILE REPORT 2003-03
NOVEMBER 2003



Ambient Groundwater Quality of the Detrital Wash Basin: A 2002 Baseline Study

By Douglas C. Towne
Maps by Larry W. Stephenson

Arizona Department of Environmental Quality (ADEQ) Open File Report 2003-03

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Photo Credits: Douglas Towne

Report Cover: White Hills Well pumping during sampling by ADEQ illustrates the potential high yield of deep wells in the Detrital Valley alluvial aquifer. This sample site is located near the junction of U.S. Highway 93 and White Hills Road.

Other Publications of the ADEQ Ambient Groundwater Monitoring Program

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

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, September 2000, 55 p. (With the U.S. Geological Survey)
Prescott Active Management Area	OFR 00-01, May 2000, 77 p.
Upper San Pedro Basin	OFR 99-12, July 1999, 50 p. (With the U.S. Geological Survey)
Douglas Basin	OFR 99-11, June 1999, 155 p.
Virgin River Basin	OFR 99-04, March 1999, 98 p.
Yuma Basin	OFR 98-07, September, 1997, 121 p.

ADEQ Ambient Groundwater Quality Factsheets (FS):

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

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

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

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

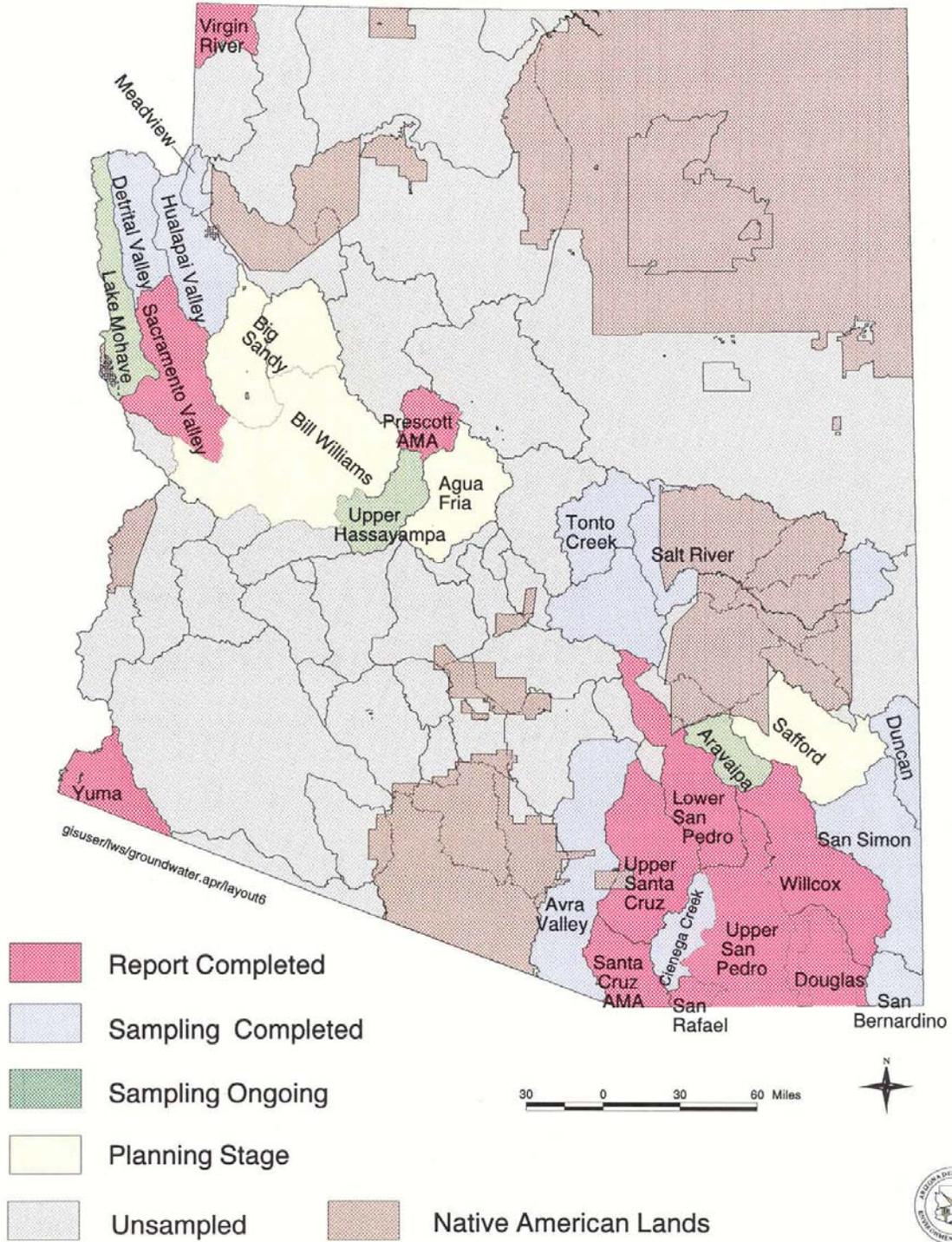
Most of these publications are available on-line.
Visit the ADEQ Ambient Groundwater Monitoring Program at:

<http://www.adeq.state.az.us/environ/water/assess/ambient.html#studies>

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Status of GW Basins in the Ambient Monitoring Program

December 2003



CONTENTS

Abstract	1
Introduction	2
Purpose and Scope	2
Physical Setting	5
Cultural Setting	5
Geohydrology Setting	6
Groundwater Characteristics	9
Groundwater Sampling Results	9
Water Quality Standards/Guidelines	9
Water Quality Standard/Guideline Exceedances	10
Suitability for Irrigation	10
Analytical Results	10
Groundwater Composition	21
Groundwater Quality Patterns	28
Aquifer Comparison	36
Watershed Comparison	39
Geological Comparison	40
Isotope Comparison	40
Time Trend Comparison	43
Conclusions	40
Suitability of Groundwater for Domestic Use	39
Discussion of Health-Based Exceedances	40
Discussion of Aesthetics-Based Exceedances	43
Groundwater Basin Overview	40
Study Design and Data Evaluation	43
Recommendations	44
References	45

APPENDICES

Basic Data	48
Data on Sample Sites	48
Groundwater Quality Data	50
Methods of Investigation	56
Sampling Strategy	56
Sample Collection	56
Laboratory Methods	57
Sample Numbers	57
Data Evaluation	60
Quality Assurance	60
Data Validation	62
Statistical Considerations	65

MAPS

Map 1. Satellite Image, Detrital Valley GW Basin.	3
Map 2. Detrital Valley GW Basin – Rock Types and Sample Sites.	8
Map 3. Detrital Valley GW Basin – Water Quality Exceedances.	13
Map 4. Detrital Valley GW Basin – Nitrate.	14
Map 5. Detrital Valley GW Basin – Total Dissolved Solids.	15
Map 6. Detrital Valley GW Basin – Sulfate.	16
Map 7. Detrital Valley GW Basin – Field pH.	23
Map 8. Detrital Valley GW Basin – Hardness.	24
Map 9. Detrital Valley GW Basin – Chromium.	25
Map 10. Detrital Valley GW Basin – Water Chemistry.	26

FIGURES

Figure 1. U.S. Highway 93.	4
Figure 2. Hoover Dam.	4
Figure 3. ADEQ Sampling Technique	4
Figure 4. Mt. Tipton Wilderness.	7
Figure 5. Detrital Wash near Lake Mead.	7
Figure 6. Rose’s Den at the Historic Boulder Inn.	7
Figure 7. Lake Mead Recreation Area.	11
Figure 8. Lake Mead aquifer sample.	11
Figure 9. Spring sample.	11
Figure 10. Windmill-powered well	12
Figure 11. Suction-powered well.	12
Figure 12. Monkey Cove Spring.	12
Figure 13. Groundwater chemistry of sample sites.	22
Figure 14. TDS - Calcium constituent covariation.	27
Figure 15. TDS - Sulfate constituent covariation.	27
Figure 16. Negative constituent covariation with groundwater depth.	29
Figure 17. Positive constituent covariation with groundwater depth.	29
Figure 18. Aquifer boxplot	31
Figure 19. Geological boxplot.	31
Figure 20. Isotope graph.	36

TABLES

Table 1. DET sites exceeding health-based water quality standards (Primary MCLs)	17
Table 2. DET sites exceeding aesthetics-based water quality guidelines (Secondary MCLs)	18
Table 3. Summary statistics for DET groundwater quality data.	19
Table 4. Relationship between groundwater quality constituent concentrations and groundwater depth	30
Table 5. Variation in groundwater quality constituent concentrations among three DET water-bearing units	32
Table 6. Summary statistics for groundwater quality constituents with significant concentration differences among three DET water bearing units	33
Table 7. Variation in groundwater quality constituent concentrations among six DET geologic units.	34
Table 8. Time-trend comparison of DET sample sites using historic USGS/ADWR data.	38
Table 9. Time-trend comparison of DET sample sites using 1982 Geo/Resources data.	39
Table 10. ADHS/Del Mar laboratory methods used in the DET study	58
Table 11. Summary results of DET duplicate samples from ADHS laboratory	61
Table 12. Summary results of DET split samples from ADHS/Del Mar laboratories	63
Table 13. Summary results of DET ADEQ / Rangeland Consulting Services Sampling	64

ABBREVIATIONS

amsl	above mean sea level
af	acre-feet
af/yr	acre-feet per year
ADEQ	Arizona Department of Environmental Quality
ADHS	Arizona Department of Health Services
ADWR	Arizona Department of Water Resources
ARRA	Arizona Radiation Regulatory Agency
AZGS	Arizona Geological Survey
As	arsenic
bls	below land surface
BLM	U.S. Department of the Interior Bureau of Land Management
°C	degrees Celsius
CI _{0.95}	95 percent Confidence Interval
Cl	chloride
DET	Detrital Valley Groundwater Basin
EPA	U.S. Environmental Protection Agency
F	fluoride
Fe	iron
gpm	gallons per minute
GWPL	Groundwater Protection List pesticide
HCl	hydrochloric acid
LLD	Lower Limit of Detection
Mn	manganese
MCL	Maximum Contaminant Level
ml	milliliter
msl	mean sea level
F g/L	micrograms per liter
F m	micron
F S/cm	microsiemens per centimeter at 25E Celsius
mg/L	milligrams per liter
MRL	Minimum Reporting Level
MTBE	Methyl tertiary-Butyl Ether
ns	not significant
ntu	nephelometric turbidity unit
pCi/L	picocuries per liter
QA	Quality Assurance
QAPP	Quality Assurance Project Plan
QC	Quality Control
SAR	Sodium Adsorption Ratio
SDW	Safe Drinking Water
SC	Specific Conductivity
su	standard pH units
SO ₄	sulfate
TDS	Total Dissolved Solids
TKN	Total Kjeldahl Nitrogen
USGS	U.S. Geological Survey
VOC	Volatile Organic Compound

“Detrital Wash extends for some fifty miles from Lake Mead into the mountains north of Kingman; it drains a big chunk of country. Most of the year the wash is as dry as chalk. During the summer months, however, superheated air rises from the scorched earth like bubbles from the bottom of a boiling kettle, rushing heavenward in turbulent convection currents. Frequently the updrafts create cells of muscular, anvil-headed cumulonimbus clouds that can rise thirty thousand feet or more above the Mojave. Two days after McCandless set up camp beside Lake Mead, an unusually robust wall of thunderheads reared up in the afternoon sky, and it began to rain, very hard, over much of Detrital Valley.

McCandless was camped at the edge of the wash, a couple of feet higher than the main channel, so when the bore of brown water came rushing down from the high country, he had just enough time to gather his tent and belongings and save them from being swept away. There was nowhere to move the car, however; as the only route of egress was now a foaming, full-blown river.”

John Krakauer in *Into the Wild*²⁶

Ambient Groundwater Quality of the Detrital Valley Basin: A 2002 Baseline Study

By Douglas C. Towne

Abstract - The Detrital Valley groundwater basin (DET), located between Kingman and Hoover Dam in northwestern Arizona, is a north-south trending, semiarid basin traversed by U.S. Highway 93. Lightly populated with retirement and recreation-oriented communities, the construction of a Hoover Dam bypass route for U.S. Highway 93 will likely bring many new residents who commute to Las Vegas. The DET is drained by the ephemeral Detrital Wash which debouches into Lake Mead at Bonelli Bay. The DET, with groundwater depth up to 800 feet below land surface near the center of the valley, is reminiscent of basins in Nevada. Groundwater from the *alluvial aquifer* is the principle water source. Where sufficiently fractured and faulted, mountain *hardrock* provides limited supplies at shallower depths to groundwater. Near Lake Mead, a *Lake Mead aquifer* recharged by Colorado River water is the main supply.

In 2002, a baseline groundwater quality study of the DET was conducted by the Arizona Department of Environmental Quality. The purpose of this study was to create a comprehensive groundwater quality baseline assessment. For this study, 28 groundwater sites were sampled for inorganic constituents as well as isotopes of hydrogen and oxygen, samples were also collected at selected sites for radon gas (9 sites) and radiochemistry (9 sites) analyses. In addition, surface water isotope samples were collected from Lake Mead and Detrital Wash. One weakness of the groundwater study was the few sites available for sampling in the northern third of the basin.

Of the 28 sites sampled, 13 (46 percent) met all Federal and State water quality standards. Nine sites (32 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.⁴⁶ Constituents that exceeded these standards included arsenic (0 sites under current standards, 3 sites under standards effective in 2006), gross alpha (3 sites), and nitrate (3 sites). Ten sites (36 percent) had concentrations of at least one constituent that exceeded an aesthetics-based, unenforceable, Federal water-quality guideline that defines the maximum concentration of a constituent that can be present in drinking water without an unpleasant taste, color, odor, or other aesthetic effects.⁴⁶ Constituents that exceeded these guidelines included chloride (1 site), fluoride (2 sites), iron (2 sites), manganese (3 sites), sulfate (7 sites), and total dissolved solids or TDS (11 sites).

Interpretation of the analytical sample results indicates that groundwater in the DET generally meets drinking water standards and is suitable for domestic, municipal, irrigation, and stock purposes. Groundwater in the DET is generally *fresh, slightly alkaline, and moderately to very hard* based on TDS, pH, and hardness concentrations.²² Groundwater is most commonly a *mixed-mixed* chemistry though it varies widely in the basin. Boron, chromium, fluoride, and zinc were the only trace elements detected at more than 25 percent of sites.

Groundwater quality constituent concentrations varied significantly among aquifers. Bicarbonate, calcium, and hardness were higher in *hardrock* than in the *alluvial aquifer*. In contrast, temperature, nitrate, and chromium were higher in the *alluvial aquifer* than in *hardrock*. The *Lake Mead aquifer* had higher levels of oxygen and hydrogen isotopes, sodium, sulfate, and boron (ANOVA test in conjunction with Tukey test, p # 0.05). Many groundwater quality constituent concentrations varied significantly with groundwater depth. Most constituents, including TDS, bicarbonate, calcium, magnesium, hardness, chloride, and sulfate decreased with groundwater depth. In contrast, temperature, pH-field, nitrate, and chromium increased with groundwater depth (regression, p # 0.05).

Hydrogen and oxygen isotope data form a *Local Meteoric Water Line* with a slope of 5.15 that is within the range normally found in arid environments.¹⁴ The most *depleted*, or isotopically lightest sites are near (and include) Lake Mead and consist of recent recharge from the Colorado River. A tight cluster of 16 *depleted* sites, consisting mainly of deep alluvial wells, may represent the oldest water in the basin that was recharged during a more humid time period than the present. Stretching from this cluster to the most *enriched* site (runoff in Detrital Wash) is an evaporation trajectory of 10 shallow wells that produce water that may include recharge from recent precipitation.

INTRODUCTION

The Detrital Valley (DET) groundwater basin is located in northwestern Arizona between Kingman and Hoover Dam and bisected by U.S. Highway 93 (**Map 1**). The north-south trending basin is characterized by relatively pristine Mojave Desert vegetation on public lands and homes located on scattered parcels of private land. Recent land transfers and the construction of the Hoover Dam bypass for U.S. Highway 93 (**Figure 1**) will enable additional population growth in the DET as residents are able to commute more easily to Las Vegas for employment.²⁷ Groundwater is the primary source for municipal, domestic, and stock water uses in the DET.¹⁸ There is no significant irrigated acreage in the basin apart from landscaping around homes. The most noteworthy hydrologic feature of the DET is Lake Mead forming the basin's northern boundary. This water body is created by the impoundment of the Colorado River water by Hoover Dam, one of the world's most famous structures (**Figure 2**).

The Arizona Department of Environmental Quality (ADEQ) Groundwater Monitoring Unit designed a study to characterize the current (2002) groundwater quality conditions in the DET. Sampling by ADEQ was completed as part of the Ambient Groundwater Monitoring Program, which is based on the legislative mandate in the Arizona Revised Statutes §49-225 that authorizes:

*"...ongoing monitoring of waters of the state, including...aquifers to detect the presence of new and existing pollutants, determine compliance with applicable water quality standards, determine the effectiveness of best management practices, evaluate the effects of pollutants on public health or the environment, and determine water quality trends."*⁴

The ADEQ ambient groundwater monitoring program is examining the DET regional groundwater quality to:

- Provide a comprehensive baseline study of the DET in preparation for a potentially greatly expanded population within the basin which will rely upon groundwater as a municipal and/or domestic source.²⁷
- Provide guidance to potential multi-state watershed issues affecting the Colorado River such as identifying wells pumping Colorado River sub-flow.⁵¹
- Determine areas where groundwater does not currently meet U.S. Environmental Protection Agency (EPA) Safe Drinking Water Act (SDWA) water quality standards.⁴⁶
- Examine water quality differences among the aquifers, watersheds, and rock types found within the DET and with groundwater depth.

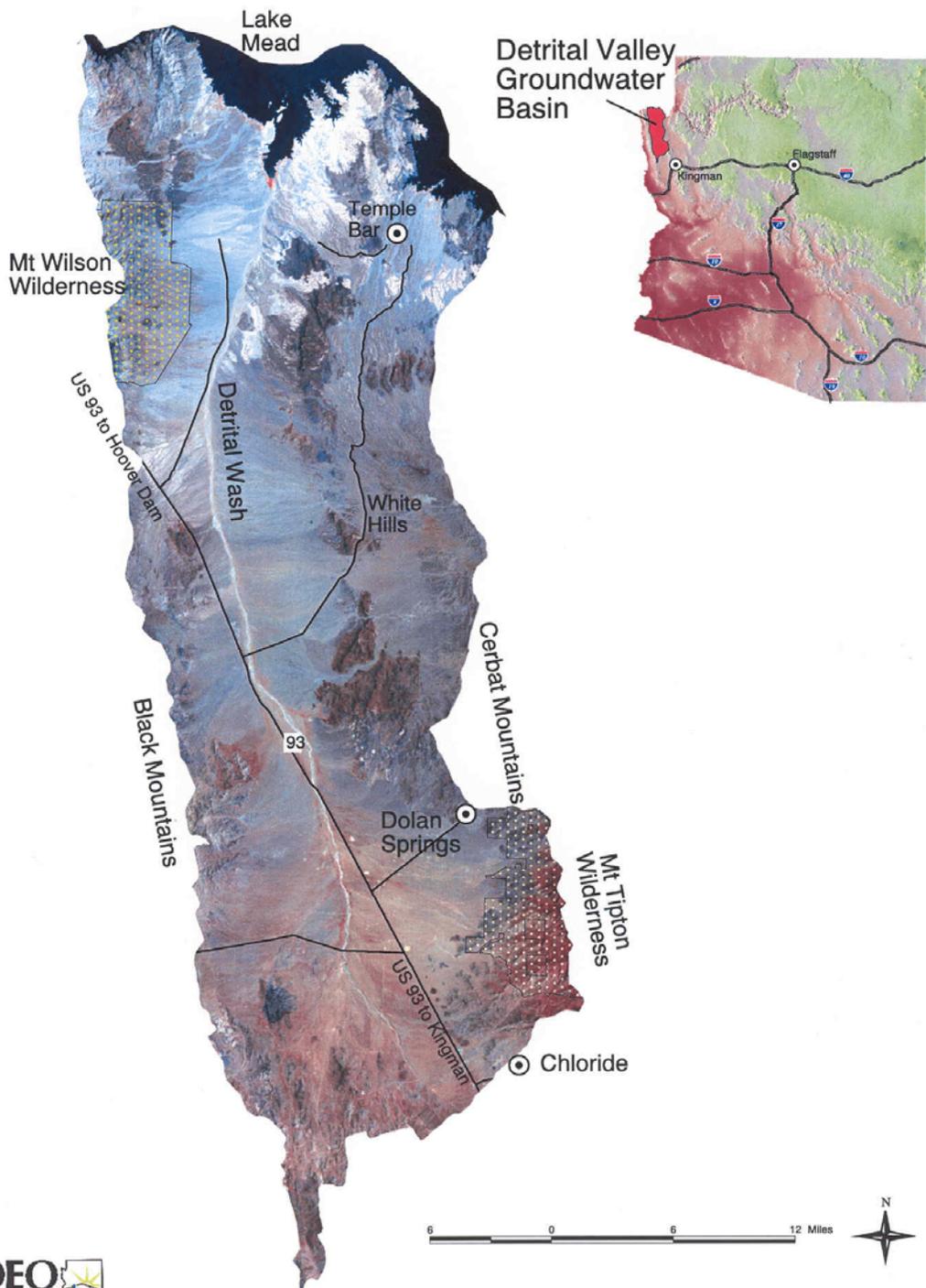
Purpose and Scope

ADEQ collected samples (**Figure 3**) from 28 sites for this groundwater quality assessment of the DET (**Map 2**). Types and numbers of samples collected and analyzed include inorganics (physical parameters, major ions, nutrient constituents, and trace elements) (28 sites), oxygen and hydrogen isotopes (29 sites), radiochemistry (11 sites), and radon gas (11 sites). In addition, surface water oxygen and hydrogen isotope samples were collected from both Lake Mead and Detrital Wash.

Reasons for Study - The DET was selected to:

- < Support the ADEQ watershed program by expanding the hydrologic information available on the Colorado River watershed. Mohave County and local community governments can also benefit from this study.
- < Add to the groundwater quality data available for the DET, a basin dependent on groundwater for municipal supplies which likely could experience a tremendous growth in population.²⁷
- < Provide support to the State of Arizona in negotiations involving the many regional and international issues involving the Colorado River.
- < Provide a more comprehensive baseline study than was previously possible due to additional types of samples collected and the increase in wells which provide greater access to groundwater.

Map 1. Satellite Image, Detrital Valley GW Basin



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Figure 1. Although the name “Detrital Valley” may be unfamiliar to most Arizona residents, many people will have actually driven through the basin on U.S. Highway 93 between Kingman and Hoover Dam while en route to Las Vegas. Heading north, the roadside oasis of Grasshopper Junction demarcates the start of the basin.

