The background of the cover is a photograph. On the left side, a large, dark, rusted metal water tower stands prominently. In the background, a suspension bridge spans across a body of water, which is Lake Mohave. The surrounding landscape is arid with mountains in the distance under a clear blue sky.

Ambient Groundwater Quality of the Lake Mohave Basin: A 2003 Baseline Study

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Janet Napolitano, Governor
Stephen A. Owens, ADEQ Director

Ambient Groundwater Quality of the Lake Mohave Basin: A 2003 Baseline Study

By Douglas C. Towne
Maps by Lisa Rowe and Larry W. Stephenson

Arizona Department of Environmental Quality Open File Report 2005-08

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Photo Credits: Douglas Towne

Report Cover: *The Burlington Northern Santa Fe (BNSF) Railroad's water tank marks the southern boundary of the Lake Mohave groundwater basin (MHV). To the south is Interstate 40, a natural gas pipeline utilizing the "Old Trails Arch Bridge" which carried Route 66 motorists from 1916 until 1947, the Colorado River, and sharp peaks called "The Needles of the Colorado River" after which Needles, California was named when founded in 1883.*

Other Publications of the ADEQ Ambient Groundwater Monitoring Program

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

Meadview Basin	OFR 05-01, January 2005, 29 p.
San Simon Sub-Basin	OFR 04-02, October 2004, 78 p.
Detrital Valley Basin	OFR 03-03, November 2003, 65 p.
San Rafael Basin	OFR 03-01, February 2003, 42 p.
Lower San Pedro Basin	OFR 02-01, July 2002, 74 p.
Willcox Basin	OFR 01-09, November 2001, 55 p.
Sacramento Valley Basin	OFR 01-04, June 2001, 77 p.
Upper Santa Cruz Basin	OFR 00-06, Sept. 2000, 55 p. (With the U.S. Geological Survey)
Prescott Active Management Area	OFR 00-01, May 2000, 77 p.
Upper San Pedro Basin	OFR 99-12, July 1999, 50 p. (With the U.S. Geological Survey)
Douglas Basin	OFR 99-11, June 1999, 155 p.
Virgin River Basin	OFR 99-04, March 1999, 98 p.
Yuma Basin	OFR 98-07, September, 1997, 121 p.

ADEQ Ambient Groundwater Quality Factsheets (FS):

Lake Mohave Basin	FS 05-21, October 2005, 4 p.
Meadview Basin	FS 05-01, January 2005, 4 p.
San Simon Sub-Basin	FS 04-06, October 2004, 4 p.
Detrital Valley Basin	FS 03-07, November 2003, 4 p.
San Rafael Basin	FS 03-03, February 2003, 4 p.
Lower San Pedro Basin	FS 02-09, August 2002, 4 p.
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Sacramento Valley Basin	FS 01-10, June 2001, 4 p.
Yuma Basin	FS 01-03, April 2001, 4 p.
Virgin River Basin	FS 01-02, March 2001 4 p.
Prescott Active Management Area	FS 00-13, December 2000, 4 p.
Douglas Basin	FS 00-08, September 2000, 4 p.
Upper San Pedro Basin	FS 97-08, August 1997, 2 p. (With the U.S. Geological Survey)

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

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

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

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

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

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

Status of GW Basins in the Ambient Monitoring Program

July 2005

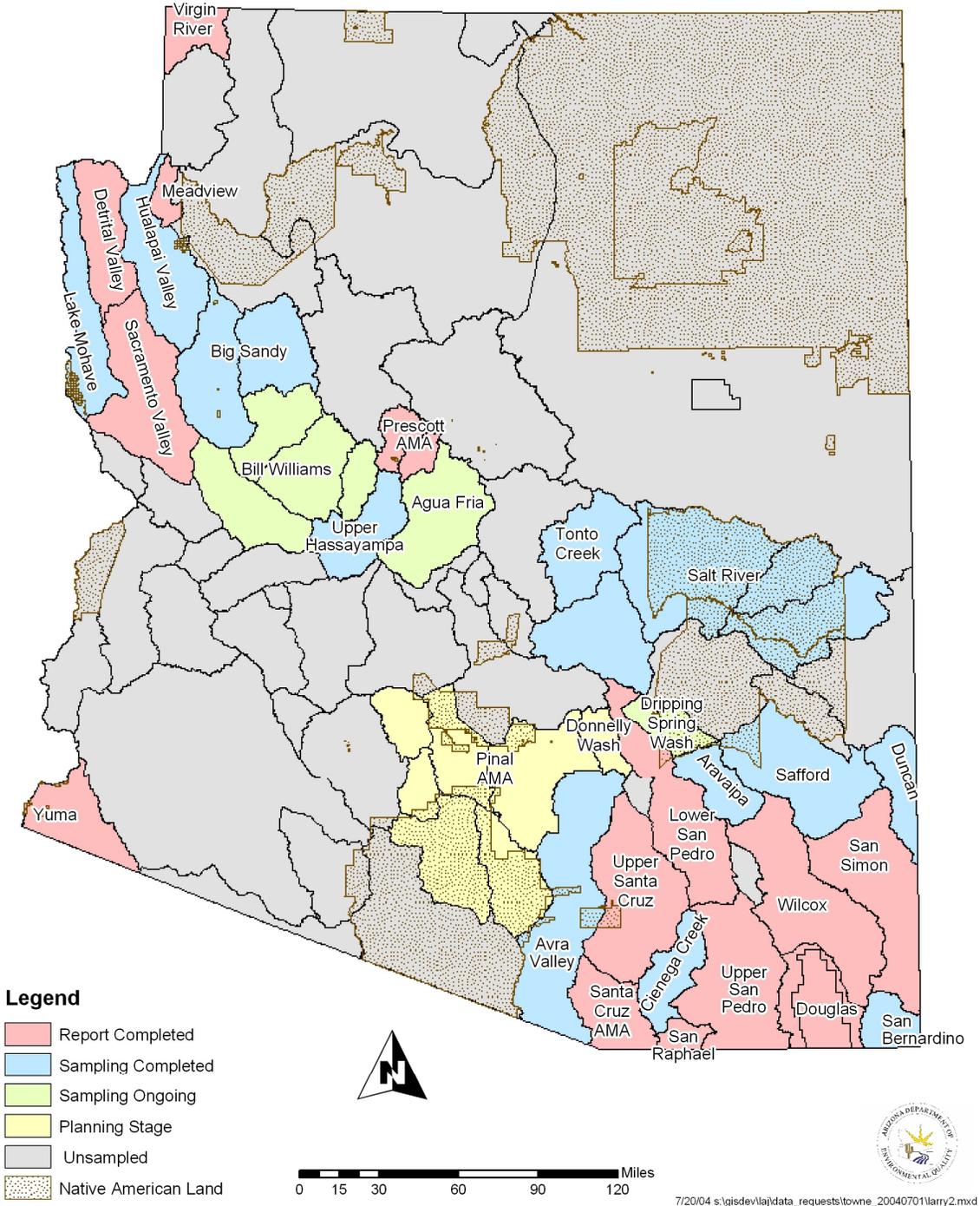


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Abbreviations

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

“The Colorado River has a reputation as party central. For college kids, it’s a popular spring break spot, with cheap hotels, chain restaurants and giant margaritas. But a trip to “the river,” as most of us simply call it, is about more than shenanigans. There are austere beautiful landscapes, places to chill out and curious bits of history.”

James Verini
Los Angeles Times, April 7, 2005

Ambient Groundwater Quality of the Lake Mohave Basin: A 2003 Baseline Study

By Douglas Towne

Abstract - Containing approximately 1,050 square miles, the Lake Mohave groundwater basin (MHV) stretches along the Colorado River from Hoover Dam south to the community of Topock in northwestern Arizona.⁶ A granite outcrop where Davis Dam on the Colorado River is located divides the MHV into North and South basins.²⁴ The North basin consists largely of rugged, undeveloped lands that are part of the Lake Mead National Recreation area. The South basin consists of uplands managed by the Bureau of Land Management and Mohave Valley which is a combination of private, State Trust, and Fort Mohave Indian Reservation lands.⁵ The South basin is a populated, highly developed area. Physically, the MHV is characterized by three distinct geologic features: Colorado River floodplain deposits, piedmont alluvial deposits, and consolidated bedrock of the Black Mountains.²³

In 2003, ADEQ conducted a baseline groundwater quality study of the MHV, a basin that was the focus of four previous Arizona Department of Environmental Quality (ADEQ) groundwater studies since the late 1980s that sampled over 150 wells to investigate links between septic systems and nitrate.^{14, 31, 32} For the 2003 study, 43 groundwater sites were sampled for inorganic constituents and isotopes of oxygen and hydrogen. Samples were also collected at selected sites for radon (31 sites), perchlorate (18 sites), and radiochemistry (15 sites) analyses.

Of the 43 sites sampled, 15 sites 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.^{3, 33} Health-based exceedances included arsenic (2 sites under the current standard, 14 sites under the standard effective in 2006), fluoride (1 site) and nitrate (3 sites). At 31 sites, concentrations of at least one constituent exceeded an aesthetics-based, federal water-quality guideline. These are unenforceable guidelines that define the maximum concentration of a constituent that can be present in drinking water without an unpleasant taste, color, odor, or other effect.³³ Aesthetics-based exceedances included chloride (19 sites), fluoride (8 sites), iron (7 sites), manganese (13 sites), sulfate (24 sites), and total dissolved solids or TDS (30 sites). Perchlorate was not detected at any site.

Because of few sources, sampling in the North basin was limited to 10 sites, including four thermal springs along the Colorado River. Hydrogen and oxygen isotope values revealed four sites recharged by local precipitation; other sites by an indeterminate recharge source.¹⁷ Sites other than thermal springs generally met health based standards.

Groundwater sites in the South basin appeared to consist of 9 sites recharged by pre-dam Colorado River water, 10 sites recharged by post-dam Colorado River water, 12 sites recharged by local precipitation, and 2 sites whose source is the marine-related Bouse Formation.^{17, 26} Their water chemistry varies: Colorado River recharge is higher in chloride and sulfate, local recharge contains more bicarbonate, and the Bouse Formation is sodium-chloride.²⁹

Patterns were found among recharge sources (ANOVA with Tukey test, $p \leq 0.05$).¹⁹ Total dissolved solids (TDS), sodium, chloride, and sulfate were higher at sites recharged by pre/post dam-Colorado River water or tapping the Bouse Formation than at sites recharged by local precipitation. Similarly, calcium, magnesium, and hardness were higher at sites recharged by pre/post-dam Colorado River water than at sites recharged by local precipitation. Arsenic, boron and fluoride were higher at sites tapping the Bouse Formation than at sites recharged by pre/post dam-Colorado River water or local precipitation. Temperature, pH, nitrate, and chromium were higher at sites recharged by local precipitation than from pre/post dam Colorado River water. Finally, total Kjeldahl nitrogen, ammonia, total phosphorus, iron, and manganese were higher at sites recharged by post-dam Colorado River water than at sites recharged by local precipitation, which may indicate that reducing conditions driven by the oxygen demand presented by decomposing soil organic carbon occur along the Colorado River in Mohave Valley.²⁶

In the South basin, groundwater recharged by local precipitation is the preferred domestic source because of its lower salinity and fewer aesthetic water quality standard exceedances. However, sites sometimes exceeded health-based water quality standards for arsenic, which are probably naturally occurring because of long groundwater residence time.²⁶ Groundwater recharged by the Colorado River had fewer health-based water quality standards but was higher in salinity with numerous aesthetics standard exceedances including TDS, sulfate, and chloride. These concentration increases from fresher river water are probably the result of the dissolution of halite and gypsum.²⁶ Sites tapping the Bouse Formation were saline and had both health and aesthetics-based standard exceedances.

INTRODUCTION

Purpose and Scope

The Lake Mohave groundwater basin (MHV) is located in northwestern Arizona within Mohave County (Map 1). The north-south trending basin covers approximately 1,050 square miles along a narrow strip bordering the Colorado River stretching generally from Hoover Dam south to the community of Topock. Groundwater is the primary source for municipal, domestic, irrigation, and stock water uses in the MHV.⁶

The MHV was selected for study because of steady population increases associated with the retirement and recreational opportunities in the Colorado River area and the economic growth of Laughlin, Nevada which is located across the river from the basin=s largest community, Bullhead City.

The Arizona Department of Environmental Quality (ADEQ) Groundwater Monitoring Unit designed a study to characterize the current (2003) groundwater quality conditions in the MHV. 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.”³

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

- Provide a comprehensive baseline study that will help guide the multi-state issues affecting the Colorado River watershed.
- Determine if there are areas where groundwater does not currently meet U.S. Environmental Protection Agency (EPA) Safe Drinking Water Act (SDWA) water quality standards.³³

- Examine water quality differences among different recharge sources within the basin.
- Continue the assessment of the groundwater quality of Mohave County that has culminated in ADEQ hydrology reports on the following basins or areas: Bullhead City (1990)¹⁴ (1995)³¹ (1999),³² Mohave Valley (1995),³⁷ Virgin River (1997),²⁷ Sacramento Valley (2000),²⁸ Detrital Valley (2003),²⁹ Meadview (2004),³⁰ Hualapai Valley (forthcoming), and Big Sandy (forthcoming).