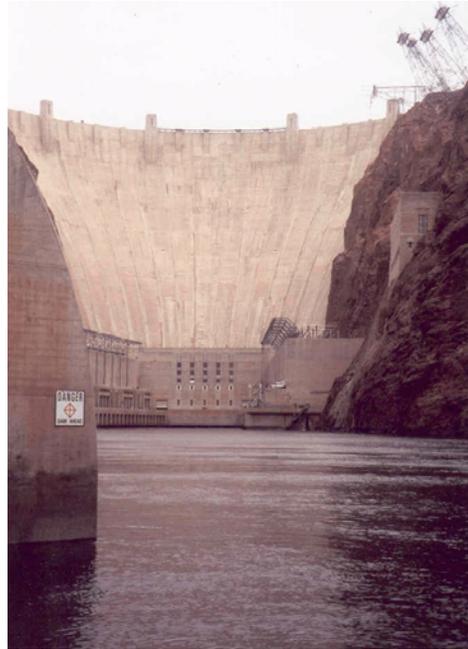


Figure 2. Hoover Dam, completed in 1935, is shown looking upstream from the Colorado River. This impoundment creates Lake Mead, which is the northern boundary of the Detrital Valley groundwater basin. Water from Lake Mead recharges groundwater in the vicinity of the resort community of Temple Bar.



Figure 3. ADEQ sampling personnel bring with them a wide variety of talents including modern dance as exhibited here by Elizabeth Boettcher. She is sampling a well used for domestic and industrial purposes by a sand and gravel operation located near Detrital Wash and Temple Bar Road. The Mount Wilson Wilderness area in the Black Mountains is seen in the background.

Benefits of Study - This groundwater quality study was undertaken with the purpose of developing a reproducible, scientific report utilizing accepted sampling techniques and quantitative analysis of the analytical results to investigate groundwater quality in the DET. The report's conclusion concerning groundwater quality is anticipated to provide the following three benefits:

#1 - Residents in the DET obtain domestic supplies from private wells whose water is seldom tested for a wide variety of possible pollutants. Arizona statutes only require well drilling contractors to disinfect, for potential bacteria contamination, new wells which are used for human consumption.⁴ Many wells are not tested for other groundwater quality concerns. Thus, contamination affecting groundwater pumped from private wells may go undetected for years and have adverse health effects on users of this resource. Testing all private wells for a wide variety of groundwater quality concerns would be prohibitively expensive. An affordable alternative is this type of statistically-based groundwater study characterizing regional groundwater quality conditions and identifying areas with impaired groundwater conditions.

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

#3 - A process for identifying future locations of public supply wells and wellhead protection areas.

Physical Setting

The DET is approximately 50 miles long (north to south) and 15 miles wide (east to west) covering approximately 875 square miles in northwestern Arizona.¹⁸ The basin lies within the Mojave Desert section of the Basin and Range physiographic province and is bounded by Lake Mead to the north, the White Hills and Cerbat Mountains to the east, a low topographic rise to the south near the roadside oasis of Grasshopper Junction, and the Black Mountains to the west.

Elevations in the DET range from Mt. Tipton at 6,900 feet above mean sea level (amsl) (**Figure 4**) in the Cerbat Mountains on the east side of the basin to Mt. Perkins at 5,456 feet amsl in the Black Mountains on the west side of the basin. The Detrital

Valley floor slopes downward from approximately 3,400 feet amsl at the southern boundary to around 1,225 feet amsl where Detrital Wash drains into the normal pool elevation of Lake Mead.

Essentially all streamflow in the DET is ephemeral and is generated in the mountains in response to summer and winter storms.¹⁹ Surface flow rarely reaches the central parts of the valley because of evapotranspiration and infiltration on the upper and middle portion of alluvial fans.¹⁸ These areas provide most of the groundwater recharge.¹⁹ The majority of the basin is drained by Detrital Wash, an ephemeral watercourse that debouches into Lake Mead west of the resort community of Temple Bar (**Figure 5**). Lake Mead is composed of Colorado River water impounded by Hoover Dam, which was completed in 1935. The reservoir was filled by 1942. However periods of drought from 1944-57, 1961-72, and 1999-2003 resulted in low reservoir levels.³⁶

The climate of the DET is typically semiarid, characterized by hot summers and mild winters. Precipitation in valley areas averages around 7 inches based on data from the community of Dolan Springs.¹⁹

Cultural Setting

Settlement within the DET began with mining in the late 1800s, particularly with the discovery of silver ore in the White Hills. White Hills established a post office in 1892 and reached a population of about 1,500 people before the depletion of ore veins resulted in the community becoming almost a ghost town by 1914. Other small mining communities in the White Hills area included Cyclopic, which had a post office from 1905-1917.²⁰

The construction of Hoover Dam, which impounded the Colorado River in the 1930s, began the basin's next phase of development involving tourism and recreation. Rose's Den at Boulder Inn along Highway 93 in Detrital Valley is a legacy of this period (**Figure 6**). Recreational opportunities in the basin abounded with the creation of Lake Mead as well as with the abundance of public lands. With the rapid growth of Las Vegas, tourism is becoming an increasingly important economic factor in the DET.

The DET is located in Mohave County with land ownership divided among the Bureau of Land Management (42 percent), Lake Mead National Recreation Area (27 percent) (**Figure 7**), private entities (22 percent), and State Trust (9 percent).⁶

Two wilderness areas are located within the basin: the Mt. Wilson Wilderness in the northern Black Mountains and the Mt. Tipton Wilderness in the Cerbat Mountains.

Currently, the largest community in the DET is Dolan Springs with a 1999 population of approximately 1,700.¹ Dolan Springs, known as the “Gateway to Grand Canyon West,” was originally a land development known as Lake Mohave Ranchos.¹ Another population center, Temple Bar, is a small resort community and marina near the shore of Lake Mead. Other residential development in the DET occurs on scattered parcels of private land.

Two recent events, the Hoover Dam bypass and land swaps, indicate that the DET may soon feel impacts from the tremendous growth that has occurred across the Nevada state line in Las Vegas. A land exchange between the U.S. Bureau of Land Management (BLM) and private parties will consolidate over 10,000 acres under a single landowner who is proposing to construct a new city in the DET.⁴⁰ If constructed, this city will likely become a bedroom community of Las Vegas due to drastically reduced commuting times when the U.S. Highway 93 Hoover Dam bypass is completed in 2007.²⁷ Eventually, an immense Las Vegas suburb has been proposed for the DET that could spread out over 31,000 acres.²⁷

GEOHYDROLOGY

The DET is considered part of the Basin and Range physiographic province. The mountain ranges in the study area are tilted fault blocks flanked by north-striking normal faults. Detrital Valley is the surface expression of the intermontane basins formed between the tilted fault blocks.¹⁹ Much of the DET is underlain by alluvium whereas mountains on both the east and west edges consist of a mixture of sedimentary, metamorphic, granitic, volcanic (felsic to intermediate rocks), and basaltic (mafic volcanic rocks) rock (**Map 2**).³²

Detrital Valley is filled with young volcanic flows, clastic sediments, and evaporite deposits. The clastic sediments are further divided into older, intermediate,

and younger alluvium with the older alluvium interbedded with both the younger volcanics and evaporite deposits. Gravity modeling indicates the basin fill beneath Detrital Valley is 6,400 to 8,000 feet deep in the southern section and much shallower in northern portions (0 to 1600 feet).³⁰ In the northern Detrital Valley, a salt body extends over several square miles in townships 29 and 30 north, range 21 west.⁹ This salt body has a maximum thickness of 715 feet and occurs from 300 to 800 feet below land surface (bls). This salt body may impede groundwater flow to the north and negatively impact groundwater quality.¹⁹

In the White Hills area, groundwater occurs in fractured bedrock and in pockets of alluvium. This area has deep and extensive alluvium relative to most occurrences in the mountains.¹⁹ The geology and groundwater flow system in the White Hills area is very complex, possibly with many bedrock faults which create outcrops separated by small, alluvial basins.

Groundwater is found in three principal water-bearing units in the DET:

- < **alluvial aquifer** - in the southern part, consisting mainly of unconsolidated to semi-consolidated conglomerate deposits, and in the northern part, consisting of, in descending order, the Chemehuevi formation, older alluvium, and the Muddy Creek formation.¹⁸
- < **bedrock** - mountain bedrock that contains limited amounts of groundwater where sufficiently faulted and fractured.¹⁸
- < **Lake Mead aquifer** - the previously dry sediments and sedimentary rocks above the Colorado River saturated with river water as Lake Mead filled following the completion in 1935 of Hoover Dam. Colorado River water is also stored in the younger alluvium near the lake shore in Detrital Wash (**Figure 8**).⁵¹

Although each sample site is subject to a myriad of site-specific influences, because of the broad regional scale of this study, the above water-bearing units are generally treated as homogeneous units for broad comparison purposes.



Figure 4. Mt. Tipton, located in the Cerbat Mountains, is the highest point in the Detrital Valley groundwater basin at 6,900 feet above mean sea level. Much of this rugged country is included in the Mt. Tipton Wilderness. Many springs issue from this area, including Lower Indian, Putnam, and Quail Springs that were sampled as part of this ADEQ study.

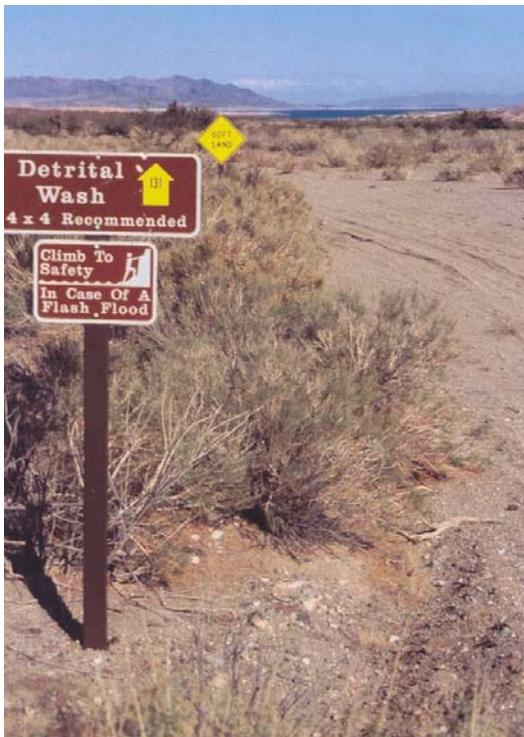
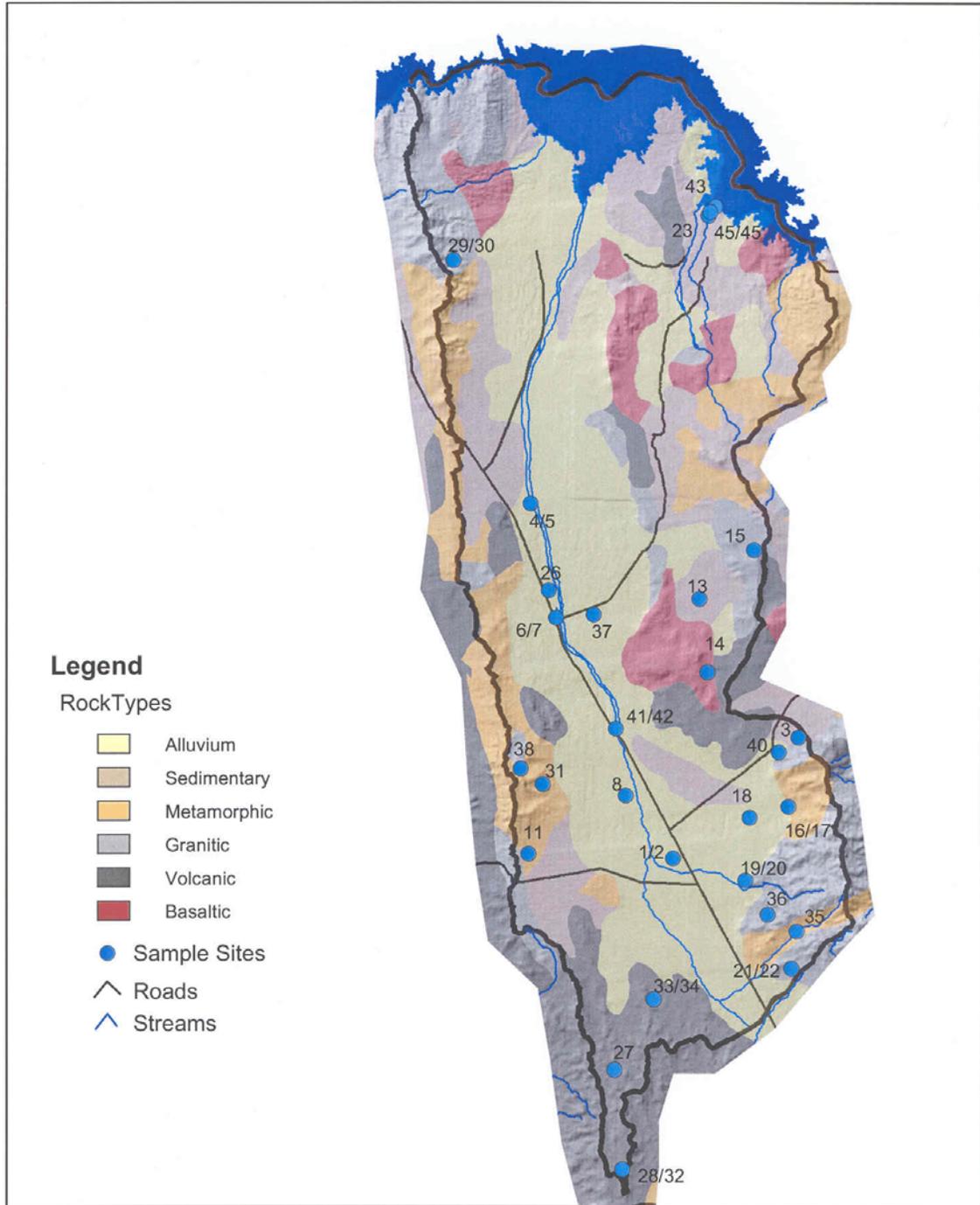


Figure 5. The Detrital Valley basin is largely drained by Detrital Wash, a wide, shallow, typically dry watercourse. Those unfamiliar with the intensity of desert thunderstorms find it difficult to understand that this dusty wash can quickly become a full-blown river.



Figure 6. Settlement in Detrital Valley originally focused on mining camps and isolated cattle ranches. The construction of Hoover Dam (originally called Boulder Dam) in the 1930s started an economic evolution toward services for travelers such as the historic Boulder Inn located on Highway 93.

Map 2. Detrital Valley GW Basin - Rock Types and Sample Sites



1: 475,000



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Groundwater Characteristics - Over one million acre-feet (af) of groundwater is estimated to be in storage in the basin to a depth of 1,200 feet.⁷ Because the basin may be as deep as 8,400 feet, considerable more groundwater may be available than this estimate.³⁰ Groundwater moves from the surrounding mountains toward the Detrital Wash and then north toward Lake Mead. Beneath Detrital Valley, hydraulic gradients range from 0.001 to 0.044 feet per foot.¹⁹ A possible groundwater drainage divide has been reported in the northern part of the DET roughly at Township 29 North, Range 21 West.³⁷ This may be related to the effects of a salt body that tends to impede groundwater flow to the north.⁹

Groundwater is discharged from the DET through both artificial and natural means. Natural outflow occurs northward into Lake Mead through a combination of groundwater underflow as well as Detrital Wash flood flow. Groundwater outflow is estimated to be between 2,100 to 3,400 af/yr.¹⁹ Discharge also occurs through evapotranspiration by riparian vegetation in shallow groundwater areas in the vicinity of Lake Mead. Groundwater pumpage is estimated to be less than 200 acre-feet per year and is used for domestic, municipal, stock, and to a very limited extent, irrigation purposes.¹⁸

The *alluvial aquifer* has the ability to transmit and supply up to 300 gallons per minute (gpm), though averaging between 10 to 130 gpm (**see cover photo**).¹⁹ It serves as the main water supply in the DET.⁷ In contrast, surrounding mountain *bedrock* yields small amounts of water, usually less than 50 gpm in springs and wells.¹⁸

Depth to water in the alluvium ranges from 20 feet bls in the northern part near Lake Mead to over 780 feet bls in southern areas of the basin.¹⁸ In mountain *bedrock*, depth to water varies but is commonly less than 100 feet bls, and in some places, may be flowing at the surface as seeps or springs (**Figure 9**).¹⁸

Groundwater recharge averages less than 1,000 af annually and occurs through mountain-front recharge and infiltration of runoff in stream channels.¹⁹ The DET basin is thought to be in a steady state condition because, as of 1985, only small quantities (190 af annually) of groundwater have been pumped. Little historic change in groundwater levels supports this conclusion.¹⁸

GROUNDWATER SAMPLING RESULTS

To characterize the regional groundwater quality of the DET, ADEQ personnel sampled 28 groundwater sites in 2002 consisting of 21 wells and 7 springs. The 21 wells consisted of 6 windmills for livestock use (**Figure 10**), 10 wells with submersible pumps (2 for livestock use, 6 for domestic use, and 2 for industrial use), 2 suction wells for stock use (**Figure 11**) and 3 wells with turbine pumps for municipal use. Of the seven springs sampled, particularly noteworthy was the sampling of Monkey Cove Spring near Temple Bar (**Figure 12**). The low levels of Lake Mead exposed the spring for the first time since July of 1969.³⁹

Information on locations and characteristics of these groundwater sample sites is provided in **Appendix A**. The following types of samples were collected:

- < Inorganic samples at 28 sites;
- < Hydrogen and oxygen isotope samples at 28 sites (plus two surface water sites and one additional groundwater site);
- < Radon samples at 11 sites; and
- < Radiochemistry samples at 11 sites.

Water Quality Standards/Guidelines

As an environmental regulatory agency, the most important determination ADEQ makes concerning the collected samples is how the analytical results compare to domestic and irrigation water quality standards.

Three sets of drinking water standards were used to evaluate the suitability of these groundwater sites for domestic purposes. These standards reflect the best current scientific and technical judgment available on the suitability of water for drinking purposes. It should be emphasized that the federal and State health-based drinking water standards are chronic being based on a daily lifetime consumption of two liters of water.⁴⁶

- 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.⁴⁶

- State of Arizona **Aquifer Water-Quality Standards** apply to aquifers that are classified for drinking water protected use. Currently all aquifers within Arizona are for drinking water use.⁴ These enforceable State standards are almost identical to the federal Primary MCLs.
- Federal SDW **Secondary MCLs**. These non-enforceable aesthetics-based guidelines define the maximum concentration of a constituent that can be present without imparting unpleasant taste, color, odor, or other aesthetic effect on the water.⁴⁶

Water Quality Standard/Guideline Exceedances

Of the 28 sites sampled for the study, 13 (46 percent) had no SDW Primary and Secondary MCL exceedances.

Health-based Primary MCL water quality standards and State aquifer water quality standards were exceeded at 9 of 28 sites (32 percent) (**Map 3**)(**Table 1**). Constituents above Primary MCLs include arsenic (0 sites under current standards, 3 sites under standards which take effect in 2006), gross alpha (3 sites), and nitrate (3 sites) (**Map 4**). Potential chronic health effects of these Primary MCL exceedances, based on a lifetime daily consumption of two liters, are also provided in **Table 1**.

Aesthetics-based Secondary MCL water quality guidelines were exceeded at 11 of 28 sites (39 percent) (**Table 2**)(**Map 3**). Constituents above Secondary MCLs include: chloride (1 site), fluoride (2 sites), iron (2 sites), manganese (3 sites), sulfate (7 sites) (**Map 6**), and TDS (11 sites) (**Map 5**). Aesthetic effects of these Secondary MCL exceedances are also provided in **Table 2**.

Radon is a naturally occurring, intermediate breakdown product from the radioactive decay of uranium-238 to lead-206.¹⁵ There are widely conflicting opinions on the risk assessment of radon in drinking water, with proposed drinking water standards varying from 300 piC/L to 4,000 piC/L.¹⁵ Eight of the 12 sites sampled for radon exceeded the 300 piC/L proposed standard; one exceeded the 4,000 proposed standard.

Suitability for Irrigation

The suitability of 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.⁴⁶ With increasing salinity, treatments such as leaching, selection of salt tolerant plants, and providing for adequate drainage are necessary.

Irrigation water may be classified using specific conductivity (SC) and the Sodium Adsorption Ratio (SAR) in conjunction with one another.⁴⁸ Groundwater sites in the DET display a narrow range of irrigation water classifications with some salinity hazards but no sodium hazards.

The 28 sample sites are divided into the following salinity hazards: low or C1 (0), medium or C2 (15), high or C3 (10), and very high or C4 (1). Likewise, the 28 sample sites are divided into the following sodium or alkali hazards: low or S1 (28), medium or S2 (0), high or S3 (0), and very high or S4 (0).

This analysis indicates that the lack of irrigated farmland in the DET is not because of groundwater quality considerations but rather from the economic costs associated with pumping groundwater from great depths for agricultural use. Although DET groundwater is only used for irrigation ancillary to dwellings, this information is useful when selecting landscaping plants around a private residential area or back country visitor center.

Analytical Results

Analytical inorganic and radiochemistry results of the 28 sample sites are summarized (**Table 4**) using the following indices: minimum reporting levels (MRLs), number of sample sites over the MRL, upper and lower 95 percent confidence intervals (CI_{95%}), 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.

Specific constituent information for each groundwater site is found in **Appendix B**.



Figure 7. Land management in the northern portion of the Detrital Valley basin is administered by the National Park Service as part of the Lake Mead National Recreation Area. Few wells or springs were sampled in this area of the basin, resulting in a much higher density of samples from the upgradient, southern part of the basin.



Figure 8. Wells in the Temple Bar area are recharged by Colorado River water impounded in Lake Mead. Doug McCarty of ADEQ is sampling one such very productive well (hidden from view) located in Temple Wash. Across Lake Mead in Nevada is Bonelli Peak.

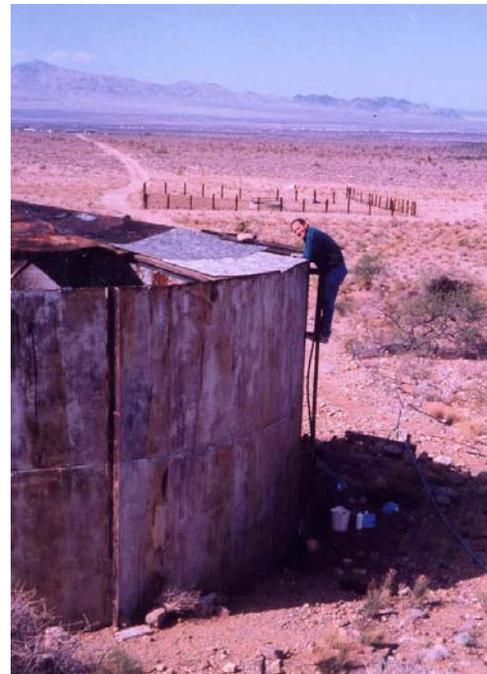


Figure 9. ADEQ's Doug McCarty demonstrates the agility occasionally required to collect a groundwater sample. Quail Spring is piped a short distance before discharging into the top of this water tank. The aridity of Detrital Valley is apparent in the surrounding range land.