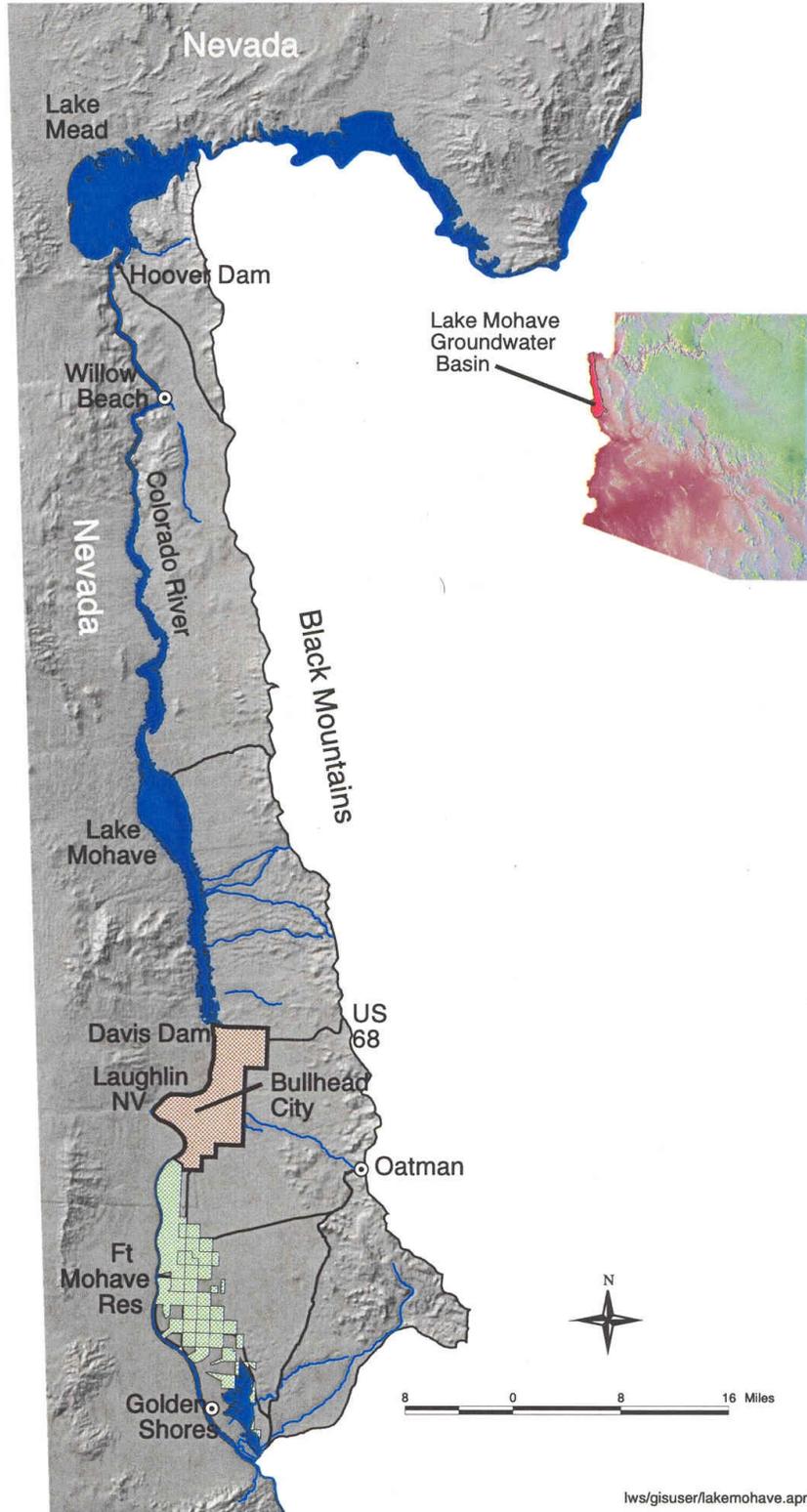
In addition, groundwater quality data on 19 wells sampled in 1996 by ADEQ for an unpublished study of the Golden Shores area are included in Addendums C, D, and E.

ADEQ collected samples from 43 sites for this groundwater quality assessment of the MHV. Types and numbers of samples collected and analyzed include inorganic constituents (physical parameters, major ions, nutrients, and trace elements) (43 sites), oxygen and hydrogen isotopes (43 sites), radon (31 sites), perchlorate (18 sites), and radiochemistry (15 sites). Three surface water hydrogen and oxygen isotope samples and one perchlorate sample were also collected.

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

- A general characterization of regional groundwater quality. Testing all private wells for a wide variety of groundwater quality concerns is prohibitively expensive. An affordable alternative is this type of statistically-based groundwater study which describes regional groundwater quality and identifies areas with impaired conditions.¹⁹
- A process for evaluating potential groundwater quality impacts arising from a variety of sources including mineralization, mining, agriculture, livestock, septic tanks, and poor well construction.
- Considerations for identifying future locations of public supply wells.

Map 1 Lake Mohave Groundwater Basin



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Physical and Cultural Characteristics

Geography - The MHV is located within the Basin and Range physiographic province which consists of northwest-trending alluvial basins separated by elongated fault-block mountain ranges.⁶ Elongated from north to south, the MHV contains approximately 1,050 square miles. The basin is bounded on the east by the Black Mountains, on the west by the Colorado River, and on the south by a subtle topographic surface water divide just north of the community of Topock (Map 1). The highest point in the basin is Mount Perkins at 5,456 feet above mean sea level (amsc). Elevations descend westward and southward to a low elevation of approximately 500 feet near Topock.⁶

The MHV basin can be separated into northern and southern basins at a bedrock divide consisting of granitic and volcanic rock that extends from the Black Mountains west to Davis Dam north of Bullhead City.⁶ The North basin, characterized by rugged topographic relief, is about 5 -10 miles wide and 55 miles long. The northernmost portions have steep slopes and vertical-walled bedrock canyons; areas to the south have deeply incised alluvial and bedrock slopes.⁸ In the South basin, a piedmont descends on the flanks of the Black Mountains from 100 to 300 feet per mile until encountering the floodplain below Bullhead City. Mohave Valley is five miles wide at its maximum width.²³

The MHV is located in Mohave County; most of the land in the basin is federally managed by the U.S. Bureau of Land Management (BLM) and the Lake Mead National Recreation Area (Map 2). Land management by BLM includes the Mount Nutt Wilderness and the Warm Springs Wilderness, located respectively to the north and south of Route 66 in the Black Mountains. Mohave Valley which is located in the southern portion of the MHV consists of scattered private and State Trust lands, the Fort Mohave Indian Reservation, and the Havasu National Wildlife Refuge, the latter managed by the U.S. Fish and Wildlife Service.⁵