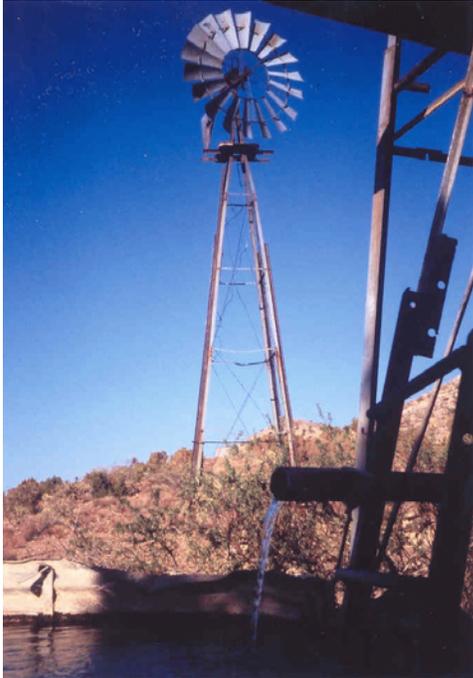


Figure 10. Detrital Valley has very deep groundwater levels. In contrast, near the valley margins and in the surrounding mountains, groundwater is found at more shallow levels. Windmills, such as Twin Mills in the Black Mountains, are commonly used by ranchers to provide water for stock.

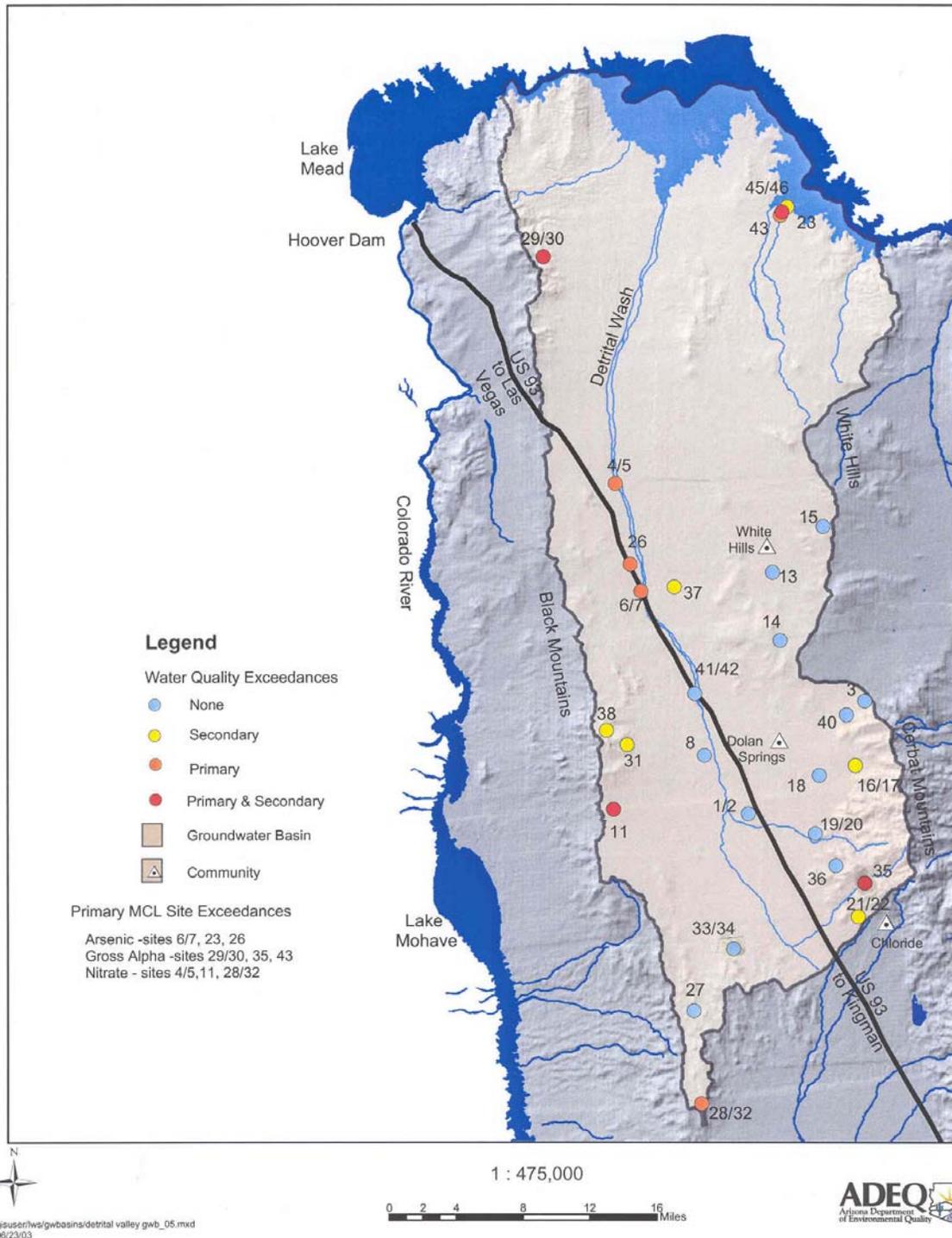


Figure 11. In some places, ranchers in the Detrital Basin use suction-flow out of wells to provide water for stock. Cow Camp Well, located high in the Black Mountains, is an historic watering source. Generally, water at shallow depths is scarce in the basin and thus, highly prized.

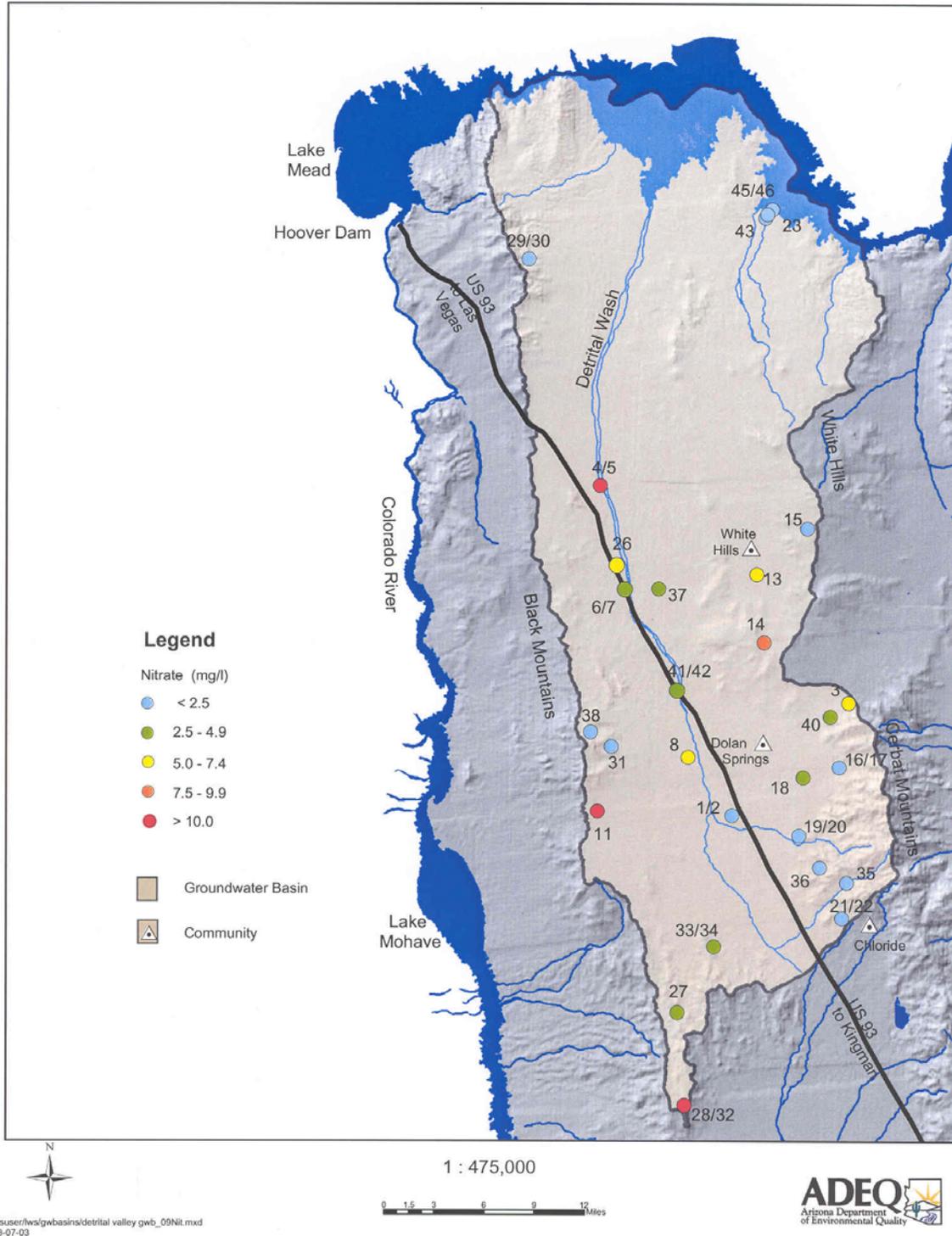


Figure 12. In a bit of hydrologic serendipity during the course of ADEQ's study of the Detrital Valley basin, Lake Mead receded to levels low enough to expose Monkey Cove Spring for the first time since July 1969. The spring flowed at an amazing 1,200 gallons per minute when measured in 1964. Isotope results indicate that the spring now consists mainly of recharged Lake Mead water.

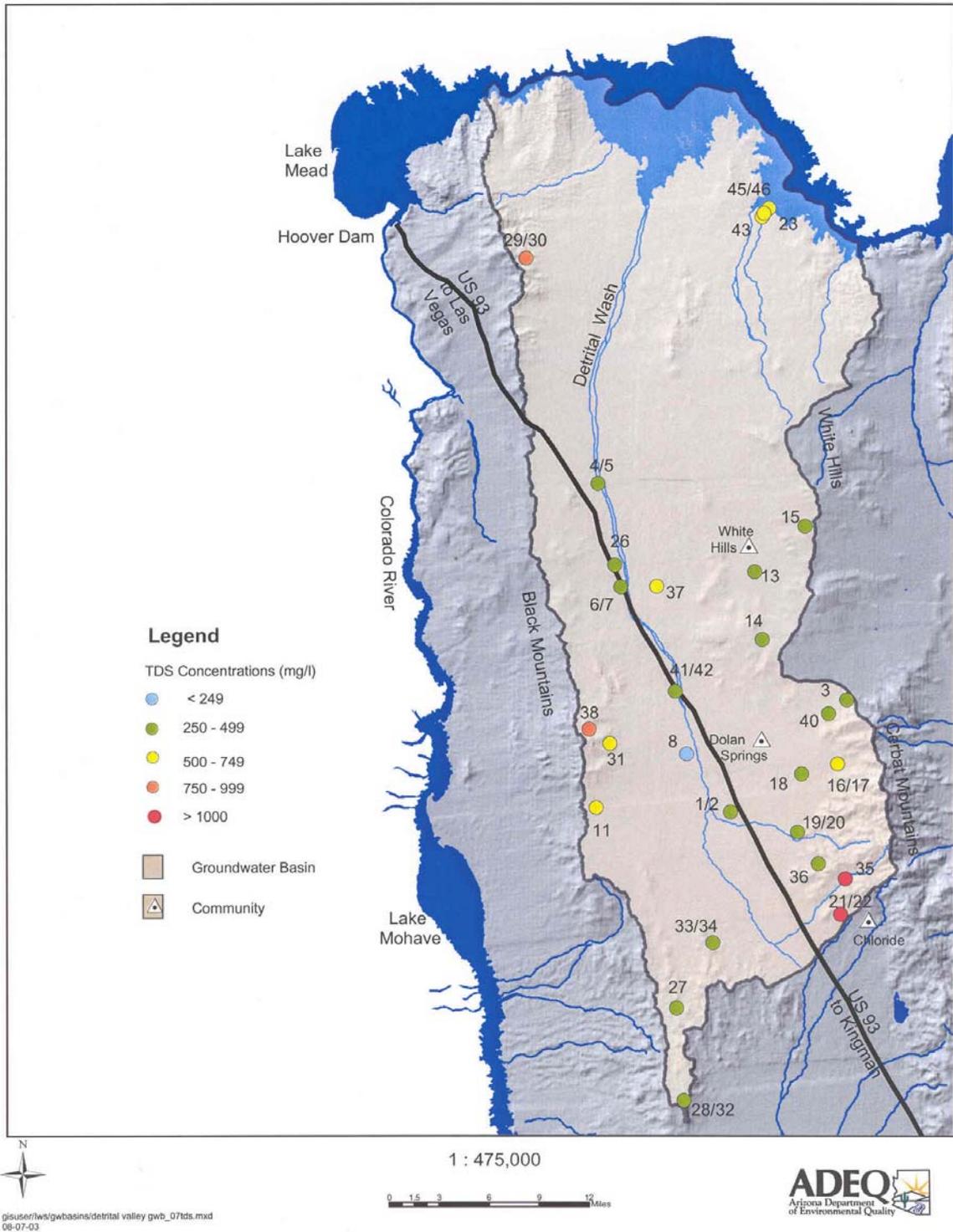
Map 3. Detrital Valley Basin -Water Quality Exceedances



Map 4. Detrital Valley Basin - Nitrate



Map 5. Detrital Valley GW Basin - Total Dissolved Solids



Map 6. Detrital Valley GW Basin - Sulfate

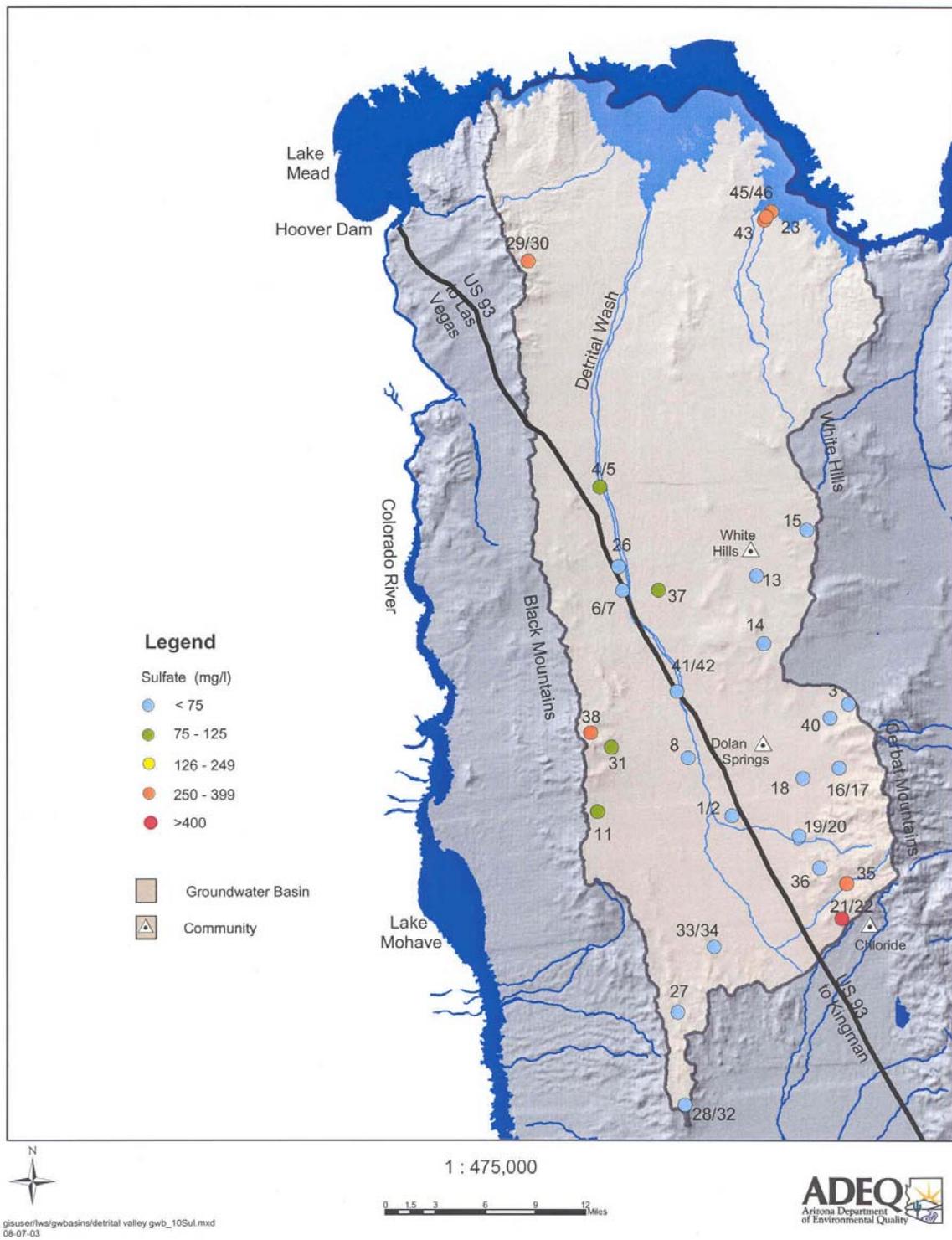


Table 1. DET Sites Exceeding Health-Based Water Quality Standards (Primary MCLs)

Constituent	Primary MCL	Sites Exceeding Primary MCLs	Concentration Range of Exceedances	Potential Health Effects with Primary MCL Exceedances*
Nutrients				
Nitrite (NO ₂ -N)	1.0	0	--	
Nitrate (NO ₃ -N)	10.0	3	10 - 16	Methemoglobinemia with very young children
Trace Elements				
Antimony (Sb)	0.006	0	-	
Arsenic (As)	0.05 0.01**	0 3	0.012 - 0.014	Dermal and nervous system toxicity
Barium (Ba)	2.0	0	--	
Beryllium (Be)	0.004	0	--	
Cadmium (Cd)	0.005	0	--	
Chromium (Cr)	0.1	0	--	
Copper (Cu)	1.3	0	--	
Fluoride (F)	4.0	0	--	
Lead (Pb)	0.015	0	--	
Mercury (Hg)	0.002	0	--	
Nickel (Ni)	0.1	0	--	
Selenium (Se)	0.05	0	--	
Thallium (Tl)	0.002	0	--	
Radiochemistry Constituents				
Gross Alpha	15 piC/L	3	16-36 piC/L	Cancer
Ra-226 + Ra-228	5 piC/L	0	--	
Uranium	30 F g/L	0	--	

All units in mg/L except gross alpha, radium-226+228, and uranium.

* Potential health effects with Primary MCL exceedances is based on a daily, lifetime consumption of two liters of water.

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

Source: ^{24 46}

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

Constituents	Secondary MCL	Sites Exceeding Secondary MCLs	Concentration Range of Exceedances	Aesthetic Effects with Secondary MCL Exceedances
Physical Parameters				
pH - field	6.5 to 8.5	0	--	
General Mineral Characteristics				
TDS	500	11	500 - 2100	Unpleasant taste
Major Ions				
Chloride (Cl)	250	1	545	Salty taste
Sulfate (SO ₄)	250	7	250 - 840	Rotten-egg odor, unpleasant taste, and laxative effect
Trace Elements				
Fluoride (F)	2.0	2	2 - 2.2	Mottling of teeth enamel
Iron (Fe)	0.3	2	0.98 - 5.75	Rusty color, reddish stains, and metallic tastes
Manganese (Mn)	0.05	3	0.051 - 1.2	Black oxide stains and bitter, metallic taste
Silver (Ag)	0.1	0	--	
Zinc (Zn)	5.0	0	--	

All units mg/L except pH is in standard units (SU).
Source: ^{24 46}

Table 3. Summary Statistics for DET Groundwater Quality Data

Constituent	Minimum Reporting Limit (MRL)	Number of Samples Over MRL	Lower 95% Confidence Interval	Median	Mean	Upper 95% Confidence Interval	Mean of Colorado River below Hoover Dam
Physical Parameters							
Temperature (°C)	N/A	26	21.4	23.3	23.3	25.1	12.7
pH-field (SU)	N/A	27	7.53	7.70	7.66	7.79	7.9
pH-lab (SU)	0.01	28	7.45	7.60	7.60	7.74	--
Turbidity (NTU)	0.01	28	-1.62	0.27	5.17	12.0	3.2
General Mineral Characteristics							
Total Alkalinity	2.0	28	141	148	169	197	137
Phen. Alkalinity	2.0	0	> 75% of data below MRL				--
SC-field (F S/cm)	N/A	28	598	650	805	1012	929
SC-lab (F S/cm)	N/A	28	606	640	824	1042	--
Hardness-lab	10.0	28	192	215	285	377	--
Hardness-calc.	--	28	189	215	281	373	--
TDS	10.0	28	375	393	519	664	600
Major Ions							
Calcium	5.0	28	45	55	71	97	69
Magnesium	1.0	28	18	20	25	33	25
Sodium	5.0	28	45	50	62	78	80
Potassium	0.5	28	3.7	4.3	4.8	5.9	4.0
Bicarbonate	2.0	28	170	175	204	239	154
Carbonate	2.0	0	> 75% of data below MRL				--
Chloride	1.0	28	45	55	84	122	70
Sulfate	10.0	28	57	48	125	193	222
Nutrients							
Nitrate (as N)	0.02	26	2.2	2.9	3.7	5.2	0.37
Nitrite (as N)	0.02	2	> 75% of data below MRL				--
TKN	0.05	16	0.07	0.08	0.13	0.19	0.13
Total Phosphorus	0.02	6	> 75% of data below MRL				--

All units mg/L except where noted with physical parameters

Table 3. Summary Statistics for DET Groundwater Quality Data--Continued

Constituent	Minimum Reporting Limit (MRL)	Number of Samples Over MRL	Lower 95% Confidence Interval	Median	Mean	Upper 95% Confidence Interval	Mean of Colorado River below Hoover Dam
Trace Elements							
Antimony	0.005	0		> 75% of data below MRL			–
Arsenic	0.01	3		> 75% of data below MRL			–
Barium	0.1	3		> 75% of data below MRL			0.09
Beryllium	0.0005	0		> 75% of data below MRL			–
Boron	0.1	19	0.11	0.15	0.16	0.22	0.11
Cadmium	0.001	0		> 75% of data below MRL			–
Chromium	0.01	10	0.008	0.005	0.013	0.017	--
Copper	0.01	1		> 75% of data below MRL			–
Fluoride	0.20	28	0.68	0.83	0.85	1.02	0.30
Iron	0.1	3		> 75% of data below MRL			–
Lead	0.005	1		> 75% of data below MRL			–
Manganese	0.05	3		> 75% of data below MRL			0.28
Mercury	0.0005	0		> 75% of data below MRL			–
Nickel	0.1	0		> 75% of data below MRL			–
Selenium	0.005	1		> 75% of data below MRL			–
Silver	0.001	0		> 75% of data below MRL			–
Thallium	0.005	0		> 75% of data below MRL			–
Zinc	0.05	12	0.023	0.025	0.026	0.499	--
Radiochemical Constituents							
Radon*	Varies	13	-29	428	729	1488	--
Gross Alpha*	Varies	11	3.3	4.7	10.8	18.2	--
Gross Beta*	Varies	--		> 75% of data below MRL			–
Ra-226*	Varies	--		> 75% of data below MRL			–
Ra-228*	Varies	--		> 75% of data below MRL			–
Uranium**	Varies	--		> 75% of data below MRL			–

All units mg/L except * = piC/L and ** = F g/L

Colorado River water quality data is a mean of four samples collected by the U.S. Geological Survey between December 2001 and August 29, 2002 at gaging station (09421500) located in powerhouse at downstream side of Hoover Dam. Source: ⁴⁷

GROUNDWATER COMPOSITION

Groundwater in the DET was characterized by qualitative classifications, chemistry, and cross-correlation of constituent concentrations.

General Summary - Groundwater in the DET is generally *fresh*, *slightly alkaline*, and *moderately hard* to *very hard* as indicated by TDS, pH, and hardness concentrations.