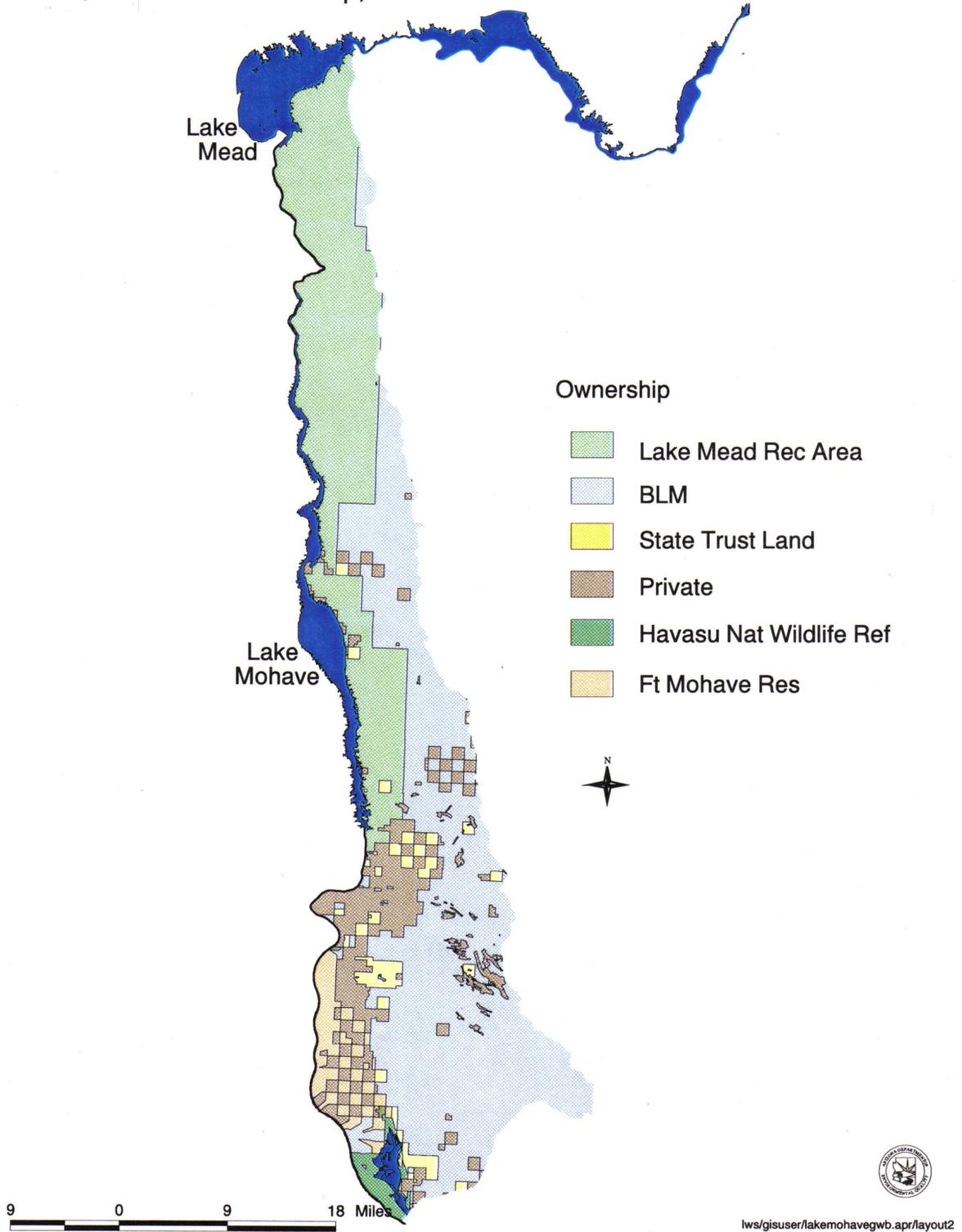
Climate -The climate of the MHV is semiarid, characterized by hot summers and mild winters. Bullhead City averages almost 6 inches of precipitation annually and this amount increases with elevation to 10 inches in the higher mountains.²³ Most rainfall occurs during two periods: gentle storms of long-duration during the winter and intense, short-duration monsoon storms during July and August.

Vegetation - Vegetation varies with precipitation that increases with elevation. The valley floor is characterized by several varieties of cactus, yucca (including Joshua trees), and desert shrubs such as mesquite, creosote bush, and ocotillo. Salt cedar is prevalent along the shoreline of Lake Mohave and the Colorado River. Higher elevation areas evolve into a mix of grasses, chaparral, oak, and juniper.²¹

Surface Water - Stream flow in the MHV is ephemeral and is generated in the mountains in response to summer and winter storms. Surface flow rarely reaches the Colorado River because of evapotranspiration and infiltration. These areas provide most of the local groundwater recharge in the uplands of the MHV.²³ Perennial surface water occurs in Colorado River waters impounded by Lake Mohave (since 1950), along the Colorado River, the associated Topock Marsh located on the east side of the Colorado River and extending from the north side of I-40 to just north of the community of Golden Shores, and a series of thermal springs located downstream from Hoover Dam.^{6, 8} The MHV is within the Colorado-Lower Gila Watershed and the stretch of the Colorado River from Hoover Dam to Lake Mohave is listed on the 303(d) list as “impaired” because of selenium concentrations. In addition, Arizona’s Integrated 305(b) and 303(d) Listing Report indicates that Lake Mohave and an unnamed tributary near Thumb Butte are “inconclusive” due to lack of sampling data.⁴

Development - Most development in the MHV has occurred in Mohave Valley, including the largest community in the basin, Bullhead City. Located along the Colorado River near the junction of Arizona, California, and Nevada, Bullhead City began as headquarters for the construction of Davis Dam in the 1940s. Incorporated in 1984, Bullhead City is currently tied economically to its sister city, Laughlin, Nevada. Laughlin employs around 14,000 people, many in its 11 major casino/resort hotels.¹ The majority of these workers make their home in Bullhead City, which had 35,760 residents in the 2003 census.¹ Mohave Valley also includes many scattered subdivisions, the resort/retirement town of Golden Shores, the Fort Mojave Indian Reservation (which is predominantly located in Arizona but also extends into California and Nevada), and the Mohave Valley Irrigation and Drainage District which had 3,830 acres under cultivation in 1989.⁶ Another community in the MHV is the former gold mining town of Oatman, located along Route 66 in the Black Mountains that now caters to the tourist trade.

Map 2 - Land Ownership, Lake Mohave Groundwater Basin



HYDROLOGY

Geology

The Lake Mohave basin is characterized by three distinct geologic features: river floodplain deposits, piedmont alluvial deposits, and consolidated bedrock (Figure 1).²³

Bedrock - The Black Mountains are rugged and rise abruptly from the pediments, piedmont slopes, or the Colorado River in the bedrock narrows.²³ Bedrock consists predominantly of Tertiary age volcanics, with lesser amounts of Proterozoic age granites. Some sedimentary and metamorphic rock is found in the northern portion of the MHV while Miocene conglomerate and basaltic rock is found in the extreme southeast part of the basin.²⁴

This bedrock is important because no significant movement of groundwater occurs from the permeable rocks adjacent to Lake Mohave and similar rocks below the dam, because the dam and an impermeable granite ridge that extends from the dam to the mountains on both sides effectively block the underflow.^{6, 9}

Groundwater in the bedrock of the Black Mountains generally produces only small yields from fractured areas.²³

Basin-fill - Three units overlie the tilted and faulted bedrock in the following order: the fanglomerate, the Bouse Formation, and the alluviums of the Colorado River.

The fanglomerate represents composite alluvial fans that were deposited from the Black Mountains to the east and dip gently toward the basin to the west and is composed of cemented sands and gravels.²³ The fanglomerate is differentiated only where it underlies the Bouse Formation, elsewhere it is arbitrarily assigned to the older alluviums.²³ The fanglomerate is a potential aquifer based on grain size and degree of cementation.²³

The sharp contact between the fanglomerate and the Bouse Formation represents a change in depositional environments, from land to a shallow marine environment. The Bouse Formation consists of marine brackish water sequence of three units that include a basal limestone, overlain by interbedded clays, silts, sands, and a tuff.²³ The Bouse Formation is thought to have been deposited in an extensional environment as part of the Gulf of California.²³ A thick section of the Bouse Formation is present

underneath the central part of Mohave Valley. Because of the clay beds in the formation, it is expected that the Bouse has a low permeability in the area.²³

Floodplain - The Colorado River floodplain from Davis Dam southward about 10 miles is narrow then widens reaching a width of 5 miles in Mohave Valley. The floodplain is generally bounded by a terrace. Alluvium consist of two units: the younger alluvium that include younger floodplain deposits, colluviums and wash deposits; and older alluvium of interbedded river sands, silts, clays, gravels and cobbles.²³ In general, the contact between the older and younger alluvium is at the present floodplain of the Colorado River and alluvial deposits.²³

The alluvium of the Colorado River are the result of several periods of extensive degradation and aggradation and are a heterogeneous mixture of gravel, sand, silt, and clay which yield large amounts of water from relatively shallow wells. They are commonly treated as a composite aquifer because of the obvious hydraulic continuity between the alluvium units as well as the difficulty of separating them on the basis of subsurface data. Wells that penetrate a significant thickness of gravel in the alluvium are reported to have specific capacities more than 400 gallons per minute (gpm) per foot of draw down.²³ Groundwater in this area exists under unconfined, shallow water table conditions.

Hydrologic Characteristics

Under natural conditions, the Colorado River annually overflowed its banks inundating much of the floodplain. The construction of Hoover Dam in 1936 ended the annual turbid spring floods and scoured the channel because controlled, relatively clear water was released from the dam.²³

Since the filling of Lake Mohave in 1950, water from the lake has moved outward into the unconsolidated rock units adjacent to the lake, which are saturated below the approximate mean lake-surface altitude of 645 feet.⁹

The Colorado River loses water to groundwater throughout its course through Mohave Valley.²³ Groundwater discharge from aquifers to the Colorado River is negligible except along the river near Topock where it is typically a gaining stream from June through January, a losing stream from February through March, and is transitional from March through June.²³ Tributary inflow associated with

Sacramento Wash may have created a groundwater mound in this area.³⁶

Locally, groundwater flows away from the Colorado River in an east-southeast direction while the regional groundwater flow roughly follows the axis of the Colorado River in a south-southwest direction. Groundwater flows affected by the narrowing of flow at Topock Gorge at the bottom of the basin may turn northeasterly⁶

Water levels generally are between 9 and 12 feet below land surface (bls) in the floodplain and equilibrate with 3 feet of the river elevation. On the alluvial slopes that border the floodplain, the depth to water is governed largely by the height of the land surface above the water level in the floodplain.²³

Recharge to groundwater results from Colorado River, unused irrigation water, underflow from bordering areas, and runoff from local precipitation.²³ The Colorado River is the primary source of recharge to the groundwater system. Recharge from local precipitation occurs in sandy washes and only the runoff from high intensity rains contribute.

In the South basin, four water-bearing units make up the MHV based on different recharge sources:

- Local recharge composed of water recharged from local precipitation is found at sites located in upland areas of the basin and near the Golden Shores area. These include areas of mountain bedrock in the Oatman area and alluvium near Golden Shores.
- Pre-dam Colorado River recharge composed of water recharged by the Colorado River prior to 1936 is generally found at floodplain sites most distant from the current river channel.
- Post-dam Colorado River recharge composed of water recharged by the Colorado River water after 1936 is generally found at sites adjacent to the current river channel. These sites stretch from the granite groundwater divide near Davis Dam south to the Topock Marsh and include most of the Bullhead City area and Mohave Valley.
- The Bouse Formation composed of water dating to the Pliocene age is found at selected sites beneath the central part of the Mohave Valley.

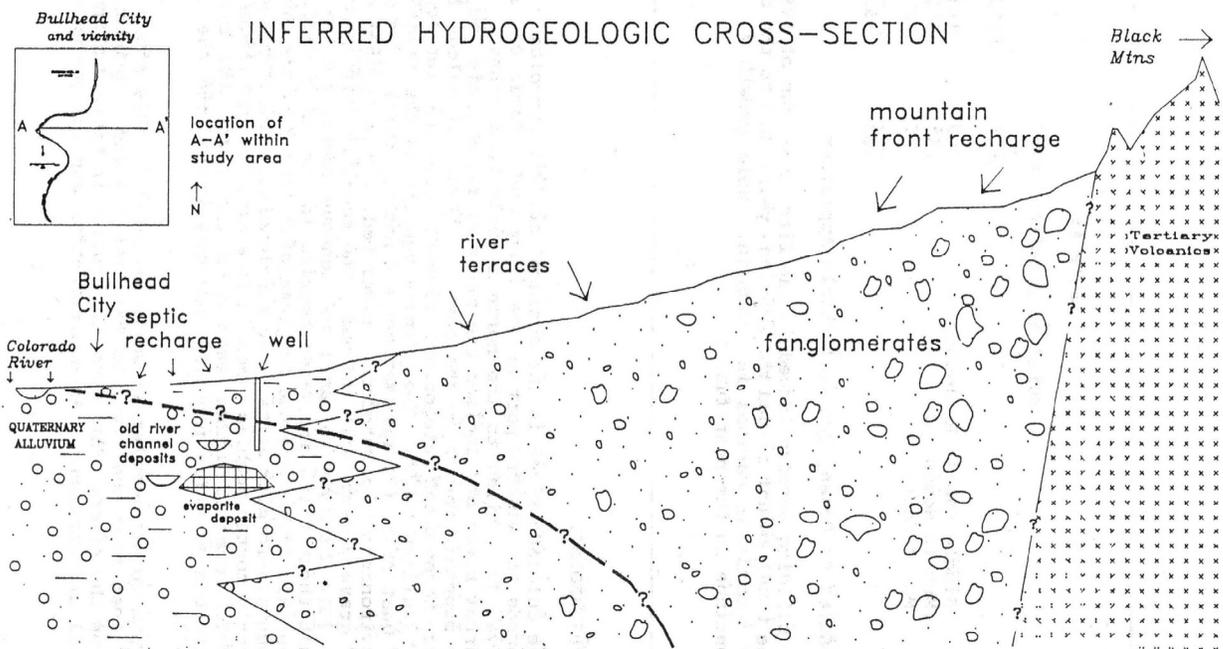


Figure 1. Inferred Hydrogeologic Cross-Section between Bullhead City and the Black Mountains.¹⁴



Figure 2 – Probably the only perennial waterfall in the basin, Sugarloaf Spring (MHV-16) pours into the Colorado River about a mile south of Hoover Dam. The spring existed previous to the dam.⁸



Figure 3 – ADEQ's Elizabeth Boettcher samples Sugarloaf Spring (MHV-16) at its source about a half mile from the Colorado River amidst the rugged terrain just south of Sugarloaf Peak.



Figure 4 – The white calcium-carbonate deposits along the shoreline of Lake Mead illustrate the low water levels found in 2003 in this water body formed by Hoover Dam. Construction on this concrete arch impoundment was started in 1931 and completed in 1936.⁶



Figure 5 – The Katherine Mine Well utilizes the 700-foot main shaft of an abandoned gold mine to produce water for public supply.⁹ Split samples (MHV-41/42) from this well met all health-based water quality standards.



Figure 6 – Doug Wall of North Mohave Water Company assists ADEQ’s Elizabeth Boettcher in sampling Well #2 (MHV-22). This 1300 foot-deep well is recharged from local precipitation. In the background is Laughlin, Nevada.