TDS concentrations (**Map 5**) were considered *fresh* (below 1,000 mg/L) at 26 sites while 2 sites were *slightly saline* (1,000 to 3,000 mg/L).²² Levels of pH (**Map 7**) were *slightly acidic* (below 7 SU) at 2 sites and *slightly alkaline* (above 7 SU) at 25 sites.²² Hardness concentrations (**Map 8**) were divided into *soft* (0 sites), *moderately hard* (7 sites), *hard* (10 sites), and *very hard* (11 sites).¹⁶

Nutrient concentrations were generally low with nitrate, TKN, and total phosphorus detected at more than 10 percent of the sites. Nitrate (as nitrogen) concentrations (**Map 4**) were divided into *natural background* (5 sites at < 0.2 mg/L), *may or may not indicate human influence* (9 sites between 0.2 - 3.0 mg/L), *may result from human activities* (11 sites between 3.0 - 10 mg/L), and *probably result from human activities* (3 sites > 10 mg/L).²⁹

Most trace elements such as antimony, arsenic, barium, beryllium, cadmium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, and thallium were rarely—if ever—detected. Only boron, chromium (**Map 9**), fluoride, and zinc were detected at more than 25 percent of the sites.

Groundwater Chemistry - The chemical composition of sites is shown in **Map 10** and illustrated using Piper trilinear diagrams (**Figure 13**):

- < The cation triangle diagram (lower left in **Figure 13**) shows that the dominant (> 50 percent) cation is calcium at 8 sites, sodium at 4 sites, magnesium at 1 site, and is mixed at 15 sites.
- < The anion triangle diagram (lower right in **Figure 13**) shows that the dominant anion (> 50 percent) is bicarbonate at 15 sites, sulfate at 4 sites, chloride at 0 sites, and is mixed at 9 sites.

- < The cation-anion diamond diagram (in center of **Figure 13**) shows that the groundwater chemistry is *mixed-mixed* at 8 sites, *mixed-bicarbonate* and *calcium-bicarbonate* at 6 sites apiece, *calcium-sulfate*, *mixed-sulfate*, and *sodium-mixed* at 2 sites apiece, and *sodium-bicarbonate* and *sodium-sulfate* at 1 site apiece.

The Piper trilinear diagrams revealed some general groundwater chemistry patterns among sample sites. Sites in the *Lake Mead aquifer* tended to be of *sodium* or *mixed-sulfate* chemistry. Springs or shallow wells in *hardrock* were typically a *calcium-bicarbonate* chemistry with the exception of DET- 21/22 which had high concentrations of chloride and sulfate. *Alluvial aquifer* sites exhibited a wide *mixed* or *sodium-mixed* or *bicarbonate* chemistry range.

Constituent Covariation - The covariation of constituent concentrations were determined to scrutinize the strength of the association. The results of each combination of constituents were examined for statistically-significant positive or negative correlations. A **positive correlation** occurs when, as the level of a constituent increases or decreases, the concentration of another constituent also correspondingly increases or decreases. A **negative correlation** occurs when, as the concentration of a constituent increases, the concentration of another constituent decreases, and vice-versa. A positive correlation indicates a direct relationship between constituent concentrations; a negative correlation indicates an inverse relationship.

Many significant correlations occurred among the 28 DET sites. TDS and SC were positively correlated with major ions (calcium, magnesium, sodium, potassium, chloride, and sulfate) as well as with hardness, turbidity, and boron (Pearson Correlation Coefficient test, p# 0.05). TDS concentrations are best predicted among major ions by calcium concentrations (**Figure 14**). Similarly, among cations, calcium plays the greatest role in predicting TDS concentrations while among anions, sulfate (**Figure 15**) is the best predictor (multiple regression analysis, p# 0.01).

Among the major ions, calcium, magnesium, potassium, chloride, and sulfate were all positively correlated with one another. In contrast, sodium was only positively correlated with magnesium.

- = Lake Mead aquifer sites
- ▲ = Deep alluvial wells
- ▼ = Shallow alluvial wells
- x = Deep hardrock wells
- + = Shallow hardrock wells
- * = Hardrock wells

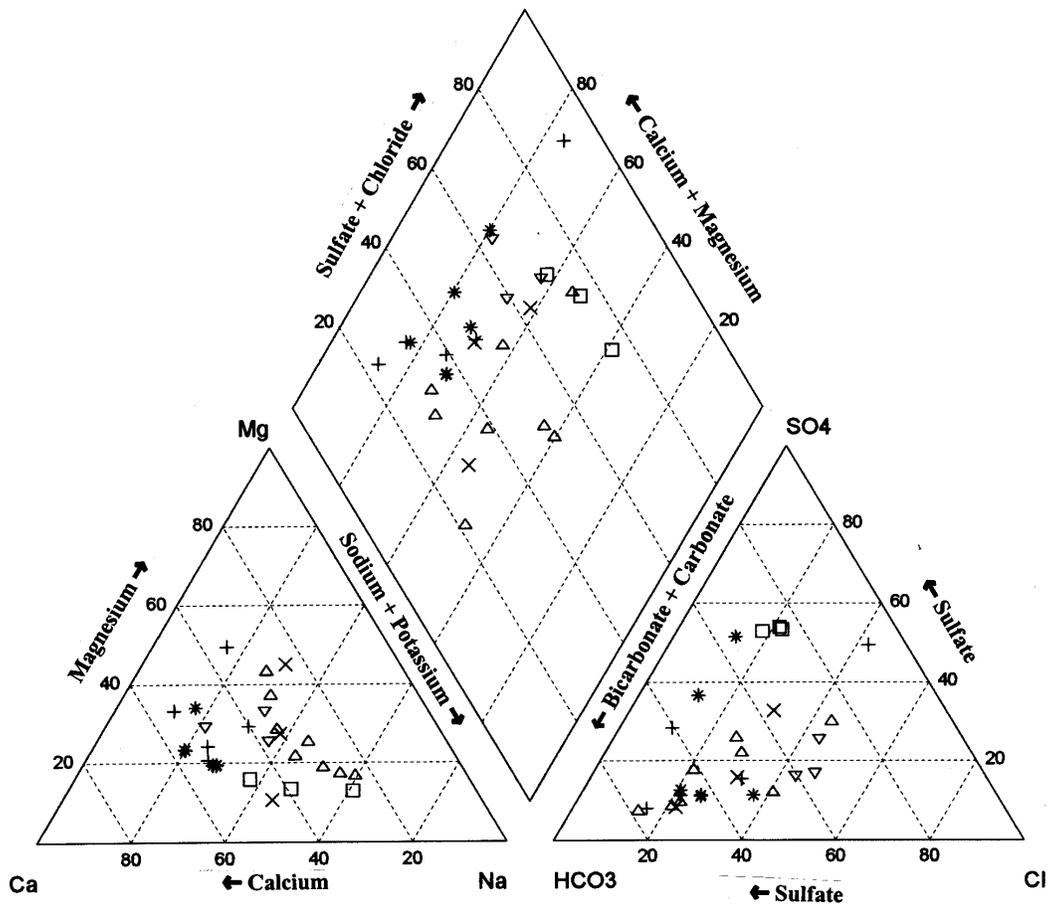
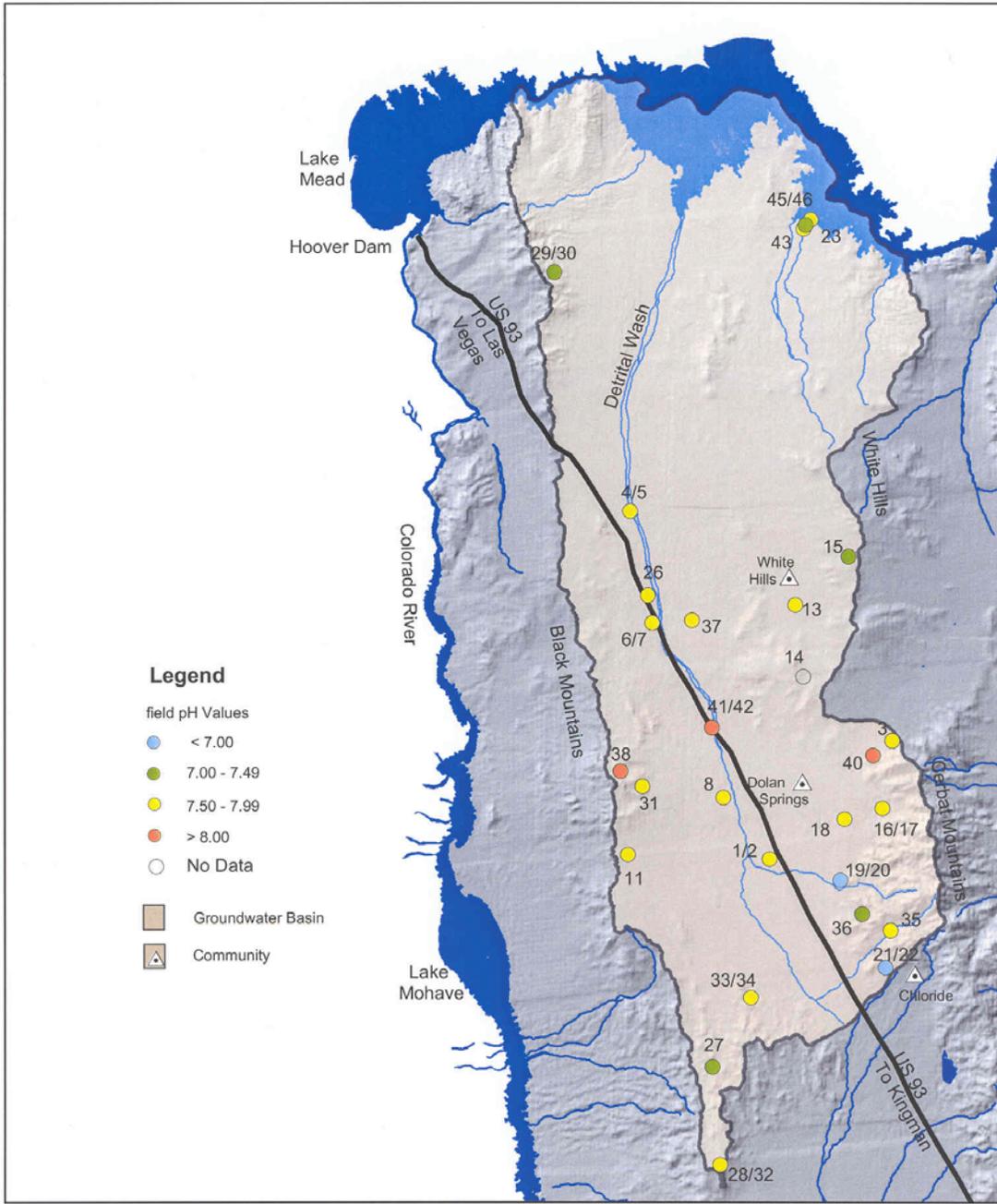


Figure 13. Groundwater chemistry of sample sites.

Map 7. Detrital Valley Basin - field pH



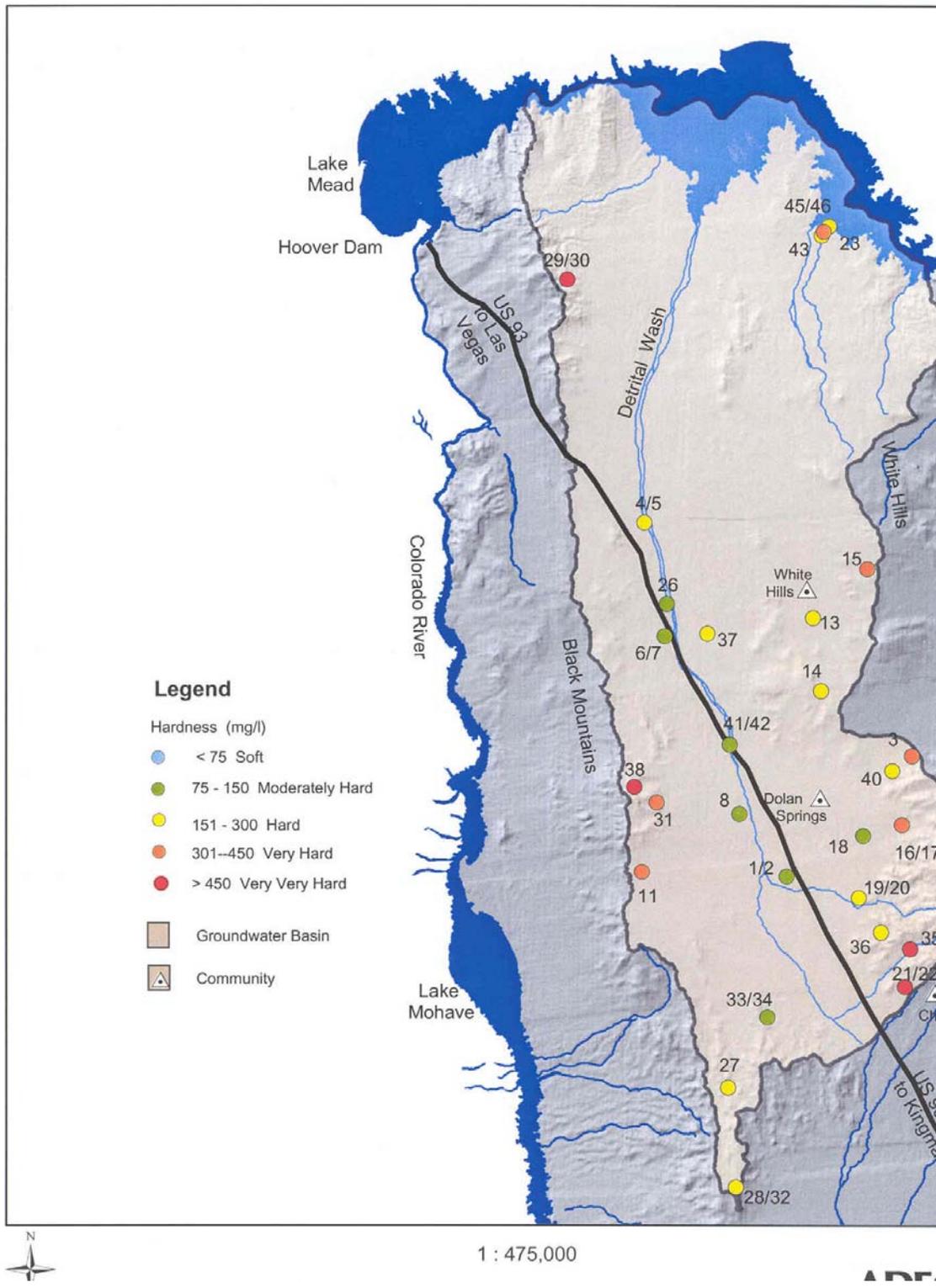
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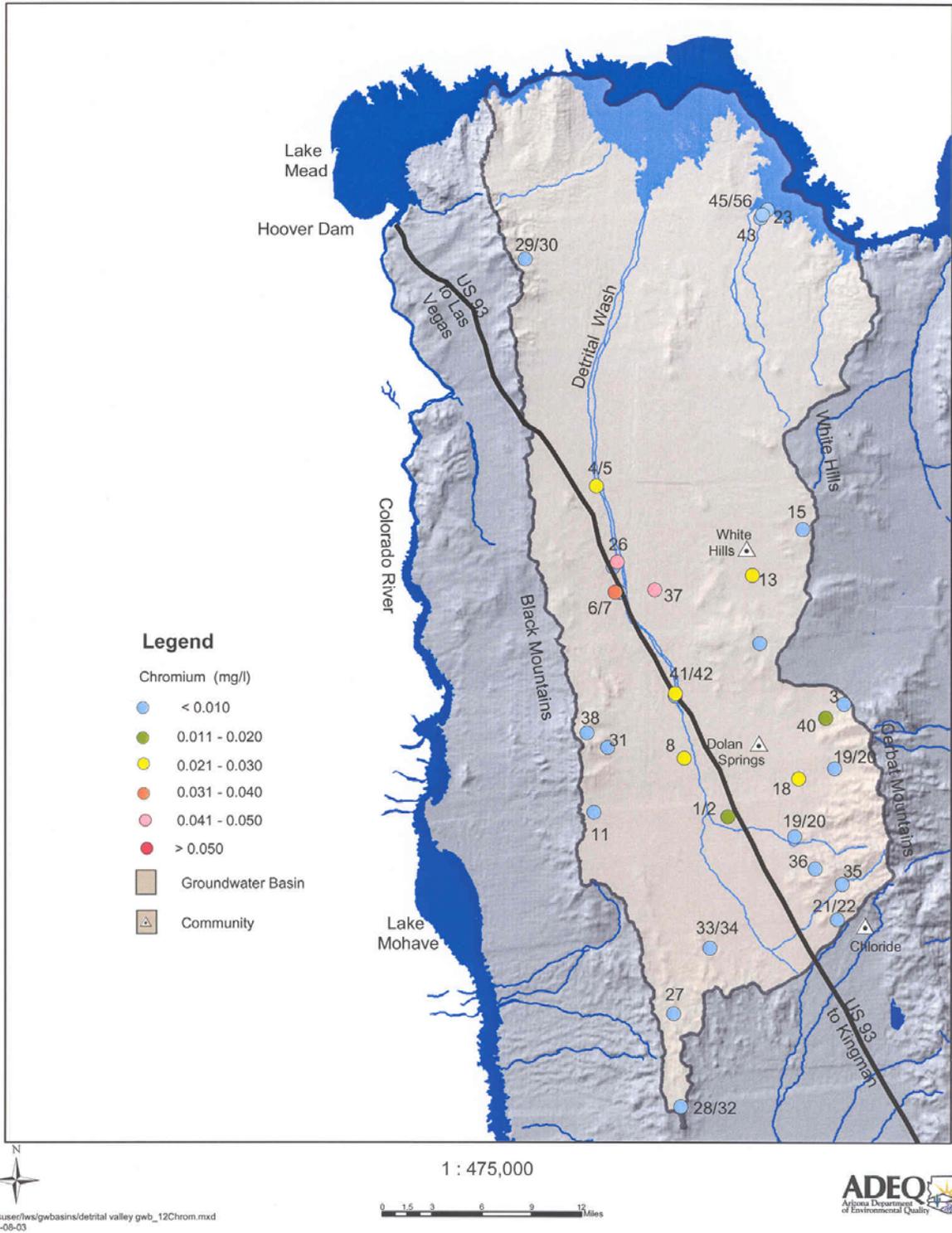
0 1.5 3 6 9 12 Miles



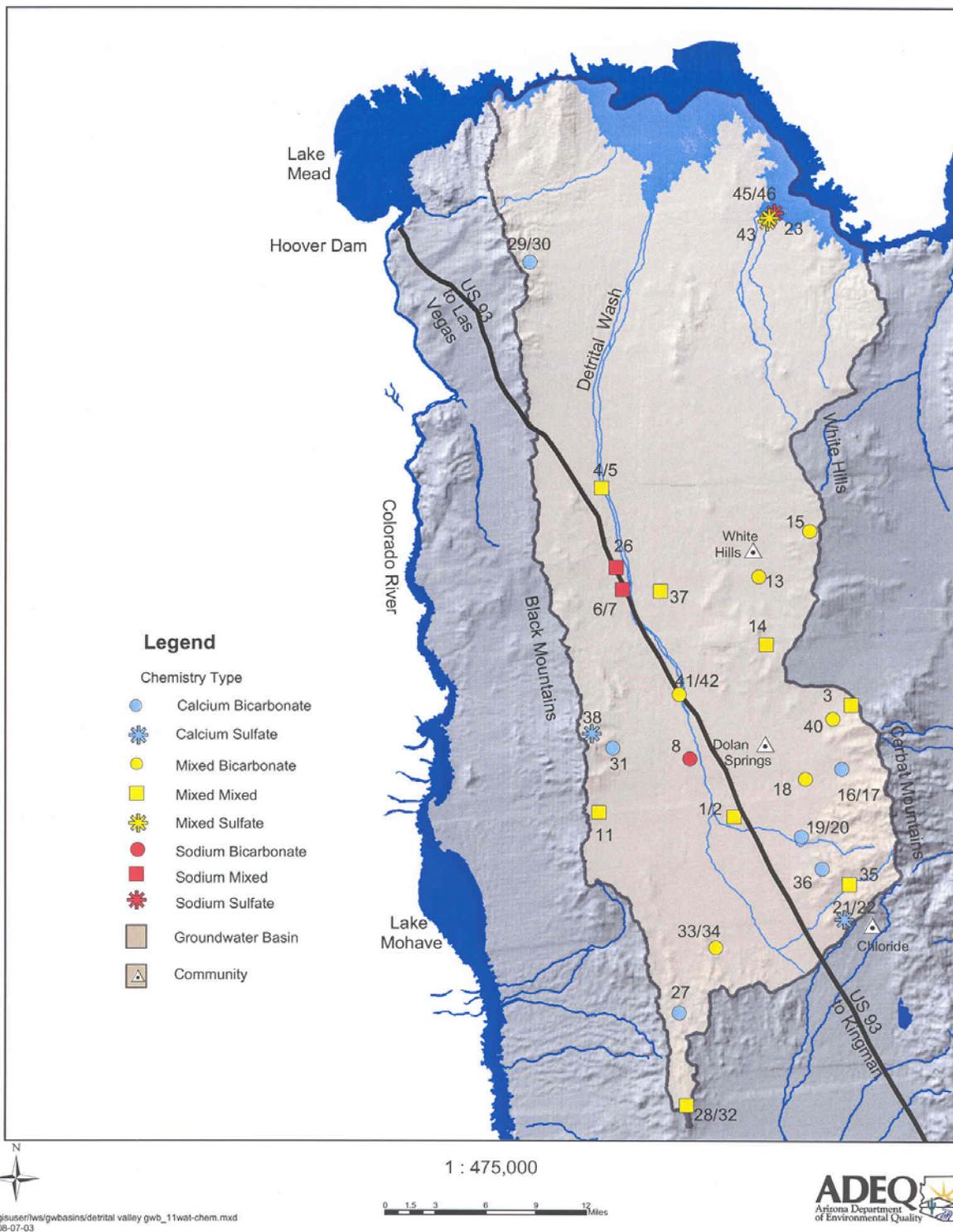
Map 8. Detrital Valley GW Basin - Hardness



Map 9. Detrital Valley GW Basin -Chromium



Map 10. Detrital Valley GW Basin - Water Chemistry



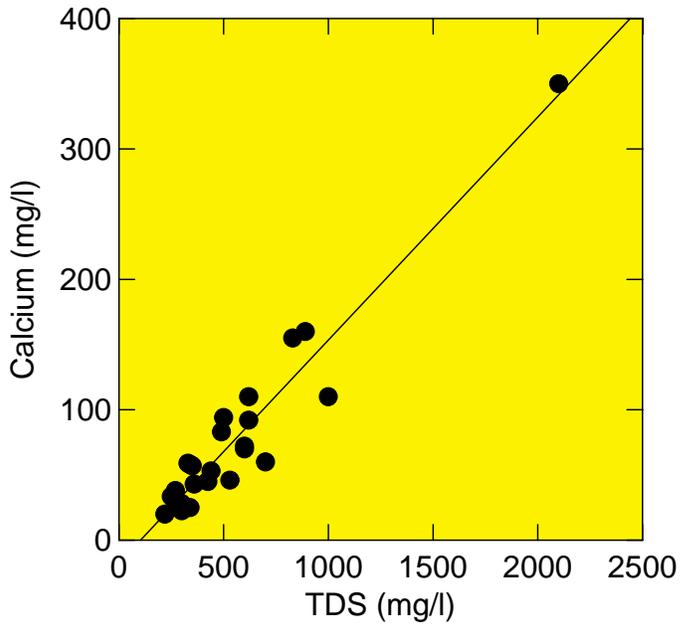


Figure 14. Of all the major ions, calcium concentrations are the best predictor of TDS concentrations in the DET (multiple regression, $p \# 0.01$). The regression equation for this relationship is $y = 0.17x - 18$, $r = 0.92$, $n = 28$.

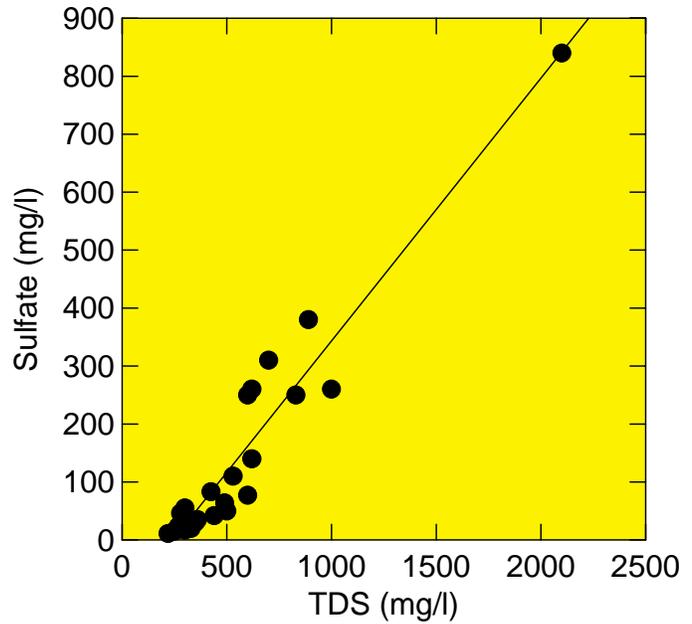


Figure 15. Of all the anions, sulfate concentrations are the best predictor of TDS concentrations in the DET (multiple regression, $p \# 0.01$). The regression equation for this relationship is $y = 0.45x - 110$, $r = 0.93$, $n = 28$.

Other significant correlations included boron positively correlated with both magnesium and sodium; calcium positively correlated with TKN; radon positively correlated with zinc and gross alpha; temperature positively correlated with potassium; oxygen-18 positively correlated with deuterium; and pH-field negatively correlated with TKN (Pearson Correlation Coefficient test, $p \# 0.05$).

Constituent Covariation with Groundwater Depth

The constituent concentrations of the sample sites were compared to the corresponding groundwater depth for each DET sample site. Depth was determined using a sounder in the field or data from ADWR well registration records.⁸

Comparisons were made using three distinct methods: a linear model, an exponential model, and a biphasic model. The linear model compares constituent concentrations to groundwater depth, the exponential model compares the log-transformed constituent concentrations to groundwater depth, and the biphasic model compares the log-transformed constituent concentrations to log-transformed groundwater depth.

The overall results, which are provided in **Table 4**, indicate that 15 of the 27 groundwater quality constituents examined had one or more mathematical equations significantly relating constituent concentrations to groundwater depth (regression analysis, $p \# 0.05$). Of these significant relationships, most constituents, such as TDS (**Figure 16**), had concentrations decreasing with increasing groundwater depth below land surface (bls). In contrast, a few constituents such as pH-field (**Figure 17**) increased with increasing groundwater depth bls.

GROUNDWATER QUALITY PATTERNS

Groundwater in the DET was characterized by assessing the spatial variation of groundwater quality among aquifers, watersheds, and rock types.

Aquifer Comparison - The DET can be divided into three water-bearing units:

- An *alluvial aquifer* composed of basin-fill material .

- Mountain *bedrock* composed of volcanic, granitic, metamorphic, basaltic or sedimentary rock with limited water production potential where sufficiently fractured or faulted.
- The *Lake Mead aquifer* that receives recharge from this reservoir on the Colorado River, was identified in this study through the use of isotopes.

Analytical results were compared between these three water-bearing units to identify significant differences in concentrations of groundwater quality constituents. Many significant differences were found, such as with bicarbonate/hardness, illustrated in **Figure 18**. The results are in **Table 5** (ANOVA test with Tukey option, $p \# 0.05$). The 95% confidence intervals for constituent concentrations of each DET water bearing unit found to be significantly different are in **Table 6**.

Watershed Comparison - The DET includes drainage areas to the west in the Black Mountains and the Cerbat Mountains to the east. These drainage areas were compared to examine for significant recharge differences in each watershed. Only TKN and arsenic had significant watershed differences, with higher concentrations found in the western Black Mountains watershed than the eastern Cerbat Mountain watershed (ANOVA test, $p \# 0.05$).

Geological Comparison - The DET can be divided into six geologic classifications: alluvium, basaltic, granitic, metamorphic, sedimentary, and volcanic (**Map 2**).⁴² Analytical results were examined for differences in concentrations of groundwater quality constituents among the six geologic classifications. Many significant patterns were revealed with this geological comparison, such as with fluoride (**Figure 19**). Data are provided in **Table 6** (ANOVA test with the Tukey test, $p \# 0.05$).

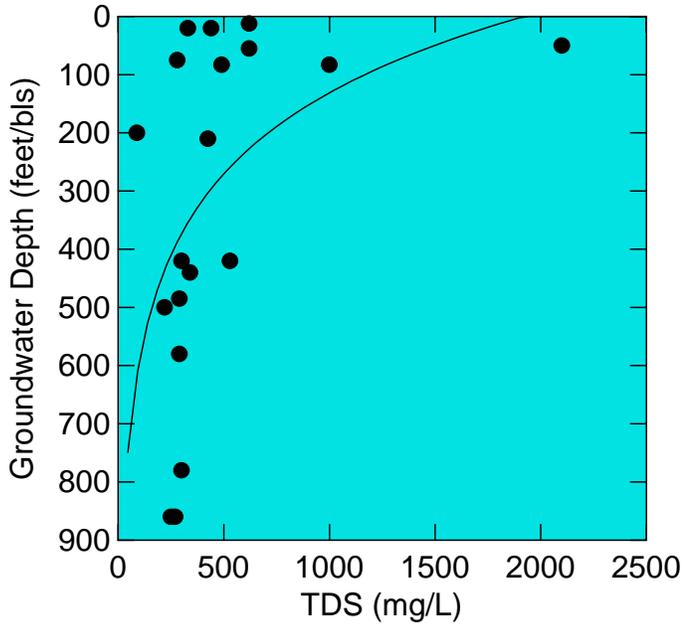


Figure 16. Many groundwater quality constituents had decreasing concentrations with increasing groundwater depth bls (regression, $p \# 0.01$). This relationship is often the result of well location. TDS concentrations are generally constant in alluvial aquifer (groundwater depth >400 feet bls) wells; in contrast, TDS concentrations are more variable in shallow hardrock wells.

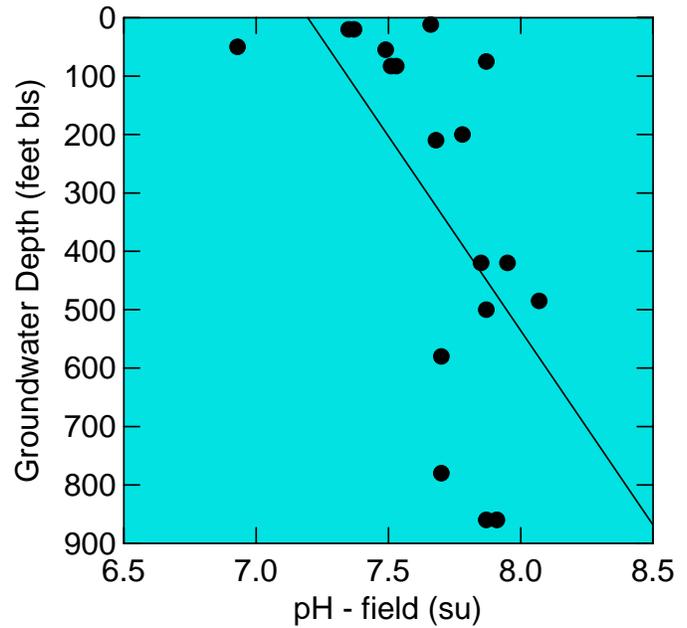


Figure 17. A few constituents such as temperature, nitrate, chromium, and pH-field increased with increasing groundwater depth bls. These relationships are often the result of well location. PH levels are generally constant in alluvial aquifer (groundwater depth > 400 feet bls) wells and are more variable in shallow hardrock wells.

Table 4. Relationship Between Groundwater Quality Constituent Concentrations and Groundwater Depth Using Three Mathematical Models

Parameter	Significance	Type of Relationship	Most Significant Model
Temperature - field	**	Increasing with depth bls	Biphasic
pH - field	**	Increasing with depth bls	Linear
pH - lab	ns		
SC - field	**	Decreasing with depth bls	Exponential
SC - lab	**	Decreasing with depth bls	Exponential
Turbidity	ns		
TDS	**	Decreasing with depth bls	Exponential
Total Alkalinity	**	Decreasing with depth bls	Biphasic
Bicarbonate	**	Decreasing with depth bls	Biphasic
Calcium	**	Decreasing with depth bls	Biphasic
Magnesium	**	Decreasing with depth bls	Exponential
Hardness	**	Decreasing with depth bls	Biphasic
Hardness (calculated)	**	Decreasing with depth bls	Exponential
Sodium	ns		
Potassium	ns		
Chloride	*	Decreasing with depth bls	Exponential
Sulfate	*	Decreasing with depth bls	Exponential
Fluoride	ns		
Nitrate (as N)	*	Increasing with depth bls	Biphasic
TKN	ns		
Total Phosphorus	ns		
Boron	ns		
Arsenic	ns		
Chromium	**	Increasing with depth bls	Biphasic
Zinc	ns		
Gross alpha	ns		
Radon	ns		

ns = not significant
 * = significant at p # 0.05
 ** = significant at p # 0.01
 bls = below land surface

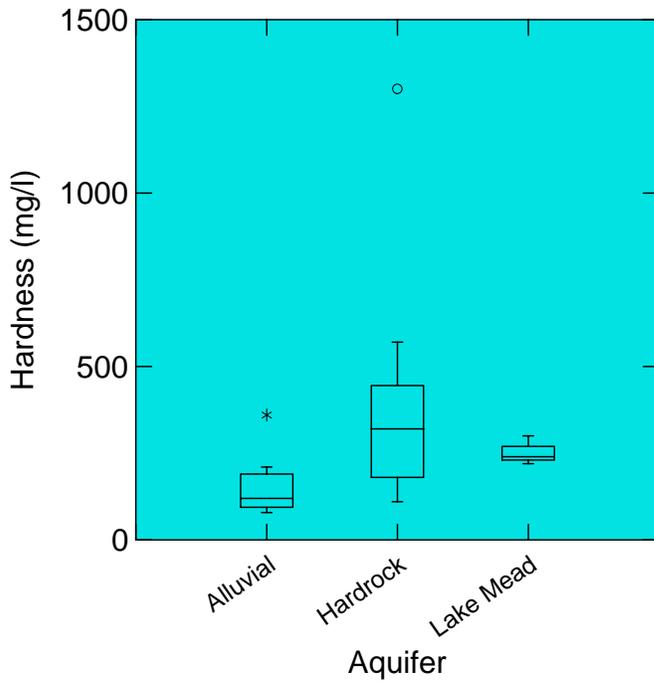


Figure 18. Hardness concentrations are higher in hardrock than in the alluvial aquifer; concentrations in the Lake Mead aquifer are not significantly different from either (ANOVA with Tukey test, $p \neq 0.05$).

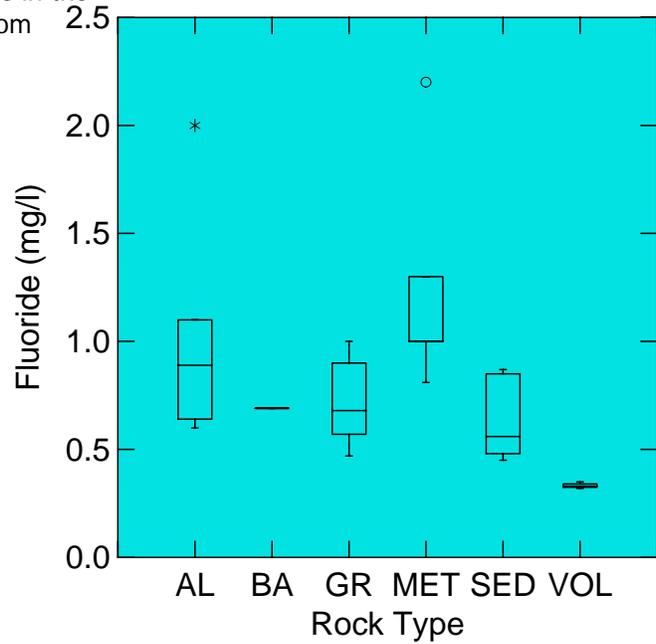


Figure 19. Fluoride concentrations vary by geologic type although the only significant differences are that alluvial and metamorphic rock sites are higher than in volcanic rock (ANOVA with the Tukey test, $p \neq 0.05$).

Table 5. Variation in Groundwater Quality Constituent Concentrations Among Three DET Water-Bearing Units Using Transformed Data with the ANOVA and Tukey Tests

Constituent	Significance	Water-Bearing Unit Significant Differences
Oxygen-18	**	Lake Mead > Alluvium, Hardrock
Deuterium	**	Lake Mead > Alluvium, Hardrock
Temperature - f	**	Alluvial > Hardrock
pH - f	ns	
pH - lab	ns	
SC - f	ns	
SC - lab	ns	
Turbidity	ns	
TDS	ns	
Total Alkalinity	**	Hardrock > Alluvial
Bicarbonate	**	Hardrock > Alluvial
Calcium	**	Hardrock > Alluvial
Magnesium	ns	
Hardness	**	Hardrock > Alluvial
Sodium	*	Lake Mead > Hardrock
Potassium	ns	
Chloride	ns	
Sulfate	*	Lake Mead > Alluvial
Fluoride	*	Alluvial > Lake Mead
Nitrate (as N)	**	Alluvial > Hardrock
TKN	ns	
Total Phosphorus	ns	
Boron	*	Lake Mead > Hardrock
Arsenic	ns	
Chromium	**	Alluvial > Hardrock & Lake Mead
Zinc	ns	
Gross alpha	ns	
Radon	ns	

ns = not significant

* = significant at p # 0.05

** = significant at p # 0.01

Table 6. Summary Statistics for Groundwater Quality Constituents With Significant Concentration Differences Among Three DET Water Bearing Units

Constituent	Significant Differences	Alluvial 95% Confidence Intervals	Hardrock 95% Confidence Intervals	Lake Mead 95% Confidence Intervals
Oxygen-18	Lake Mead > Alluvium, Hardrock	-10.7 to -9.3	-10.5 to -9.1	-14.2 to -12.4
Deuterium	Lake Mead > Alluvium, Hardrock	-71.1 to -79.0	-70.7 to -77.3	-109.5 to -101.9
Temperature - f	Alluvial > Hardrock	26.0 to 28.5	17.3 to 22.3	-
pH - f	-	-	-	-
pH - lab	-	-	-	-
SC - f	-	-	-	-
SC - lab	-	-	-	-
Turbidity	-	-	-	-
TDS	-	-	-	-
Total Alkalinity	Hardrock > Alluvial	105 to 148	164 to 256	-
Bicarbonate	Hardrock > Alluvial	127 to 178	197 to 312	-
Calcium	Hardrock > Alluvial	24 to 52	47 to 145	-
Magnesium	-	-	-	-
Hardness	Hardrock > Alluvial	110 to 230	193 to 546	-
Sodium	Lake Mead > Hardrock	-	30 to 88	22 to 205
Potassium	-	-	-	-
Chloride	-	-	-	-
Sulfate	Lake Mead > Alluvial	28 to 71	-	199 to 345
Fluoride	Alluvial > Lake Mead	0.71 to 1.43	-	0.32 to 0.69
Nitrate (as N)	Alluvial > Hardrock	3.6 to 9.0	0.6 to 4.1	-
TKN	-	-	-	-
T. Phosphorus	-	-	-	-
Boron	Lake Mead > Hardrock	-	0.07 to 0.16	-0.29 to 1.01
Arsenic	-	-	-	-
Chromium	Alluvial > Hardrock & Lake Mead	0.015 to 0.032	0.005 to 0.006	0.005 to 0.005
Zinc	-	-	-	-
Gross alpha	-	-	-	-
Radon	-	-	-	-

Table 7. Variation in Groundwater Quality Constituent Concentrations Among Six DET Geologic Units Using Transformed Data with the ANOVA and Tukey Tests

Constituent	Significance	Geologic Unit Significant Differences
Oxygen-18	*	Basaltic > Sedimentary
Deuterium	*	Alluvium, Basaltic, Granitic, Volcanic > Sedimentary
Temperature - f	**	Alluvium > Granitic
pH - f	ns	
pH - lab	ns	
SC - f	*	Metamorphic > Alluvium
SC - lab	*	Metamorphic > Alluvium
Turbidity	ns	
TDS	*	Metamorphic > Alluvium
Total Alkalinity	**	Granitic, Metamorphic > Alluvium ; Metamorphic > Sedimentary, Volcanic
Bicarbonate	**	Granitic, Metamorphic > Alluvium ; Metamorphic > Sedimentary, Volcanic
Calcium	**	Granitic, Metamorphic > Alluvium
Magnesium	**	Granitic, Metamorphic > Alluvium
Hardness	**	Granitic, Metamorphic > Alluvium
Sodium	ns	
Potassium	ns	
Chloride	ns	
Sulfate	ns	
Fluoride	**	Metamorphic, Alluvium > Volcanic
Nitrate (as N)	ns	
TKN	ns	
Total Phosphorus	ns	
Boron	ns	
Arsenic	ns	
Chromium	**	Alluvium > Granitic, Metamorphic, Sedimentary & Volcanic
Zinc	ns	
Gross alpha	ns	
Radon gas	ns	

ns = not significant

* = significant at p # 0.05

** = significant at p # 0.01

Isotope Comparison - Groundwater characterizations using oxygen and hydrogen isotope data may be made with respect to the climate and/or elevation where the water originated, residence within the aquifer, and whether or not the water was exposed to extensive evaporation prior to collection.¹⁴

These characterizations are made by comparing oxygen-18 isotopes ($\delta^{18}\text{O}$) and deuterium (δD), an isotope of hydrogen, data to the Global Meteoric Water Line (GMWL). The GMWL is described by the linear equation: $\delta\text{D} = 8\delta^{18}\text{O} + 10$ where δD is deuterium in parts per thousand (per mil, ‰), 8 is the slope of the line, $\delta^{18}\text{O}$ is oxygen-18 ‰, and 10 is the y-intercept.¹⁴ The GMWL is the standard by which water samples are compared and represents the best fit isotopic analysis of numerous worldwide water samples.

Isotopic data from a region may be plotted to create a Local Meteoric Water Line (LMWL) which is affected by varying climatic and geographic factors. When the LMWL is compared to the GMWL, inferences may be made about the origin or history of the local water.¹⁴

The LMWL created by $\delta^{18}\text{O}$ and δD values for samples collected at sites in the DET were compared to the GMWL. The δD and $\delta^{18}\text{O}$ data lie to the right of the GMWL (**Figure 20**). Meteoric waters exposed to evaporation characteristically plot increasingly below and to the right of the GMWL. Evaporation tends to preferentially contain a higher percentage of lighter isotopes in the vapor phase and causes the water that remains behind to be isotopically heavier.¹⁴

Groundwater from arid environments is typically subject to evaporation which enriches δD and $\delta^{18}\text{O}$ resulting in a lower slope value (usually between 3 and 6) as compared to the slope of 8 associated with the GMWL.¹⁴ The data for the arid DET conform to this theory, having a slope of 5.15, with the LMWL described by the linear equation:

$$\delta\text{D} = 5.15^{18}\text{O} - 20.8$$

The DET isotope data fall into three general groups.

The most *depleted*, or isotopically lighter sites, were the three sites (two wells and one spring) located near Temple Bar along Lake Mead (**Figure 20**). These sites appear to be producing water which is essentially Colorado River water stored behind Hoover Dam, a conclusion supported by samples collected from Lake

Mead. This lake sample has a similar isotopic signature though slightly to the right indicating an evaporative shift due to the collection at the edge of the reservoir during a time of receding lake levels. Isotopic data from previous studies of Lake Mead are comparable to these obtained in this study.³⁵

Significant differences were found in the $\delta^{18}\text{O}$ and δD in these *Lake Mead aquifer* sites compared with sites in either *hardrock* or the *alluvial* aquifer (Kruskal-Wallis test in combination with a Tukey test, $p \# 0.01$). Based on this isotopic data, the sample sites near Temple Bar in the *Lake Mead aquifer* can be considered a separate water unit with recharge provided almost exclusively by precipitation occurring in the Upper Basin states of Wyoming, Colorado, Utah, and New Mexico and flowing down the Colorado River until temporarily stored in Lake Mead.

Previous studies indicate that the *Lake Mead aquifer* extends some distance up Detrital Wash, perhaps to the vicinity of Highway 93; however, that finding was not confirmed in this study, although tangential evidence supports that finding.⁵¹ Bibler Well, an inoperable windmill along Detrital Wash near the intersection of Highway 93 and Temple Bar Road, was sampled by lowering a bailer down the well casing; only an isotope sample was collected. The well could not be adequately purged and no other samples were collected. The isotopic signature of Bibler Well is slightly below that of the tight cluster of the *depleted* sites that may represent the oldest water in the basin. Thus, Bibler Well may be receiving some recharge from Lake Mead.

Sixteen sites form a tight data cluster in the center of the isotope graph. These *depleted* sites are the start of the evaporation trajectory and consist almost exclusively of deep wells located in or near the center of Detrital Valley or springs along the margins of the basin. This cluster may represent the oldest water in the basin, recharged during a time period cooler than the present. A similar pattern was found in the adjoining Sacramento Valley basin where the deepest well also was the most *depleted* site.⁴² Two shallow wells, Cow Camp Well and Lower Big Wash Windmill located in *bedrock*, were also in this cluster indicating these wells may be located in areas of shallow groundwater that receives minimal recent recharge.

Further up the evaporation trajectory are the remaining 10 sites that form a linear pattern. These are more *enriched* sites and typically consist of shallow wells, especially windmills located in canyons of the surrounding mountain ranges. This may represent more recent recharge that occurred during an arid climate. Two deep alluvial wells (DET-4/5 and DET-8) are within this linear pattern. Both wells are located near Detrital Wash which may be the recharge source. However, other wells are located near this wash do not show any isotopic evidence of recent recharge indicating this recharge may be moving from the mountains along specific pathways. These two wells may represent a mixture of recharge sources whereas the windmills higher up on the trajectory represent a greater percentage of recent recharge.