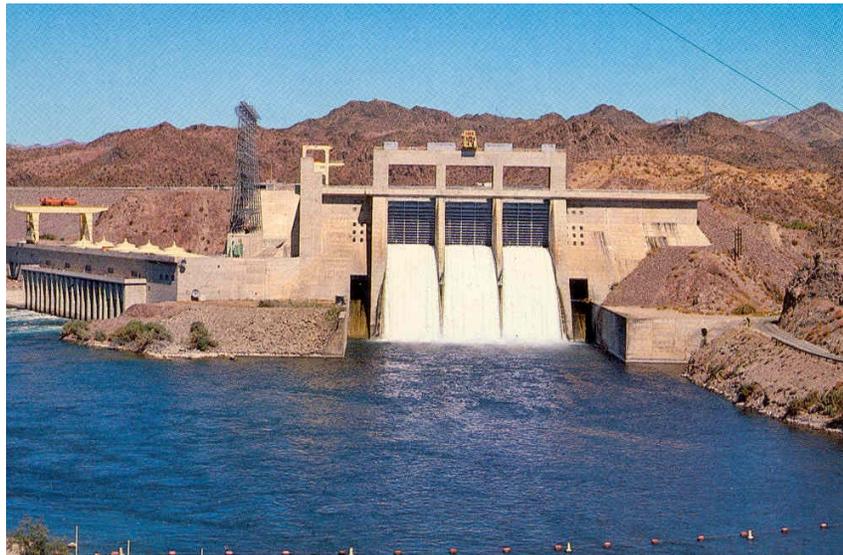


Figure 7 – Located 67 miles downstream from Hoover Dam, Davis Dam is an earthfill impoundment finished in 1950 that forms Lake Mohave, a long narrow reservoir that is four miles wide as its maximum, has a capacity of 1.8 million acre-feet.⁶

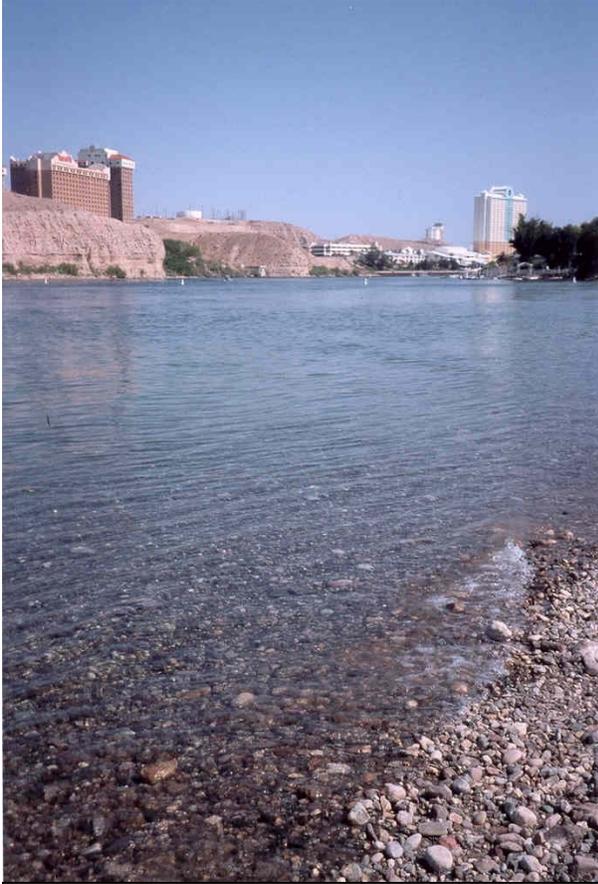


Figure 8 – Population growth in Bullhead City is linked to the balmy winter climate, inexpensive cost of living, and the development of the resort town of Laughlin, Nevada across the Colorado River.



Figure 9 – ADEQ’s Elizabeth Boettcher samples a 170-foot deep well (MHV-39) serving a trailer park near Bullhead City. Throughout much of Mohave Valley, residences are served by private wells.



Figure 10 – Purging the production well at Tri-State Refuse near Bullhead City. Duplicate samples (MHV-32/33) from this well exceeded aesthetic standards for TDS, chloride and sulfate, which are common in wells recharged by Colorado River water.



Figure 11 – A shallow well in southern Mohave Valley shows the effects of scale build-up. A nearby well (MHV-20) had hardness concentrations of 2,200 milligrams per Liter (mg/L) and TDS concentrations of 4,900 mg/L.



Figure 12 – With TDS concentrations from Mohave Valley wells typically exceeding 1,000 mg/L, twice the aesthetics-based water quality standard, “Fresh Salt Free Water” vending machines are popular in the area.

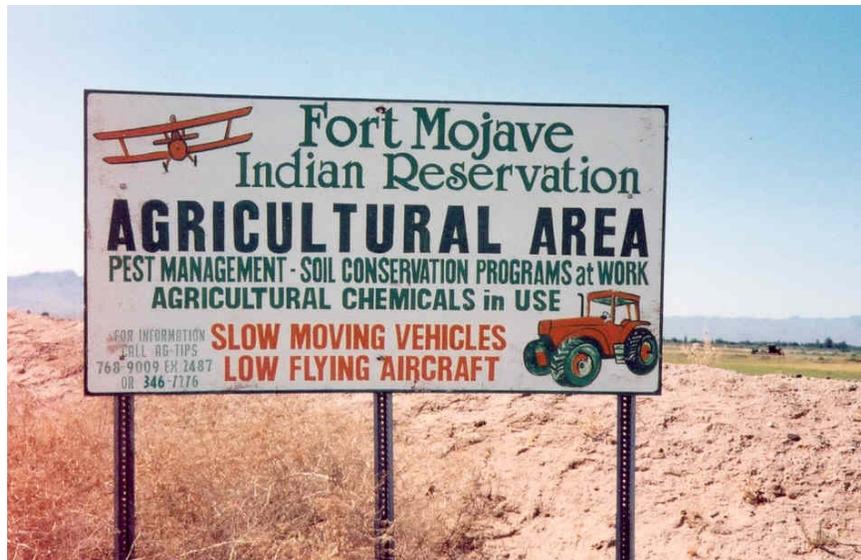


Figure 13 – A checkerboard pattern of lands owned by the Fort Mojave Indian Reservation and private interests occurs in Mohave Valley. Much of the reservation lands are still in agricultural production while private lands are increasingly developed for residential use.

GROUNDWATER SAMPLING RESULTS

To characterize the regional groundwater quality of the MHV basin, ADEQ personnel sampled 43 groundwater sites consisting of 36 wells and 7 springs. The wells were equipped with submersible pumps and used for domestic and/or municipal use. The springs were used for livestock watering. Information on these groundwater sample sites is provided in Appendix A.

At the 43 sites, the following types of samples were collected: inorganics at 43 sites, hydrogen and oxygen isotopes at 43 sites, radon at 31 sites, perchlorate at 18 sites, and radiochemistry at 15 sites. Perchlorate and radiochemistry samples were collected at sites deemed most likely to have detections and/or elevated concentrations. Three surface water samples for hydrogen and oxygen isotopes and one perchlorate were also collected to allow comparison with groundwater samples.

Water Quality Standards/Guidelines

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

- Federal Safe Drinking Water (SDW) Primary Maximum Contaminant Levels (MCLs). These enforceable health-based standards establish the maximum concentration of a constituent allowed in water supplied by public systems.³³
- State of Arizona Aquifer Water Quality Standards. These apply to aquifers that are classified for drinking water protected use.³ All aquifers within Arizona are currently classified and protected for drinking water use unless otherwise reclassified. To date no aquifers have been reclassified. These enforceable State standards are almost identical to the federal Primary MCLs.
- Federal SDW Secondary MCLs. These non-enforceable aesthetics-based guidelines define the maximum concentration of a

constituent that can be present without imparting unpleasant taste, color, odor, or other aesthetic effect on the water.³³

Health-based drinking water quality standards (such as Primary MCLs) are based on a lifetime consumption of two liters of water per day and, as such, are chronic not acute standards.³³

MHV Sites - Of the 43 sites sampled for the MHV study, only 9 (21 percent) met all SDW Primary and Secondary MCLs.