The most *enriched* site was a surface water sample collected from Detrital Wash after a precipitation event and represents the current

precipitation isotopic signature. The validity of this sample site from Detrital Wash was confirmed by the collection of a sample having a similar isotopic signature from the ephemeral Horsethief Canyon near Hoover Dam in the Black Mountains. This sample was also collected after local precipitation for a subsequent study in the Lake Mohave basin .⁴⁵

Significant differences were found in the $\delta^{18}\text{O}$ and δD when comparing the *Lake Mead aquifer* sites (3), *depleted* sites (16), and *enriched* sites (10). *Enriched* sites were greater than both *depleted* sites and *Lake Mohave* sites while *depleted* sites were greater than *Lake Mohave* sites (Kruskal-Wallis test in combination with a Tukey test, significant, $p \# 0.01$).

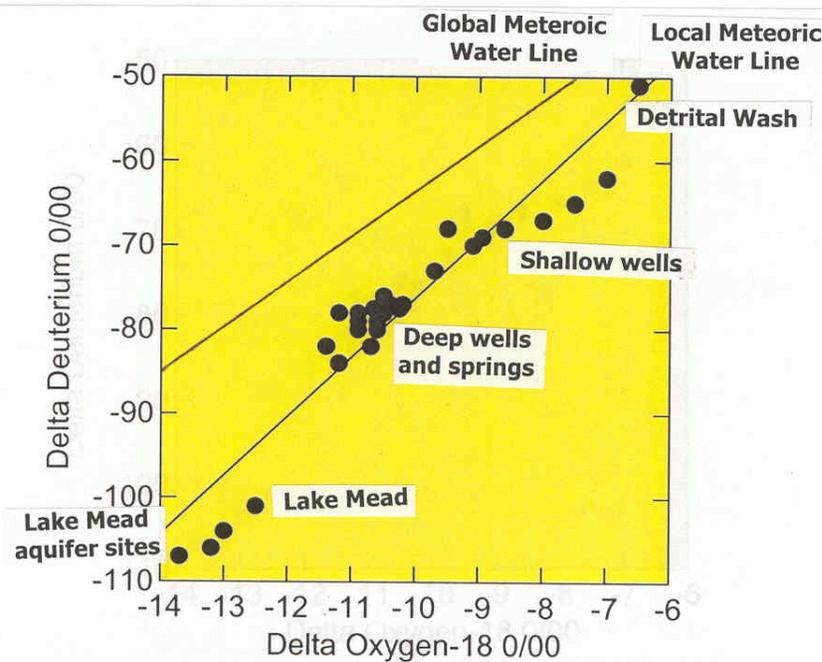


Figure 20. Values for oxygen-18 and deuterium isotopes for 29 Detrital Valley basin groundwater sites as well as surface water samples from Lake Mead and Detrital Wash are shown above. The most depleted sites are from Lake Mead and the Lake Mead aquifer. Higher on the evaporation trajectory is a cluster of deep wells and springs which may represent the oldest groundwater in the basin. The remaining sites are mostly shallow wells that may be receiving limited recent recharge as judged by the isotopic signature of the most enriched sample from Detrital Wash.

Time-Trend Analysis

Groundwater quality data collected as part of this study was compared to historical sampling conducted by ADWR and/or the USGS to determine the variation over time in constituent concentrations.³⁰ Six sites sampled by ADEQ for this study were identified as having historical data. The amount of historical data at sites varied widely. Scales Well (DET-8) has been sampled for a wide variety of constituents on 17 occasions between 1985 and 2001. At the other extreme, South Well (DET-11) and Twin Well (DET-27) had only physical parameters recorded in 1984. Constituent comparisons of sites having historical data are provided in **Table 7**. Historical groundwater quality data comparisons may be generally grouped into three categories: those showing little variability, those showing great variability, and those sites not having enough data to properly assess the variability.

An example of the former is Scales Well, a 650 foot deep well in Detrital Valley. This well (DET-8) has a long, comprehensive sampling history that showed little constituent concentration variability over the almost 20-year sampling period. All the constituents compared showed less than 5 percent difference between the mean of the historical constituent concentrations and the 2002 ADEQ results. An example of the latter are sample sites such as South Well (DET-11), Twin Wells (DET-27), and Monkey Cove Spring (DET-45/46) which have limited data from which few conclusions can be drawn.

A site which appears to show significant variability in constituent concentrations is DET-23 (Lower #3 Well), a well; of moderate depth (240 feet bls) located adjacent to Lake Mead at Temple Bar. Generally, the well has evolved to a more calcium-dominated chemistry. This variability associated with the Temple Bar wells may be due to impacts from the filling of Lake Mead beginning in 1935. Although the reservoir was at capacity by 1942, periods of drought from 1944 through 1957, 1961 through 1972, and from 2000 to the present, brought low levels to Lake Mead.³⁶

By the time the historical samples were collected at the Temple Bar wells in the late 1960s and early 1970s, impacts from Colorado River water stored in Lake Mead would have impacted the native groundwater in the Temple Bar area, though not to the extent that sampling by ADEQ in 2002 would have shown after a long period of high reservoir levels.

Another site exhibiting significant variability was Missouri Spring located in the Mt. Wilson Wilderness within the Black Mountains. Since 1972, the TDS concentration almost doubled from 429 mg/l to 830 mg/l. From site observations, Missouri Spring was homesteaded in the early 20th century with limited mining taking place in the vicinity, which may account for the elevated sulfate concentrations. The increasing constituent concentrations may be due to Missouri Spring producing lower volumes of discharge that are more saline during the current drought period when the study occurred. However, since the Temple Bar well and Missouri Spring are based on limited historical samples, caution should be exercised in accepting conclusions from the data.

For a more comprehensive evaluation of groundwater quality changes over time, data from the 2002 ADEQ study were compared with similar data collected for the most comprehensive previous study, a 1982 study produced for the Bureau of Land Management.¹⁹ Comparable numbers of sites were sampled in each study: 24 sites for the 1982 study and 28 sites for the 2002 study. The 2002 sample sites tended to be spread throughout the basin. In contrast, the 1982 sample sites had clusters around Dolan Springs and the Boulder Inn; no samples were collected from sites in the *Lake Mead aquifer*.¹⁹ There did not conclusively appear to be a well and/or spring that was sampled in both studies. The 1982 study does not provide ADWR well registration numbers for sampled sites making well matching difficult.

For both studies, a basic statistical analysis (95 percent confidence intervals, mean, and median) is provided for constituents common to both studies (**Table 8**). Empirically examining these statistical measures found similar results. For further statistical examination of time-trends, an ANOVA test was used to examine for significant differences between the two data sets. Only pH-field values were found to significantly differ between 1982 and 2002 (ANOVA test, p # 0.05).

Reasons for the pH-field changes can be found in the field methodology in the 1982 report. Sometimes, water stored in pipes or tanks was collected if the well could not be pumped to obtain groundwater fresh from the aquifer.¹⁹ Typically, once water that is under pressure is pumped from the aquifer, out-gassing occurs and the pH is likely to be altered, usually increasing, by pumping and storage.²⁴

Table 8. Time-Trend Comparison of DET Sample Sites Using Historical USGS / ADWR Data

Constituent	DET-8		DET-11		DET-23		DET-27		DET-29/30		DET-45/46	
	Number of samples collected from site / Time span over which sampling occurred											
	17 / 1985-01		1 / 1984		4 / 1967		1 / 1984		2 / 1972-87		1 / 1964	
Percentage difference / Absolute difference												
General Mineral Characteristics												
Temp. (°C)	4 %	2.2	12 %	6.1	3 %	1.6	7 %	2.8	9 %	3.0	22 %	8.3
pH - field (su)	1 %	0.2			1 %	0.2			0 %	0.1		
pH - lab (su)	3 %	0.48										
SC - f (F/S/cm)	0 %	1	4 %	88	11 %	167	8 %	75	29 %	544		
SC - lab (F/S/cm)	2 %	10										
TDS	1 %	5			13 %	140			32 %	401	18 %	215
Alk, Total	2 %	4										
Hardness	2 %	3			40 %	170			30 %	240	1 %	6
Major ions												
Calcium	4 %	1.5			40 %	53			34 %	79	6 %	7
Magnesium	1 %	0.2			42 %	27			29 %	17.5	8 %	2.5
Sodium	1 %	1			13 %	25			27 %	29		
Potassium	2 %	0.1			3 %	0.2			15 %	3.3		
Bicarbonate											19 %	58
Chloride	3 %	1			31 %	31			33 %	32	27 %	30
Sulfate	0 %	0			16 %	70			63 %	193		
Nutrients												
Nitrate	3 %	0.3			28 %	0.52			50 %	1		
Trace Elements												
Arsenic					11 %	0.003						
Fluoride	3 %	0.04	0 %	0	19 %	0.22	3 %	0.02	15 %	0.18		

Source: ³¹

Note: For multiple samples from the same site, the constituent mean was used to compare to 2002 ADEQ data. All units mg/L except where noted with physical parameters and general mineral characteristics.

Table 9. Time-Trend Comparison of DET Sample Sites Using 1982 Geo/Resource Consultants Data

Constituent	Number of Samples	Lower 95% Confidence Interval	Median	Mean	Upper 95% Confidence Interval	Significance
Physical Parameters						
Temp. - 1982 (°C)	24	20.0	21.7	22.3	24.5	ns
Temp. - 2002 (°C)	26	21.4	23.3	23.3	25.1	
pH-field -1982 (su)	24	8.00	8.25	8.27	8.54	**
pH-field - 2002 (su)	27	7.53	7.70	7.66	7.79	
General Mineral Characteristics						
SC-f - 1982 (F S/cm)	24	548	526	882	1216	ns
SC-f - 2002 (F S/cm)	28	598	650	805	1012	
TDS - 1982	24	237	322	553	870	ns
TDS - 2002	28	375	393	519	664	
Major Ions						
Calcium - 1982	24	16	33	69	122	ns
Calcium - 2002	28	45	55	71	97	
Magnesium - 1982	24	11	18	28	45	ns
Magnesium - 2002	28	18	20	25	33	
Sodium - 1982	24	42	49	56	70	ns
Sodium - 2002	28	45	50	62	78	
Potassium - 1982	24	3.5	4.5	6.3	9.1	ns
Potassium - 2002	28	3.7	4.3	4.8	5.9	
Chloride - 1982	24	33	37	49	66	ns
Chloride - 2002	28	45	55	84	122	
Sulfate - 1982	24	- 42	43	161	365	ns
Sulfate - 2002	28	57	48	125	193	
Trace Elements						
Boron - 1982	24	0.13	0.14	0.18	0.22	ns
Boron - 2002	28	0.11	0.15	0.16	0.22	
Fluoride - 1982	24	0.76	0.80	1.04	1.32	ns
Fluoride - 2002	28	0.68	0.83	0.85	1.02	

Source: ¹⁹

All units mg/L except where noted with physical parameters and general mineral characteristics.

CONCLUSIONS

Groundwater Suitability for Domestic Use

Groundwater in the DET generally is suitable for domestic and/or municipal uses with 68 percent of sample sites (19 of 28) meeting all health-based water quality standards. Since three of the site exceedances involved revised arsenic standards that do not take effect until 2006, actually 79 percent of sample sites (22 of 28) currently meet all health-based water quality standards.

In addition, 61 percent of sample sites (11 of 28) meet all aesthetics-based water quality standards. Most of the sites that had aesthetics-based water quality exceedances could probably be used for domestic and/or municipal uses. Only one sample site (DET-21/22) has TDS, sulfate, chloride, iron, and manganese concentrations of the magnitude that would probably preclude this source being used for drinking water purposes.

These findings support previous studies that concluded that groundwater quality was moderate to good with some constituents, principally heavy metals, locally concentrated in areas affected by mining.^{18,19}

Discussion of Health-Based Exceedances

Nitrate, gross alpha, and arsenic (not under current standards, only under standards effective in 2006) each exceeded health-based water quality standards at three sites apiece.

Nitrate - Nitrate exceedances at two of the sample sites (DET-11 and DET-28/32) are likely the result of nearby livestock corrals. Both these sites are fairly shallow windmills located in remote locations and cattle are frequently watering in the immediate area. No other anthropomorphic sources of nitrate were apparent at either of these locations. Other likely occurrences of cattle impacting shallow windmills in remote locations have been noted in both the Douglas and Sacramento Valley basins.^{41,42} The other nitrate exceedance occurred at a well (DET-4/5) used at a sand and gravel extraction site along Detrital Wash.

Gross Alpha - Gross alpha exceedances occurred at three distinct areas within the basin: in the Cerbat Mountains near the town of Chloride, in the Black Mountains near the Mt. Wilson Wilderness Area, and near Temple Bar in the Lake Mead National

Recreation Area. A groundwater study in the nearby Sacramento Valley basin documented many gross alpha exceedances near Chloride that were probably the result of granitic geology exacerbated by extensive mining in the district.^{28, 42} Two wells showed elevated gross alpha levels, with DET-35 exceeding health-based water quality standards and DET-21/22 just below these standards. Similarly, the elevated gross alpha levels in the sample obtained from Missouri Spring within the Mt. Wilson Wilderness area is also likely the result of the area's granitic geology combined with some historic mining activity.

A well near Temple Bar (DET-43) also had a gross alpha exceedance. Historic elevated gross alpha exceedances in this well were confirmed by the National Park Service as well as by the 11.7 piC/l gross alpha level in the sample collected from the nearby Monkey Cove Spring (DET-45/46).³⁹ Both these sites are located in sedimentary rock.³² This study has conjectured that the Temple Bar sites mainly produce water that has been recharged from Colorado River water stored in Lake Mead. The gross alpha levels may be the result of this Colorado River recharge though no gross alpha levels of this water source could be found in the available surface water literature.⁴⁷ Other potential sources could be abandoned mines near the Wilson Ridge area.³⁹

Arsenic - Arsenic was detected at three sites, all at levels just exceeding the revised 2006 standard of 0.01 mg/l but far below the current standard of 0.05 mg/l. Two sites were deep wells located in close proximity to each other in the center of the basin near Boulder Inn. Other sites sampled in this area by other sources also found similar arsenic levels.³⁵ The other exceedance occurred in a shallow well near Temple Bar. The sources of arsenic in these locations is likely natural with the concentrations in the Temple Bar well being contributed by recharge by water from Lake Mead. Arsenic in Lake Mead average 0.0025 mg/l.⁴⁷

Discussion of Aesthetics-Based Exceedances

Aesthetics-based water quality standards were exceeded for the following constituents: TDS (11 sites), sulfate (7 sites), manganese (3 sites), iron (2 sites), fluoride (2 sites), and chloride (1 site). These exceedances primarily occurred in three areas in the basin: near Chloride, near Temple Bar, and in the Black Mountains.

Chloride Area - The area most impacted by aesthetics-based water quality standard exceedances is in the Cerbat Mountains near the town of Chloride. The two shallow windmills (DET-21/22 and DET-35) each exceeded standards for TDS, sulfate, manganese, and iron with the former also exceeding chloride standards. The magnitude of the exceedances at DET-21/22 (TDS = 2100 mg/l, sulfate = 840 mg/l, chloride = 545 mg/l, manganese = 5.75 mg/l, iron = 11.2 mg/l) limits the use of this source for domestic purposes. These exceedances were found in nearby Chloride in 1999 and likely result from combination of historic mining activity and wastewater disposal.⁴²

Ore deposits are the source of sulfate in most Arizona basins. Mining activity exposes greater amounts of rock surfaces to weathering which oxidizes the metallic sulfides to yield sulfate ions to percolating groundwater.^{24,35} Iron and manganese are also often elevated downgradient of mining activity.²⁵ Most groundwater in Arizona is oxidizing in nature, however reducing conditions appear to exist in some locations in the DET including around Chloride. Reducing conditions tend to increase the solubility of iron and manganese and keep any nitrogen contributed by septic systems in the ammonia state.³⁵ This statement is supported by TKN concentrations (0.53 mg/l) higher than nitrate (as nitrogen) concentrations (0.057 mg/l) in DET-21/22; both TKN and nitrate were below detection limits in DET-35.

Domestic wastewater disposal using older septic systems in soils that have *severe limitations* for this purpose may also contribute to these elevated constituent levels at these sites.³³ The high density of these systems in the Chloride area may also contribute to the groundwater conditions. Inadequate septic system operation would increase chloride concentrations and thus, TDS concentrations.¹¹

An interesting comparison is that the springs sampled north of these windmills (Quail, Lower Indian, Putnam, and Dolan) had low sulfate (a mean of 35 mg/l) and TDS (a mean of 365 mg/l) concentrations. This may indicate that the source water for these springs is much deeper than the shallow windmills and remains relatively un-impacted by mining and wastewater activities in the Chloride area.

Temple Bar Area - The three sites (two shallow wells and one spring) sampled in the Temple Bar area each had a moderate exceedance of both sulfate (250 to 310 mg/l) and TDS (600 to 700 mg/l) water quality

standards. The conclusion that these sites are recharged largely by water from Lake Mead is further supported by the similar concentrations of sulfate (215 mg/l) and TDS (565 mg/l) of Colorado River water at Hoover Dam.⁴⁷

Black Mountains - The four sites (two shallow wells and two springs) sampled in the Black Mountains north of Cottonwood Road each moderately exceeded TDS water quality standards, with the two springs also exceeding sulfate standards. Similar to that detailed in the Chloride area, mining activity may contribute to the increased sulfate and TDS concentrations. Reducing conditions may also be present at the sites as the manganese standard was exceeded at one spring and both springs had higher concentrations of TKN than nitrate.

Groundwater Basin Overview

Groundwater in the DET is generally *fresh* and *slightly alkaline*.²² Hardness ranged widely from *moderately hard* to *very hard*.¹⁶ Eight different water chemistries were identified with *mixed-mixed*, *mixed-bicarbonate*, and *calcium-bicarbonate* the most prevalent. Nitrogen is typically found as nitrate in the *alluvial aquifer* with few TKN detections. In contrast, *Lake Mead aquifer* sites typically have more nitrogen as TKN. *Hardrock* sites have both nitrogen forms. Trace elements above ADHS laboratory MRLs were seldom encountered with only fluoride, boron, zinc, and chromium detected at more than 25 percent of sample sites.

The DET appears to be both an *open* and *closed hydrologic system* based on isotope results which support findings of previous studies.³⁵

An *open hydrologic system* is one in which groundwater chemistry is in part controlled or influenced by atmospheric gases or liquids that enter the system along flow paths subsequent to initial recharge. This assertion is supported by two deep wells (DET-4/5 and DET-8) located along the axis of the basin near Detrital Wash that show evidence of recent recharge from isotope results. This recharge could be originating on the margins of the basin as shallow windmills located upgradient of each site (DET-15 and DET-11, respectively) also show evidence of recent precipitation. Recent recharge could also be occurring along Detrital Wash, particularly along the lower stretch near DET-4/5, the most downgradient alluvial well sampled.

In contrast, the majority of deep wells and springs have an isotopic signature that reveals no evidence of recent recharge. It appears that these parts of the basin have a *closed hydrologic system* in which the groundwater chemistry is determined solely by the reactions of the initial recharge waters with the various aquifer minerals and gases as the groundwater moves downgradient.³⁵

Groundwater quality patterns generally support the above assertions. Calcium and bicarbonate concentrations (and their related constituents, hardness and total alkalinity) were found to be significantly higher at *hardrock* sites than at *alluvial aquifer* sites (ANOVA test with the Tukey test, p# 0.05). Elevated concentrations of calcium and bicarbonate are typical of recharge areas.³⁵

Other significant patterns include higher temperature, nitrate, and chromium concentrations in the *alluvial aquifer* than in *hardrock*. In addition, TDS, SC-lab, and SC-field were greater in *hardrock* than in the *alluvial aquifer*, but this relationship was only significant at p # 0.10.

These constituent patterns were noted by previous studies in the DET as well as in other nearby Arizona groundwater basins.^{19,42} In the Sacramento Valley basin, groundwater in springs and shallow wells in or near the mountains tends to be more highly mineralized than that from deep alluvial wells in the center of the basin. Several possible reasons for this water quality difference have been cited.¹⁹ The most likely appears to be that the center portions of Detrital Valley may receive most of their recharge from high rainfall events causing percolating flow in the coarse alluvium beneath stream beds on the upper portions of the alluvial fans. This pathway would have less opportunity to dissolve and transport minerals.¹⁹ In contrast, alluvium near the perimeter of the valley also receives recharge from this route but probably also receives water leaking through fractured bedrock aquifers. These waters are expected to have elevated concentrations of dissolved salts and minerals because they have traveled considerable distances underground through weathered, mineralized zones.¹⁹

Some constituents have more specific reasons for their aquifer patterns.

Temperature differences can be attributed to greater groundwater depth bls in the *alluvial aquifer* than in shallow *hardrock*. Groundwater temperatures

typically increase with depth (approximately 3 degrees Celsius with every 328 feet) after the relatively shallow *neutral zone* depth has been reached where shallow subsurface temperatures no longer vary seasonally.¹²

Nitrate differences between water-bearing units can be attributed to several factors. Nitrogen in DET groundwater is usually found as nitrate in the *alluvial aquifer* and as TKN in *hardrock* and in the *Lake Mead aquifer*. Several sample sites in *hardrock* appear to have *reducing conditions* that would favor nitrogen as TKN (especially ammonia), as opposed to the *oxidizing conditions* found generally in the basin. The elevated nitrate found in samples from deep wells in the *alluvial aquifer* probably is from natural soil organic matter. This is based upon both the very deep depths to groundwater as well as the nitrogen isotope signature from similar deep wells in the adjacent Sacramento Valley.⁴² Elevated nitrate at selected windmills with nearby livestock corrals and, in one case, a shallow alluvial well near a subdivision, may also be impacted by livestock and/or septic systems.

Chromium, in the hexavalent (+ 6) oxidation state, is a naturally occurring constituent in groundwater throughout much of central and western Arizona.³⁵ The source of hexavalent chromium is the trivalent chromium (Cr⁺³) in basin fill. Although highly insoluble and immobile, under oxidizing conditions and elevated pH levels, it is oxidized to form Cr⁺⁶. Basins that contain the largest hexavalent chromium concentrations are those that receive the least recharge, resulting in groundwater having long residence time.³⁵ This explains why the ten sites where chromium was detected were almost exclusively very deep wells in the alluvial aquifer, pumping very old groundwater.

Groundwater quality was also found to vary significantly with groundwater depth (regression, p # 0.05). Many constituents such as TDS, SC, total alkalinity, bicarbonate, calcium, magnesium, hardness, chloride, and sulfate decreased with increasing groundwater depth bls. In contrast, temperature, pH-field, nitrate, and chromium increased with increasing groundwater depth bls. Although these relationships were significant, there was generally a fairly tight distribution of constituent levels. Well locations strongly influences the groundwater depth - constituent concentration relationship. Constituent concentrations are fairly constant in the *alluvial aquifer* and are much more variable in shallow *hardrock* wells.

Estimates of the depth from which springs were originating from were made by plotting the spring analytical results onto the regression curve formed by each constituent. The results are fairly consistent with each constituent; Cottonwood and Missouri Springs appear to be fairly shallow (< 100 feet bls), Lower Indian Spring to be from slightly deeper depths (< 150 feet bls), and Quail, Putnam, and Dolan Spring appear to emanate from still deeper depths (> 300 feet bls).

Groundwater depth data provided from outside sources appear to indicate more saline groundwater below a confining bed in Detrital Valley.³⁷ After the White Hills Well (see cover photo) was sampled for this study by ADEQ, it was deepened from 870 feet bls to 1378 feet bls. The static groundwater level in the well changed from 420 feet bls to 230 feet bls.³⁷ Reportedly, a gypsum bed was encountered at 1,040 feet bls that may have acted as a partial confining bed. A sample was collected from the deepened well and the limited constituents analyzed indicated significant increases in TDS (300 to 2251 mg/l), sulfate (55 to 1252 mg/l), and calcium (22 to 174 mg/l) which would be consistent with groundwater in contact with gypsum.²⁴

Historical groundwater quality data is limited in the DET, but enough is available to make some broad, semi-quantitative statements. Generally, deep alluvial wells in Detrital Valley appear to possess stable constituent concentrations. Springs in the Black Mountains appear to have more variable constituent concentrations.

The source of water in the Temple Bar area appears to be recharge from Lake Mead causing steady increases in salinity concentrations. Although a previous report indicated that bedding generally dips southward away from Lake Mead that probably prevents major intrusion of lake water into the Temple Bar area, perhaps enough time had not elapsed to reveal the long-term effects.³⁸ The report further speculated that these southward dipping silt beds of low permeability acted as a barrier to horizontal movement of groundwater, forcing it to the surface to form the springs and seeps in the Temple Bar area. Current data, especially oxygen and hydrogen isotope sample results, show clearly that these sites consist mainly of recharged Lake Mead water.

Finally, the White Hills area has been characterized as a very complex groundwater flow system with deep and extensive occurrences of alluvium.¹⁹ Data from a

deep well in this area collected by Rangeland Consulting Services suggest this is a correct description.³⁷ The sample is the most sodium-dominated as well as the only occurrence of carbonate in the study. These characteristics are suggestive of highly-evolved, old water.

Study Design and Data Evaluation

The 28 groundwater sample sites were generally selected using a modified grid-based, random site-selection approach. A weakness of the study was the paucity of sample sites in the northern one-third of the DET. Thus, additional samples were collected from both the southern two-thirds of the DET as well as from sites in the *Lake Mead aquifer* in an attempt to examine the basin more comprehensively.

Quality assurance procedures were followed and quality control samples were collected to ensure the validity of groundwater quality data. Analysis of equipment blank samples indicated systematic contamination of SC-lab and turbidity; however, the extent of contamination by these parameters was not considered significant.

Analysis of duplicate samples revealed excellent correlations of less than 10 percent difference with the exception of turbidity (15 percent) and copper (67 percent). Similarly, analysis of split samples showed the maximum difference between split constituents rarely exceeded 20 percent. TKN exhibited the largest maximum difference, a pattern found in other ADEQ studies, that is probably due to the difficulty in analyzing this constituent.^{34 43 44}

Data validation was also examined in five QA/QC correlations that affirmed the acceptability of the groundwater quality data for further analysis. Overall, the effects of sampling procedures and laboratory methods on the data were not considered significant.

Data analysis for this study was conducted using Systat software.⁵⁰ The non-normality of non-transformed data and the normality for most of the log-transformed data was determined by using the Kolmogorov-Smirnov one-sample test with the Lilliefors option.¹³ Spatial variations in constituent concentrations were investigated using the parametric Analysis of Variance (ANOVA) test in conjunction with the Tukey test.²³ Correlations among constituent concentrations were analyzed using the Pearson Correlation Coefficient test.²³

RECOMMENDATIONS

Recommendations for domestic well owners in the DET are provided in this section. These are based on interpretations of the analytical results from groundwater samples collected for this study.

- < ADEQ encourages well owners concerned about their water supply to periodically collect samples, with the assistance of certified laboratories, for analysis of the full range of groundwater quality constituents. The ADHS, Environmental Laboratory Licensure and Certification Section at (602) 255-3454 provides a list of certified labs.

- < ADEQ encourages well owners to inspect and, if necessary, repair faulty surface seals, degraded casing, or other factors that may affect well integrity. Septic systems should also be inspected periodically to assure safety and compliance with ADEQ's *Engineering Bulletin #12*.²

Recommendations for future hydrology studies in the DET are as follows:

- < In the basin, one million acre-feet of groundwater is estimated to be in storage to a depth of 1,200 feet and annual water use was as low as 190 acre-feet annually as recently as 1985.⁷ Furthermore, the amount stored from 1,200 to 8,000 feet has not been determined. However, several factors suggest that the long-term sustainability of groundwater resources in the DET might want to be comprehensively evaluated because of several factors. These factors include what may be the lack of a recent recharge isotopic signature in groundwater samples collected from many deep alluvial wells in the Detrital Valley, the encountering of gypsum beds in the deep in the alluvium which can negatively impact the quality of groundwater stored at greater depths, and the increasing annual water use in the basin based on population growth projections.

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Appendix A. Data on Sample Sites, Detrital Valley Basin, 2002

Site #	Cadastral/ Pump Type	Lat/ Long (NAD27)	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Aquifer
1st Field Trip, October 8 - 11, 2002 - Towne & Boettcher (Equipment Blank, DET-9/10)									
DET-1/2	B(25-19)31acd submersible	35°30'36.18" 114°20'58.90"	585883	60497	Siegfried Well	Inorganic O, H isotopes	905'	860'	Alluvial
DET-3	B(26-18)29bdd submersible	35°36'43.58" 114°13'47.98"	529826	60498	Williams Well	Inorganic, Radiochem Radon, O, H isotopes	250'	83'	Alluvial
DET-4/5	B(28-21)23ccc submersible	35°47'38.053" 114°30'09.778"	535632	60499	Gravel Well	Inorganic, Radon, O, H isotopes	365'	210'	Alluvial
DET-6/7	B(27-21)25aca submersible	35°42'07.967" 114°28'27.450"	584114	60396	White Hills Well	Inorganic O, H isotopes	870'	420'	Alluvial
DET-8	B(25-20)15aaa submersible	35°33'35.558" 114°23'54.188"	637009	000734	Scales Well	Inorganic O, H isotopes	650'	500'	Alluvial
DET-11	B(25-21)35acd windmill	35°33'38.54" 114°23'53.21"	621800	60500	South Well	Inorganic O, H isotopes	--	--	Alluvial
DET-13	B(27-19)17ddd submersible	35°43'17.360" 114°19'57.038"	576840	60393	Moody Well	Inorganic O, H isotopes	665'	580'	Alluvial
DET-14	B(26-19)04cda windmill	35°39'44.778" 114°19'18.986"	506071	60394	Lost Well	Inorganic, Radiochem O, H isotopes	490'	440'	Hardrock
DET-15	B(27-19)02aba suction	35°42'07.967" 114°28'27.450"	807718	60395	Cyclopic Well	Inorganic, Radiochem O, H isotopes	80'	20'	Hardrock
DET-16/17	B(25-18)17bac	35°33'20.236" 114°14'15.476"	--	22187	Lwr Indian Spring	Inorganic, Radon O, H Isotopes	--	--	Hardrock
DET-18	B(25-19)23bbb submersible	35°32'44.718" 114°16'32.634"	553126	60397	Jamie Well	Inorganic Isotopes	830'	780'	Alluvial
2nd Field Trip, October 28-31, 2002 - Towne & McCarty (Equipment Blank, DET-24/25)									
DET-19/20	B(24-19)02dca	35°29'40.426" 114°16'40.261"	--	22144	Quail Spring	Inorganic, Radiochem O, H isotopes	--	--	Hardrock
DET-21/22	B(24-18)32cac windmill	35°25'24.793" 114°13'45.262"	801521	22141	Grass. Junc. Well	Inorganic, Radiochem Radon, O, H isotopes	125'	50'	Hardrock
DET-23	B(31-19)32daa submersible	36°02'10.456" 114°20'08.405"	629086	22423	Lwr Temple Bar #3 Well	Inorganic, Radon O, H isotopes	240'	55'	Lake Mead
DET-26	B(27-21)13cc submersible	35°43'26.456" 114°28'54.333"	606080	22328	Oasis Well	Inorganic, Radon O, H isotopes	550'	75'	Alluvial
DET-27	B(23-20)34dba windmill	35°20'11.819" 114°23'59.968"	651163	22083	Twin Wells	Inorganic, Radiochem Radon, O, H isotopes	120'	20'	Hardrock
DET-28/32	B(22-20)35bab windmill	35°15'22.023" 114°23'19.791"	642110	21927	Basin Well	Inorganic, Radon O, H isotopes	330'	--	Hardrock
DET-29/30	B(30-22)13adc	35°59'22.523" 114°35'18.375"	--	60384	Missouri Spring	Inorganic, Radiochem O, H isotopes	--	--	Hardrock
DET-31	B(25-21)12bdd suction	35°34'00.478" 114°28'50.014"	--	60385	Cow Camp Well	Inorganic, Radon O, H isotopes	--	12'	Hardrock

Appendix A. Data for Sample Sites, Detrital Valley Basin, 2002–Continued

Site #	Cadastral / Pump Type	Lat / Long (NAD27)	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Aquifer
3rd Field Trip, December 2 - 5, 2002 - Towne & Boettcher (Equipment Blank, DET-39)									
DET-33/34	B(23-20)12dba submersible	35°23'41.406" 114°21'49.636"	651160	22081	Producer Mine Well	Inorganic, Radon O, H isotopes	905'	860'	Hardrock
DET-35	B(24-18)20dbb windmill	35°27'15.564" 114°13'31.603"	651162	22138	Lower Big Wash Well	Inorganic, Radiochem Radon, O, H isotopes	250'	83'	Hardrock
DET-36	B(24-19)13dad	35°28'01.115" 114°15'16.706"		61106	Putnam Spring	Inorganic, Radiochem O, H isotopes	--	--	Hardrock
DET-37	B(27-20)29abb submersible	35°42'20.571" 114°26'10.370"	576054	60364	King Well	Inorganic, Radon O, H isotopes	870'	420'	Alluvial
DET-38	B(25-21)02cbd	35°34'43.747" 114°30'10.890"		22206	Cottonwood Spring	Inorganic O, H isotopes	--	--	Hardrock
DET-40	B(26-18)31bdb	35°35'57.874" 114°14'56.299"		22268	Dolan Spring	Inorganic O, H isotopes	--	--	Hardrock
DET-41/42	B(26-20)27bcd submersible	35°36'49.787" 114°24'37.064"	502441	57382	Detrital Wash Well	Inorganic, O, H isotopes	640'	485'	Alluvial
4th Field Trip, March 3-7, 2003 - Towne & Boettcher (Equipment Blanks, MHV-7,8,22 & 23)									
DET-43	B(31-19)32ada submersible	36°01'58.974" 114°20'14.497"	629085	22422	Up Temple Bar #4 Well	Inorganic, Radiochem O, H isotopes	200'	89'	Lake Mead
DET-44					Detrital Wash	O, H isotopes			
5th Field Trip, April 23-25, 2003 - Towne & Boettcher (Equipment Blanks, MHV-31)									
DET-45/46	B(31-19)28ccd	36°02'26.38" 114°19'49.38"	--	22421	Monkey Cove Spring	Inorganic, Radiochem Radon, O, H isotopes	--	--	Lake Mead
DET-47			--	--	Lake Mead	O, H isotopes	--	--	
DET-48	B(29-21)35ccb windmill		637019		Bibler Well	O, H isotopes	100'	33'	Alluvial

Appendix B. Groundwater Quality Data, Detrital Valley Basin, 2002

Site #	MCL Exceedances	Temp (°C)	pH-field (su)	pH-lab (SU)	SC-field (F S/cm)	SC-lab (F S/cm)	TDS (mg/l)	Hardness (mg/l)	Hard (cal) (mg/l)	Turbidity (ntu)
DET-1/2		27.67	7.87	8.0	415	420	270	120	120	1.0
DET-3		25.38	7.51	7.8	866	880	490	320	330	0.09
DET-4/5	NO ₃	24.97	7.68	7.9	752	765	425	190	220	0.01
DET-6/7	As*	27.36	7.85	7.5	491	490	300	90	96	0.85
DET-8		31.20	7.87	7.6	346	340	220	79	82	0.05
DET-11	TDS, NO ₃ , F	27.65	7.67	7.8	1044	990	600	340	340	2.0
DET-13		25.48	7.70	7.7	479	450	290	160	170	0.04
DET-14		--	--	8.7	519	490	340	180	180	0.58
DET-15		--	7.37	7.8	748	700	440	320	320	0.11
DET-16/17	TDS	28.19	7.51	7.2	885	820	500	320	320	0.04
DET-18		26.43	7.70	7.2	462	420	300	150	150	0.05
DET-19/20		21.08	6.81	7.0	543	570	340	200		0.10
DET-21/22	TDS, Cl, SO ₄ , Fe, Mn	19.52	6.93	7.3	3036	3150	2100	1300	1300	92
DET-23	TDS, SO ₄ , As*	22.61	7.49	7.6	927	960	620	300	310	9.9
DET-26	As*	26.73	7.87	7.4	471	490	280	94	100	0.04
DET-27		20.27	7.35	7.2	509	520	330	230	240	1.2
DET-28/32	NO ₃	21.55	7.90	7.3	551	560	360	180	180	1.0
DET-29/30	TDS, SO ₄ , Mn, gross α	14.45	7.41	7.4	1218	1300	830	520	530	6.6
DET-31	TDS	18.29	7.66	7.7	921	950	620	370	380	7.0
DET-33/34		23.3	7.91	7.95	382	405	250	110	110	0.03
DET-35	TDS, SO ₄ , Fe, Mn, gross α	19.2	7.53	7.4	1519	1600	1000	520	490	19
DET-36		17.4	7.37	6.9	534	580	350	200	200	0.0
DET-37	TDS, F	27.9	7.95	7.7	838	870	530	210	210	1.7
DET-38	TDS, SO ₄	13.3	8.01	7.4	1237	1300	890	570	560	0.33
DET-40		20.7	8.09	7.7	395	420	270	160	160	0.0
DET-41/42		29.0	8.07	7.85	435	450	290	115	120	0.205
DET-43	TDS, gross α	21.6	7.78	7.5	892	980	600	240	240	0.82
DET-45/46	TDS, SO ₄	23.3	7.95	8.08	1116	1200	695	220	220	0.17

bold = constituent level exceeds Primary or Secondary MCL

italics = constituent exceeded holding time

* = concentration exceeds the revised arsenic SDW Primary MCL of 0.01 mg/l which becomes effective in 2006

Appendix B. Groundwater Quality Data, Detrital Valley Basin, 2002--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)
DET-1/2	26	13	32	6.6	92	110	ND	55	22
DET-3	83	30	41	5.6	140	170	ND	130	64
DET-4/5	45	17.5	60	4.7	100	120	ND	100	83
DET-6/7	22.5	9.55	64.5	4.1	110	130	ND	41	55
DET-8	20	7.7	40	3.2	120	150	ND	16	11
DET-11	70	41	74	2.1	200	240	ND	150	77
DET-13	28	25	30	4.0	150	180	ND	34	20
DET-14	25	28	36	4.8	130	140	14	48	33
DET-15	53	46	28	3.8	260	320	ND	59	42
DET-16/17	94	21	57	1.25	240	290	ND	120	50
DET-18	28	20	32	7.3	150	180	ND	31	17
DET-19/20	58	13	36.5	1.4	170	210	ND	50	29
DET-21/22	350	105	195	10.8	145	160	ND	545	840
DET-23	92	19	85	3.1	150	180	ND	66	260
DET-26	25	9.8	60	3.1	110	130	ND	45	46
DET-27	59	22	16	2.6	200	240	ND	29	20
DET-28/32	43	19	37.5	4.45	120	150	ND	54	35
DET-29/30	155	38.5	63	13	360	440	ND	64	250
DET-31	110	26	62	2.7	310	380	ND	41	140
DET-33/34	35.5	5.15	41	1.55	135	160	ND	29	15
DET-35	110	53	140	5.4	300	370	ND	180	260
DET-36	57	13	36	1.4	170	210	ND	50	30
DET-37	46	24	81	10	100	120	ND	120	110
DET-38	160	40	64	5.3	270	330	ND	72	380
DET-40	38	16	15	6.5	130	160	ND	29	24
DET-41/42	28.5	11	42.5	6.45	120	150	ND	30	34
DET-43	72	15	100	3.5	100	120	ND	70	250
DET-45/56	59	17.5	155	4.5	150	180	ND	91.5	305

bold = constituent level exceeds Primary or Secondary MCL

Appendix B. Groundwater Quality Data, Detrital Valley Basin, 2002--Continued

Site #	Nitrate-Nitrite-N (mg/l)	Nitrate-N (mg/l)	Nitrite-N (mg/l)	TKN (mg/l)	Ammonia-N (mg/l)	Total Phosphorus (mg/l)	SAR (value)	Irrigation Quality
DET-1/2	2.1	2.1	ND	ND	-	ND	1.28	C2 - S1
DET-3	6.5	6.5	ND	0.080	-	0.032	0.98	C3 - S1
DET-4/5	11	11	ND	0.13	-	0.032	1.72	C3 - S1
DET-6/7	3.5	3.5	ND	ND	-	0.042	2.88	C2 - S1
DET-8	5.4	5.4	ND	ND	-	ND	1.93	C2 - S1
DET-11	16	16	ND	0.10	-	ND	1.74	C3 - S1
DET-13	6.8	6.8	ND	ND	-	ND	1.00	C2 - S1
DET-14	7.68	7.55	0.13	0.14	-	ND	1.18	C2 - S1
DET-15	2.35	2.31	0.038	0.12	-	0.074	0.68	C2 - S1
DET-16/17	1.0	1.0	ND	ND	-	ND	1.38	C3 - S1
DET-18	3.6	3.6	ND	ND	-	ND	1.13	C2 - S1
DET-19/20	1.0	1.0	ND	ND	-	ND	1.14	C2 - S1
DET-21/22	0.057	0.057	ND	0.53	-	ND	2.31	C4 - S1
DET-23	1.2	1.2	ND	0.092	-	ND	2.11	C3 - S1
DET-26	6.0	6.0	ND	0.14	-	ND	2.58	C2 - S1
DET-27	3.4	3.4	ND	0.12	-	ND	0.45	C2 - S1
DET-28/32	10	10	ND	0.11	-	ND	1.21	C2 - S1
DET-29/30	ND	ND	ND	0.28	-	ND	1.21	C3 - S1
DET-31	0.17	0.17	ND	0.082	-	0.048	1.38	C3 - S1
DET-33/34	3.25	3.25	ND	0.56	-	ND	1.61	C2 - S1
DET-35	ND	ND	ND	ND	-	ND	2.74	C3 - S1
DET-36	1.1	1.1	ND	0.065	-	ND	1.12	C2 - S1
DET-37	3.8	3.8	ND	ND	-	ND	2.41	C3 - S1
DET-38	0.05	0.05	ND	0.29	-	0.042	1.17	C3 - S1
DET-40	2.6	2.6	ND	ND	-	ND	0.51	C2 - S1
DET-41/42	4.1	4.1	ND	ND	-	ND	1.70	C2 - S1
DET-43	0.41	0.41	ND	ND	ND	ND	2.80	C3 - S1
DET-45/46	0.70	0.70	ND	0.45	ND	ND	4.65	C3 - S1

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

Appendix B. Groundwater Quality Data, Detrital Valley Basin, 2002--Continued

Site #	Antimony (mg/l)	Arsenic (mg/l)	Barium (mg/l)	Beryllium (mg/l)	Boron (mg/l)	Cadmium (mg/l)	Chromium (mg/l)	Copper (mg/l)	Fluoride (mg/l)
DET-1/2	ND	ND	ND	ND	0.11	ND	0.0185	ND	0.64
DET-3	ND	ND	0.16	ND	ND	ND	ND	ND	0.85
DET-4/5	ND	ND	0.104	ND	0.14	ND	0.022	ND	0.89
DET-6/7	ND	0.0125*	ND	ND	0.21	ND	0.0365	ND	1.1
DET-8	ND	ND	ND	ND	ND	ND	0.023	ND	0.60
DET-11	ND	ND	ND	ND	0.31	ND	ND	ND	2.2
DET-13	ND	ND	ND	ND	0.15	ND	0.022	ND	0.87
DET-14	ND	ND	ND	ND	0.13	ND	ND	ND	0.69
DET-15	ND	ND	ND	ND	0.12	ND	ND	ND	0.57
DET-16/17	ND	ND	ND	ND	ND	ND	ND	ND	0.81
DET-18	ND	ND	ND	ND	0.15	ND	0.020	ND	0.64
DET-19/20	ND	ND	ND	ND	ND	ND	ND	ND	0.98
DET-21/22	ND	ND	ND	ND	0.24	ND	ND	ND	0.90
DET-23	ND	0.012*	ND	ND	0.15	ND	ND	ND	0.48
DET-26	ND	0.014*	ND	ND	0.12	ND	0.043	ND	1.1
DET-27	ND	ND	ND	ND	ND	ND	ND	ND	0.32
DET-28/32	ND	ND	ND	ND	ND	ND	ND	0.020	0.33
DET-29/30	ND	ND	ND	ND	0.27	ND	ND	ND	0.68
DET-31	ND	ND	ND	ND	0.20	ND	ND	ND	1.0
DET-33/34	ND	ND	.029	ND	ND	ND	ND	ND	0.35
DET-35	ND	ND	ND	ND	0.17	ND	ND	ND	1.0
DET-36	ND	ND	ND	ND	ND	ND	ND	ND	1.0
DET-37	ND	ND	ND	ND	0.38	ND	0.042	ND	2.0
DET-38	ND	ND	ND	ND	0.17	ND	ND	ND	1.3
DET-40	ND	ND	ND	ND	ND	ND	0.011	ND	0.47
DET-41/42	ND	ND	ND	ND	0.155	ND	0.0235	ND	0.89
DET-43	ND	ND	ND	ND	0.27	ND	ND	ND	0.45
DET-45/46	ND	ND	0.11	ND	0.65	ND	ND	ND	0.59

bold = constituent level exceeds Primary or Secondary MCL

* = concentration exceeds the revised arsenic SDW Primary MCL of 0.01 mg/l which becomes effective in 2006