Health-based Primary MCL water quality standards and State aquifer water quality standards were exceeded at 15 of 43 sites (35 percent) (Map 3) (Table 1). Constituents exceeding Primary MCLs include arsenic (2 sites under the current standard, 14 sites under the standard which take effect in 2006), fluoride (1 site), and nitrate (3 sites). Potential health effects of these chronic Primary MCL exceedances are provided in Table 1.^{33, 35} A constituent of particular interest in the area, chromium, did not exceed its Primary MCL in any sample site.

Aesthetics-based Secondary MCL water quality guidelines were exceeded at 31 of 43 sites (72 percent) (Map 3) (Table 2). Constituents above Secondary MCLs include chloride (19 sites), fluoride (8 sites), iron (7 sites), manganese (13 sites), sulfate (24 sites), and TDS (30 sites).

Radon is a naturally occurring, intermediate breakdown product from the radioactive decay of uranium-238 to lead-206.¹² Different opinions exist on the risk assessment of radon in drinking water, with proposed drinking water standards varying from 300 pCi/L to 4,000 pCi/L.¹² Of the 31 sites sampled for radon, 7 exceeded the proposed 300 pCi/L standard; none exceeded the proposed 4,000 pCi/L standard.

Perchlorate was not detected in any of the groundwater samples that were mainly collected from shallow floodplain wells. Perchlorate was detected (4.4 ug/L) in the single surface water sample (MHV-37) ADEQ collected from the Colorado River near Needles. No drinking water standard has yet been established for perchlorate.

North Basin - The North basin of the MHV stretches from the Hoover Dam area along the west flank of the Black Mountains to the Colorado River south to the granite bedrock barrier where Davis Dam is located.⁶ Most of this basin is part of the Lake Mead National Recreation Area and there is little water

Map 3 Water Quality Status

Legend

MHV Sample Site Exceedances

- None
- Secondary MCL
- Primary MCL
- P & S MCLs
- Towns
- - - Lake Mohave Groundwater Basin
- Streams
- Roads
- Lakes



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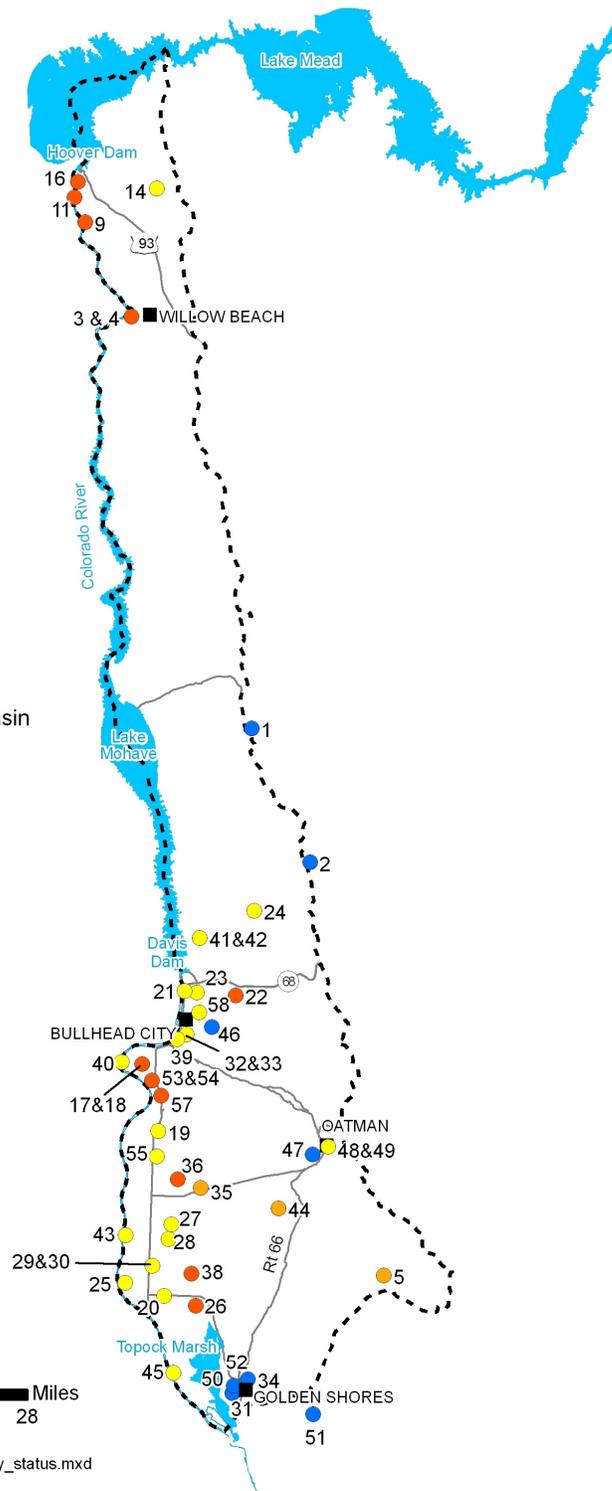


Table 1. MHV Sites Exceeding Health-Based Water Quality Standards (Primary MCLs)

Constituent	Primary MCL	Sites Exceeding Primary MCL	Concentration Range of Exceedances	Potential Health Effects of MCL Exceedances *
Nutrients				
Nitrite (NO ₂ -N)	1.0	0	-	
Nitrate (NO ₃ -N)	10.0	3	10 – 15	Methemoglobinemia
Trace Elements				
Antimony (Sb)	0.006	0	-	
Arsenic (As)	0.05 0.01**	2 14	0.012 – 0.096	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	1	4.0	Skeletal damage
Lead (Pb)	0.015	0	-	
Mercury (Hg)	0.002	0	-	
Nickel (Ni)	0.1	0	-	
Selenium (Se)	0.05	0	-	
Thallium (Tl)	0.002	0	-	
Radiochemistry Constituents				
Gross Alpha	15	0	-	
Ra-226 + Ra-228	5	0	-	
Uranium	30	0	-	

All units in mg/L except gross alpha and radium-226+228 (pCi/L), and uranium (•g/L). Source: ^{33, 35}

* Health-based drinking water quality standards are based on a lifetime consumption of two liters of water per day (USEPA).

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

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

Constituents	Secondary MCL	Sites Exceeding Secondary MCLs	Concentration Range of Exceedances	Aesthetic Effects of MCL Exceedances
Physical Parameters				
pH - field	6.5 to 8.5	0	-	
General Mineral Characteristics				
TDS	500	30	590 – 4,900	Unpleasant taste
Major Ions				
Chloride (Cl)	250	19	260 – 1,550	Salty taste
Sulfate (SO ₄)	250	24	250 – 1,800	Rotten-egg odor, unpleasant taste and laxative effect
Trace Elements				
Fluoride (F)	2.0	8	2.2 – 4.0	Mottling of teeth enamel
Iron (Fe)	0.3	7	0.30 – 2.5	Rusty color, reddish stains and metallic tastes
Manganese (Mn)	0.05	13	0.88 – 2.1	Black stains and bitter taste
Silver (Ag)	0.1	0	-	
Zinc (Zn)	5.0	0	-	

All units mg/L except pH is in standard units (su). Source: ^{20, 33, 35}

development. As such, sample collection was limited to 10 sites. Of these 10 sites, four were wells (two public water supply, one domestic, and one stock) and six were springs. Of the six spring sites, four of the spring samples were collected from thermal springs located just downgradient from Hoover Dam.