Appendix B. Groundwater Quality Data, Detrital Basin, 2002--Continued

Site #	Iron (mg/l)	Lead (mg/l)	Manganese (mg/l)	Mercury (mg/l)	Nickel (mg/l)	Selenium (mg/l)	Silver (mg/l)	Thallium (mg/l)	Zinc (mg/l)
DET-1/2	ND	ND	ND	ND	ND	ND	ND	ND	0.175
DET-3	ND	ND	ND	ND	ND	ND	ND	ND	0.18
DET-4/5	ND	ND	ND	ND	ND	ND	ND	ND	ND
DET-6/7	ND	ND	ND	ND	ND	ND	ND	ND	ND
DET-8	ND	0.0065	ND	ND	ND	ND	ND	ND	ND
DET-11	ND	ND	ND	ND	ND	ND	ND	ND	2.9
DET-13	ND	ND	ND	ND	ND	ND	ND	ND	0.38
DET-14	ND	ND	ND	ND	ND	ND	ND	ND	0.056
DET-15	ND	ND	ND	ND	ND	ND	ND	ND	ND
DET-16/17	ND	ND	ND	ND	ND	ND	ND	ND	ND
DET-18	ND	ND	ND	ND	ND	ND	ND	ND	0.25
DET-19/20	ND	ND	ND	ND	ND	ND	ND	ND	ND
DET-21/22	5.75	ND	1.2	ND	ND	ND	ND	ND	ND
DET-23	ND	ND	ND	ND	ND	ND	ND	ND	ND
DET-26	ND	ND	ND	ND	ND	ND	ND	ND	ND
DET-27	0.11	ND	ND	ND	ND	ND	ND	ND	0.059
DET-28/32	ND	ND	ND	ND	ND	ND	ND	ND	0.41
DET-29/30	ND	ND	0.068	ND	ND	ND	ND	ND	ND
DET-31	ND	ND	ND	ND	ND	0.0076	ND	ND	ND
DET-33/34	ND	ND	ND	ND	ND	ND	ND	ND	0.089
DET-35	0.98	ND	0.051	ND	ND	ND	ND	ND	1.7
DET-36	ND	ND	ND	ND	ND	ND	ND	ND	ND
DET-37	ND	ND	ND	ND	ND	ND	ND	ND	0.17
DET-38	ND	ND	ND	ND	ND	ND	ND	ND	ND
DET-40	ND	ND	ND	ND	ND	ND	ND	ND	ND
DET-41/42	ND	ND	ND	ND	ND	ND	ND	ND	0.54
DET-43	ND	ND	ND	ND	ND	ND	ND	ND	ND
DET-45/46	ND	ND	ND	ND	ND	ND	ND	ND	ND

bold = constituent level exceeds Primary or Secondary MCL

Appendix B. Groundwater Quality Data, Detrital Valley Basin, 2002–Continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Ra-226 (pCi/L)	Uranium (µg/l)	δ ¹⁸ O (‰)	δ D (‰)	Type of Chemistry
DET-1/2	--	--	--	--	--	- 11.4	- 82	mixed-mixed
DET-3	200+/-25	2.0+/-0.6	--	--	--	- 9.7	- 73	mixed-mixed
DET-4/5	428+/-46	--	--	--	--	- 8.95	- 69	mixed-mixed
DET-6/7	--	--	--	--	--	- 10.9	- 80	sodium-mixed
DET-8	--	--	--	--	--	- 9.5	- 68	sodium-bicarbonate
DET-11	--	--	--	--	--	- 7.5	- 65	mixed-mixed
DET-13	--	--	--	--	--	- 9.7	- 73	mixed-bicarbonate
DET-14	--	1.7+/-0.6	--	--	--	- 7.0	- 62	mixed-mixed
DET-15	--	3.5+/-0.8	--	--	--	- 8.0	- 67	mixed-bicarbonate
DET-16/17	848+/-87	--	--	--	--	- 10.9	- 78	calcium-bicarbonate
DET-18	--	--	--	--	--	- 10.5	- 76	mixed-bicarbonate
DET-19/20	--	4.6+/-1.0	--	--	--	- 10.9	- 78	calcium-bicarbonate
DET-21/22	527+/-57	14.1+/-2.2	--	--	--	- 9.1	- 70	calcium-sulfate
DET-23	495+/-53	--	--	--	--	- 13.0	- 104	mixed-sulfate
DET-26	393+/-43	--	--	--	--	- 10.6	- 80	sodium-mixed
DET-27	238+/-29	1.9+/-0.7	--	--	--	- 8.6	- 68	calcium-bicarbonate
DET-28/32	193+/-23	--	--	--	--	- 8.6	- 68	mixed-mixed
DET-29/30	--	20.0+/-2.0	--	0.5+/-0.2	15.1+/-1.0	- 10.5	- 78	calcium-bicarbonate
DET-31	84+/-14	--	--	--	--	- 10.4	- 77	calcium-bicarbonate
DET-33/34	595+/-64	--	--	--	--	-10.65	- 77.5	mixed-bicarbonate
DET-35	4839+/-486	38.0+/-4.0	--	--	--	- 10.9	- 79	mixed-mixed
DET-36	--	4.7+/-1.0	--	--	--	- 11.2	- 78	calcium-bicarbonate
DET-37	561+/-61	--	--	--	--	- 10.7	- 82	mixed-mixed
DET-38	--	--	--	--	--	-10.6	- 79	calcium-sulfate
DET-40	--	--	--	--	--	- 10.2	- 77	mixed-bicarbonate
DET-41/42	--	--	--	--	--	- 10.25	- 77.5	mixed-bicarbonate
DET-43	--	16.0 +/- 2.0	6.8 +/- 1.2	--	--	- 13.7	- 107	mixed-sulfate
DET-44	--	--	--	--	--	- 6.5	-51	--
DET-45/46	78 +/- 9	11.7 +/- 1.7	< 0.3	< 0.4	--	- 13.2	- 106	sodium-sulfate
DET-47	--	--	--	--	--	- 12.5	- 101	--
DET-48	--	--	--	--	--	- 11.2	- 84	--

bold = Primary MCL Exceedance
 LLD = Lower Limit of Detection
italics = constituent exceeded holding time

APPENDIX D. INVESTIGATION METHODS

Various groundwater sites were sampled by the ADEQ Groundwater Monitoring Program to characterize regional groundwater quality in the DET. Samples were collected at all sites for inorganic (physical parameters, major ions, nutrients, and trace elements) as well as hydrogen and oxygen isotope analyses. At selected sites radon and radiochemistry samples were collected for analysis. No bacteria sampling was conducted since microbiological contamination problems in groundwater are often transient and subject to a variety of changing environmental conditions including soil moisture content and temperature.²¹

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 regional degradation of groundwater quality such as occurs from non-point sources of pollution or a high density of point sources. The quantitative estimation of regional groundwater quality conditions requires the selection of sampling locations that follow scientific principles for probability sampling.²³

Sampling in the DET conducted by ADEQ 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.²³ The main benefit of a statistically-designed sampling plan is that it allows for greater groundwater quality assumptions than would be allowable with a non-statistical approach.

Wells pumping groundwater for a variety of purposes - domestic, stock, and industrial - were sampled for this study, provided each individual well met ADEQ requirements. A well was considered suitable for sampling if the well owner gave permission to sample, if a sampling point existed near the wellhead, and if the well casing and surface seal appeared to be intact and undamaged.¹⁰ Other factors such as casing access to determine groundwater depth and construction

information were preferred but not essential.

If registered wells were unavailable for sampling, springs or unregistered wells were randomly selected for sampling. Springs were considered adequate for sampling if they had a constant flow through a clearly-defined point of egress, and if the sample point had minimal surface impacts. Well information compiled from the ADWR well registry and spring characteristics 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.²³

Sample Collection

The personnel who designed the DET study were also responsible for the collection and interpretation of the data. This protocol helps ensure that consistently high quality data are collected, from which are drawn relevant and meaningful interpretations. The sample collection methods for this study conformed to the *Quality Assurance Project Plan (QAPP)*³ and the *Field Manual For Water Quality Sampling*.¹⁰ While these sources should be consulted as references to specific sampling questions, a brief synopsis of the procedures involved in collecting a groundwater sample is provided.

After obtaining permission from the owner to sample the well, the water level was measured with a sounder if the casing had access for a probe. The volume of water needed to purge the well three bore hole volumes was calculated from well log and on-site information. Physical parameters - temperature, pH, and specific conductivity - were monitored at least every five minutes using a YSI multi-parameter instrument. In order to be assured of obtaining fresh water from the aquifer, typically after three bore volumes had been pumped and the physical parameters were stabilized within 10 percent, a sample representative of the aquifer was collected from a point as close to the wellhead as possible. In certain

instances, it was not possible to purge three bore volumes. In these cases, at least one bore volume was evacuated and the physical parameters had stabilized within 10 percent.

Sample bottles were filled in the following order:

1. Radon
2. Inorganic
3. Radiochemistry
4. Isotope

Radon samples were collected in two unpreserved, 40-ml clear glass vials. Radon samples were carefully filled and sealed so that no headspace remained.¹⁷

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

- < Samples to be analyzed for dissolved metals were filtered into bottles preserved with 5 ml nitric acid (70 percent). An on-site positive pressure filtering apparatus with a 0.45 micron (μm) pore size groundwater capsule filter was used.
- < Samples to be analyzed for nutrients were collected in bottles preserved with 2 ml sulfuric acid (95.5 percent).
- < Samples to be analyzed for other parameters were collected in unpreserved bottles.³²

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

Hydrogen and oxygen isotope samples were both collected in a single 500 ml unpreserved plastic bottle.

Samples were kept at 4°C with ice in an insulated cooler, with the exception of the isotope and radiochemistry samples. Chain of custody procedures were followed in sample handling. Samples for this study were collected between October 2002 and April 2003.

Laboratory Methods

The inorganic analyses for this study were conducted by the ADHS Laboratory in Phoenix, Arizona, with inorganic splits analyzed 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 both laboratories is provided in **Table 10**.

The radon and radiochemistry samples were analyzed by Radiation Safety Engineering, Inc. Laboratory in Chandler, Arizona. The analysis of radiochemistry samples was treated according to the following SDW protocols:⁵ Gross alpha was analyzed, and if levels exceeded 5 pCi/L, then radium-226 was measured. When radium-226 exceeded 3 pCi/L, radium-228 was measured. If gross alpha levels exceeded 15 pCi/L initially, then radium-226/228 and mass uranium were measured.

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

Sample Numbers

Twenty (28) sites (plus two surface water sites and one groundwater site where only isotope samples were collected) were sampled for the study. Various numbers and types of samples were collected and analyzed:

- < 28 - inorganic
- < 31 - hydrogen and oxygen isotopes
- < 11 - radon
- < 11 - radiochemistry.

Table 10. ADHS/Del Mar Laboratory Methods Used for the DET 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 (F S/cm)	Electrometric	EPA 120.1/ SM2510B	1 / 2
Hardness	Titrimetric, EDTA	EPA 130.2 / SM2340B	10 / 1
Hardness - Calc.	Calculation	--	--
pH (SU)	Electrometric	EPA 150.1	0.1
TDS	Gravimetric	EPA 160.1 / SM2540C	10 / 20
Turbidity (NTU)	Nephelometric	EPA 180.1	0.01 / 1
Major Ions			
Calcium	ICP-AES	EPA 200.7	5 / 2
Magnesium	ICP-AES	EPA 200.7	1 / 0.5
Sodium	ICP-AES	EPA 200.7 / EPA 273.1	5
Potassium	Flame AA	EPA 258.1	0.5 / 1
Bicarbonate	Calculation	--	2
Carbonate	Calculation	--	2
Chloride	Potentiometric Titration	SM 4500 CLD / EPA 300.0	1 / 5
Sulfate	Colorimetric	EPA 375.2 / EPA 300.0	10 / 5
Nutrients			
Nitrate as N	Colorimetric	EPA 353.2	0.02 / 0.50
Nitrite as N	Colorimetric	EPA 353.2	0.02
Ammonia	Colorimetric	EPA 350.1/ EPA 350.3	0.02 / 0.5
TKN	Colorimetric	EPA 351.2 / SM4500	0.05 / 0.5
Total Phosphorus	Colorimetric	EPA 365.4 / EPA 365.3	0.02 / 0.05

All units are mg/l except as noted
 Source ^{17 34}

Table 10. ADHS/Del Mar Laboratory Methods Used for the DET Study--Continued

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

All units are mg/l

Source ^{17 34}

APPENDIX E. 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 DET study. The design of the QA/QC plan was based on recommendations included in the *Quality Assurance Project Plan (QAPP)*³ and the *Field Manual For Water Quality Sampling*.¹⁰ The types and numbers of QC samples collected for this study are as follows:

Inorganic: (1 full duplicate, 6 partial duplicates, 3 splits, 6 full blanks, 4 partial blanks).
Isotope: (5 duplicates, 0 splits, 0 blanks).
Radiochemical: (0 duplicates, 0 splits, 0 blanks).
Radon: (0 duplicates, 0 splits, 0 blanks).

Based on the QA/QC results which follow, 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 deionized water were not impacting the groundwater quality sampling.¹⁰ Equipment blank samples for major ion and nutrient analyses were collected by filling unpreserved and sulfuric acid preserved bottles with deionized water. Equipment blank samples for trace element analyses were collected with deionized 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.²³ As such, SC-lab and turbidity were considered to be affected by systematic contamination; however, the extent of contamination was not considered significant. Both SC and turbidity were detected in all six equipment blanks. SC had a mean level of 2.6 F S/cm which was less than 1 percent of the SC mean level for the study. The SC detections may be explained in two ways: water passed through a deionizing exchange unit will normally have an SC value of at least 1 F S/cm, and carbon dioxide from the air can dissolve in deionized water with the resulting bicarbonate and hydrogen ions imparting the observed conductivity.³² Similarly,

turbidity had a mean level of 0.035 ntu, less than 1 percent of the turbidity median level for the study. Testing indicates turbidity is present at 0.01 ntu in the deionized water supplied by the ADHS laboratory, and levels increase with time due to storage in ADEQ carboys.³⁴ No other constituents were detected in the blanks.

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.¹⁰ Duplicate samples were collected from sampling sites that were believed to have elevated constituent concentrations as judged by field SC values.

Variability in constituent concentrations between each pair of duplicate samples is provided both in terms of absolute levels and as the percent difference. Percent difference is defined as the absolute difference between levels in the duplicate samples divided by the average level for the duplicate samples, multiplied by 100. Only constituents having levels exceeding the Minimum Reporting Level (MRL) were used in this analysis. Most constituents were examined using one duplicate sample, cations and trace elements were examined using seven duplicate samples.

Analytical results indicate that of the 37 constituents examined, only 14 had any quantitative difference (**Table 5**). Two constituents, barium and selenium, were each detected near the MRL by one lab, the other lab reporting a non-detect. The maximum difference between duplicate constituents never exceeded 10 percent with the exception of turbidity (15 percent) and copper (67%). Turbidity values can be impacted by the exceedance of this parameter's holding time³⁴; this occurred frequently during the study. Although copper had a high percentage difference, it had a relatively small concentration difference (0.013 mg/l). Based on these results, the differences in constituent concentrations of duplicate samples were not considered to significantly impact the groundwater quality data.

Table 11. Summary Results of DET Duplicate Samples from ADHS Laboratory

Parameter	Number	Difference in Percent			Difference in Concentrations		
		Minimum	Maximum	Median	Minimum	Maximum	Median
Physical Parameters and General Mineral Characteristics							
Alkalinity, Total	1	0 %	0 %	0 %	0	0	0
SC (F S/cm)	1	0 %	0 %	0 %	0	0	0
Hardness	1	0 %	9%	0 %	0	10	0
pH-field (su)	1	0 %	1 %	0 %	0	0.1	0
TDS	1	0 %	0 %	0 %	0	0	0
Turbidity (NTU)	1	15 %	15 %	15 %	0.03	0.03	0.03
Major Ions							
Bicarbonate	1	0 %	0 %	0 %	0	0	0
Calcium	7	0 %	7 %	0 %	0	10	0
Magnesium	7	0 %	3 %	0 %	0	1	0
Sodium	7	0 %	3 %	2 %	0	2	1
Potassium	7	0 %	8 %	0 %	0	0.1	0
Chloride	1	0 %	0 %	0 %	0	0	0
Sulfate	1	0 %	0 %	0 %	0	0	0
Nutrients							
Nitrate (as N)	1	0 %	0 %	0 %	0	0	0
Trace Elements							
Arsenic	1	8 %	8 %	8 %	0.001	0.001	0.001
Boron	4	0 %	7%	0%	0	0	0.01
Chromium	3	3%	5%	4%	0.001	0.001	0.001
Copper	1	67%	67%	67%	0.013	0.013	0.013
Fluoride	1	0 %	0 %	0 %	0	0	0
Manganese	1	3%	3%	3%	0.002	0.002	0.002
Zinc	3	0 %	7%	6%	0	0.01	0.004

All units are mg/l except as noted with certain physical parameters

Note: In one duplicate, barium and selenium were detected at near the MRL in one sample and not detected in the other 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.¹⁰ Four inorganic split samples were collected. Analytical results from the split samples 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 38 constituents examined, only 21 had concentrations above MRLs for both ADHS and Del Mar laboratories in at least one sample. The maximum difference between split constituents rarely exceeded 20 percent (**Table 6**). One split sample (DET-4/5) showed fairly major differences (between 32 - 38%) in calcium, magnesium, and hardness which probably was the result of low concentrations of these constituents measured by the Del Mar laboratory. TKN exhibited the largest maximum difference (157%), a pattern which has been found in other ADEQ ambient groundwater studies and is due to the difficulty in analyzing this constituent.^{41 42 43}

Split samples were also evaluated using the non-parametric Sign test to determine if there were any significant (p # 0.05) differences between ADHS laboratory and Del Mar Laboratory analytical results.²³ Results of the Sign test showed that none of the 21 constituents examined had significantly different concentrations between the laboratories.

ADEQ / Rangeland Consulting Company Sampling Comparison - As an additional QA/QC measurement, three wells that were sampled as part of the ADEQ study were compared to samples obtained from the same wells during the same period by the Rangeland Consulting Company. The Rangeland Consulting Company samples were analyzed for major ions, nitrate, and some trace elements by the Soil and Plant Laboratory, Inc of Orange, California.³⁷

Analytical results indicate that of the 12 constituents examined, the maximum difference between sample constituents rarely exceeded 15 percent except for trace elements (**Table 6**). Only chloride concentrations from one well had a higher maximum percentage difference (67%) but there was only a 9 mg/l concentration difference. In contrast, trace elements having small absolute concentration differences often had large percentage differences. This pattern was particularly accentuated with fluoride. These results indicate that a fourth well sampled by Rangeland

Consulting Company (Ralph's Well at Township 27 North, Range 19 West in Section 7) could be included as part of the ADEQ study.

Based on these results, the differences in parameter levels of split samples were not considered to significantly impact the groundwater quality data.

Data Validation

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

Cation/Anion Balances - In theory, water samples exhibit electrical neutrality. Therefore, the sum of milliequivalents per liter (meq/L) of cations must equal the sum of meq/L of anions. However, this neutrality rarely occurs due to unavoidable variation inherent in all water quality analyses. Still, if the cation/anion balance is found to be within acceptable limits, it can be assumed there are no gross errors in concentrations reported for major ions.²⁴

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

SC/TDS - The SC and TDS concentrations measured by contract laboratories were significantly correlated as were field-SC and TDS concentrations (regression analysis, p # 0.01). Typically, the TDS concentration in mg/l should be from 0.55 to 0.75 times the SC in F S/cm for groundwater up to several thousand mg/l.²⁴ Groundwater in which the ions are mostly bicarbonate and chloride will have a factor near the lower end of this range and groundwater high in sulfate may reach or even exceed the upper end. The relationship of TDS to SC becomes undefined for groundwater both with very high and low concentrations of dissolved solids.²⁴

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

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

Table 12. Summary Results of DET 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	4	0%	7%	0	10	ns
SC (FS/cm)	4	0%	3%	0	100	ns
Hardness	4	0%	32%	0	60	ns
pH (su)	4	2%	3%	0.016	0.25	ns
TDS	4	0%	2%	0	10	ns
Turbidity (ntu)	1	7%	7%	6	6	ns
Major Ions						
Calcium	4	0%	35%	0	16	ns
Magnesium	4	2%	38%	0.1	10	ns
Sodium	4	3%	10%	2	10	ns
Potassium	4	13%	37%	0.5	2.4	ns
Chloride	4	0%	21%	0	50	ns
Sulfate	4	0%	7%	0	40	ns
Nutrients						
Nitrate as N	2	9%	18%	0.3	2	ns
TKN	2	117%	157%	0.62	0.74	ns
Trace Elements						
Barium	2	0%	32%	0	0.033	ns
Boron	1	9%	9%	0.06	0.06	ns
Chromium	1	27%	27%	0.006	0.006	ns
Fluoride	4	6%	20%	0.02	0.18	ns
Iron	1	5%	5%	0.3	0.3	ns
Manganese	1	5%	5%	0.01	0.01	ns
Zinc	1	25%	25%	0.022	0.022	ns

All units are mg/l except as noted with certain physical parameters
 ns = No significant (p # 0.05) difference between labs

Table 13. Summary Results of DET ADEQ / Rangeland Consulting Services Sampling

Constituents	Number	Difference in Percent		Difference in Levels		Significance
		Minimum	Maximum	Minimum	Maximum	
Physical Parameters and General Mineral Characteristics						
pH-field (su)	3	1%	3%	0.07	0.25	ns
Major Ions						
Calcium	3	2%	5%	0.5	1	ns
Magnesium	3	4%	5%	0.3	1	ns
Sodium	3	3%	8%	2	3	ns
Potassium	3	0%	6%	0	0.2	ns
Bicarbonate	3	2%	15%	3	20	ns
Chloride	3	7%	67%	8	9	ns
Sulfate	3	0%	10%	0	6	ns
Nutrients						
Nitrate as N	3	5%	12%	0.2	0.6	ns
Trace Elements						
Boron	3	10%	46%	0.03	0.09	ns
Fluoride	3	61%	85%	0.28	1.19	ns
Zinc	3	0%	100%	0	0.10	ns

All units are mg/l except as noted with certain physical parameters
 ns = No significant (p # 0.05) difference between labs

pH - The pH value is closely related to the environment of the water and is likely to be altered by sampling and storage.²⁴ Still, 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, $p \# 0.01$).

Groundwater Temperature/Groundwater Depth - Groundwater temperature measured in the field was compared to groundwater 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.¹² Groundwater temperature and water depth were significantly correlated (regression analysis, $p \# 0.01$).

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

Statistical Considerations

Various methods were used to complete the statistical analyses for the groundwater quality data of this study. All statistical tests were conducted on a personal computer using SYSTAT software.⁵⁰

Data Normality: Initially, data associated with 25 constituents were tested for both non-transformed and log-transformed normality using the Kolmogorov-Smirnov one-sample test with the Lilliefors option.¹³ Results of this test using non-transformed data revealed that five constituents (temperature, pH-field, pH-lab, potassium, and oxygen-18) were normally distributed. This is not unusual as the distribution of many groundwater quality parameters is often not Gaussian or normal, but skewed to the right.²³ The results of the log-transformed test revealed that 17 of the 23 log-transformed constituents were normally-distributed with only SC-field, total alkalinity, bicarbonate, nitrate, TKN, and boron not normally distributed. In summary, 20 percent of non-transformed data were normally-distributed while 74 percent of the log-transformed constituents were normally-distributed.

Spatial Relationships: The parametric analysis of variance (ANOVA) test was applied to investigate the hypothesis that constituent concentrations from groundwater sites in different aquifers, rock types, and/or watersheds of the DET 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. 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 basin aquifers (*alluvial, hardrock, and Lake Mead*), watersheds (western Black Mountains and eastern Cerbat Mountains), and rock types (alluvium, granitic rock, metamorphic rock, volcanic rock, basaltic rock, and sedimentary rock).³²

If the null hypothesis was rejected for any of the tests conducted, the Tukey method of multiple comparisons on the ranks of the data was applied. The Tukey test identified significant differences between constituent concentrations when compared to each possibility within each of the four tests.²³

The ANOVA and Tukey tests are not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.²³ Consequently, they were not calculated for trace parameters such as antimony, arsenic, barium, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel, selenium, silver, thallium, zinc, phenolphthalein alkalinity, carbonate, nitrite, ammonia, and total phosphorus. Highlights of these statistical tests are summarized in the groundwater quality section.

Correlation Between Constituent Concentrations:

In order to assess the strength of association between constituents, their various 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.⁵⁰ The Pearson test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.²³ Consequently, Pearson Correlation Coefficients were not calculated for the same constituents as in spatial relationships.