Of these 10 sites, two sites near the crest of the Black Mountains met all health and aesthetic water quality standards, three sites (two near Davis Dam, one near the crest of the Black Mountains) had aesthetic water quality exceedances, and five sites along the Colorado River immediately south of Hoover Dam had health and aesthetic water quality standards. The health-based exceedances were all from elevated arsenic concentrations while aesthetics-based exceedances included chloride, fluoride, sulfate, and TDS.

South Basin - The South basin of the MHV stretches from Davis Dam to Topock. There is intensive water development in the South basin stemming from municipal, domestic and irrigation uses especially in Mohave Valley. Fewer samples sites are available in upland areas.

Of the 33 sites sampled, based on oxygen and hydrogen isotope values, 9 sites consisted of recharged pre-dam Colorado River water, 10 sites consisted of recharged post-dam Colorado River water, 12 sites consisted of recharged local precipitation, and 2 sites consisted of water from the Bouse Formation (Figure 16).

The 19 sites that consisted of recharged Colorado River water all had aesthetics-based exceedances including TDS, chloride, sulfate, and fluoride; post-dam recharged Colorado River water also had iron, and manganese exceedances. Four sites had health-based water quality standards with arsenic and nitrate at one site. Of the 12 sites consisting of local precipitation, 7 sites had no water quality exceedances, 4 sites had health-based water quality exceedances (mainly arsenic), and 1 site had aesthetic-based exceedances. The two samples from the Bouse Formation (based on water quality characteristics) had both health and aesthetics-based standard exceedances.

Suitability for Irrigation

The groundwater at each sample site was assessed as to its suitability for irrigation use based on salinity and sodium hazards. With increasing salinity, leaching, salt tolerant plants, and adequate drainage

are necessary. Excessive levels of sodium are known to cause physical deterioration of the soil.³⁴ Irrigation water may be classified using specific conductivity (SC) and the Sodium Adsorption Ratio (SAR) in conjunction with one another.³⁴ Groundwater sites in the MHV basin display a wide range of irrigation water classifications with salinity hazards generally greater than sodium hazards. The 43 sample sites are divided into the following salinity hazards: low or C1 (0), medium or C2 (13), high or C3 (14), and very high or C4 (16). The 43 sample sites are divided into the following sodium or alkali hazards: low or S1 (28), medium or S2 (11), high or S3 (2), and very high or S4 (2). Sites tapping the Bouse Formation had both high salinity and sodium hazards; sites with recharged Colorado River water generally had salinity hazards.

Analytical Results

Analytical inorganic and radiochemistry results of the 43 MHV sample sites are summarized (Table 3) using the following indices: minimum reporting levels (MRLs), number of sample sites over the MRL, upper and lower 95 percent confidence intervals (CI_{95%}), and the median and mean. Confidence intervals are a statistical tool which indicates that 95 percent of a constituent's population lies within the stated confidence interval.¹⁹ Specific constituent information for each groundwater site is found in Appendix B.

MHV GROUNDWATER COMPOSITION

General Summary

Groundwater in the Lake Mohave basin is *slightly alkaline, fresh, and moderately hard-to-very hard* as indicated by pH values and TDS and hardness concentrations. Levels of pH were *slightly alkaline* (above 7 SU) at the 43 sites measured.¹⁸ TDS concentrations were considered *fresh* (below 1,000 mg/L) at 21 sites, *slightly saline* (1,000 to 3,000 mg/L) 18 sites, and *moderately saline* (3,000 to 10,000 mg/L) at 4 sites.¹⁸ Hardness concentrations were divided into *soft* (below 75 mg/L) at 3 sites, *moderately hard* (75 to 150 mg/L) at 6 sites, *hard* (150 to 300 mg/L) at 13 sites, and *very hard* (above 300 mg/L) at 21 sites.¹³

Nitrate, TKN, ammonia, and total phosphorus were detected at more than 20 percent of the sites. Nitrate (as nitrogen) concentrations were divided into natural background (15 sites < 0.2 mg/L), may or may not indicate human influence (11 sites between 0.2 to 3.0

Table 3. Summary Statistics for Lake Mohave Basin Groundwater Quality Data

Constituent	Minimum Reporting Limit (MRL)	Number of Samples Over MRL	Lower 95% Confidence Interval	Median	Mean	Upper 95% Confidence Interval	Colorado River Mean at Peach Spr
Physical Parameters							
Temperature (C)	N/A	43	25.1	27.1	27.0	29.1	13.4
pH-field (su)	N/A	43	7.47	7.56	7.57	7.68	8.06
pH-lab (su)	0.01	43	7.64	7.70	7.73	7.81	-
Turbidity (ntu)	0.01	40	0.38	0.23	2.31	4.23	109
General Mineral Characteristics							
T. Alkalinity	2.0	43	154	150	189	216	142
Phenol. Alk.	2.0	0	> 50% of data below MRL				
SC-fld (uS/cm)	N/A	43	1584	1796	2078	2571	-
SC-lab (uS/cm)	N/A	43	1623	1800	2153	2683	897
Hardness-lab	10.0	43	358	280	511	663	273
TDS	10.0	43	1039	1100	1397	1755	585
Major Ions							
Calcium	5.0	43	104	87	144	186	70
Magnesium	1.0	41	24	21	36	48	24
Sodium	5.0	43	192	175	269	346	78
Potassium	0.5	43	5.3	5.7	7.1	8.8	3.5
Bicarbonate	2.0	43	187	180	225	263	169
Carbonate	2.0	0	> 50% of data below MRL				
Chloride	1.0	43	241	372	220	503	72
Sulfate	10.0	43	257	320	377	498	203
Nutrients							
Nitrate (as N)	0.02	34	1.7	2.8	2.0	3.9	0.3
Nitrite (as N)	0.02	0	> 50% of data below MRL				
Ammonia	0.02	12 *	> 50% of data below MRL				
TKN	0.05	32	0.12	0.09	0.23	0.35	-
T. Phosphorus	0.02	11	> 50% of data below MRL				

Table 3. Summary Statistics for Lake Mohave Basin Groundwater Quality Data—Continued

Constituent	Minimum Reporting Limit (MRL)	Number of Samples Over MRL	Lower 95% Confidence Interval	Median	Mean	Upper 95% Confidence Interval	Colorado River Mean at Peach Spr
Trace Elements							
Antimony	0.005	0		> 50% of data below MRL			
Arsenic	0.01	14		> 50% of data below MRL			
Barium	0.1	4		> 50% of data below MRL			
Beryllium	0.0005	0		> 50% of data below MRL			
Boron	0.1	41	0.26	0.24	0.35	0.45	0.10
Cadmium	0.001	0		> 50% of data below MRL			
Chromium	0.01	10		> 50% of data below MRL			
Copper	0.01	0		> 50% of data below MRL			
Fluoride	0.20	35	0.7	0.8	1.1	1.4	0.30
Iron	0.1	10		> 50% of data below MRL			
Lead	0.005	2		> 50% of data below MRL			
Manganese	0.05	13		> 50% of data below MRL			
Mercury	0.0005	1		> 50% of data below MRL			
Nickel	0.1	0		> 50% of data below MRL			
Selenium	0.005	0		>50% of data below MRL			
Silver	0.001	0		> 50% of data below MRL			
Thallium	0.005	0		> 50% of data below MRL			
Zinc	0.05	4		> 50% of data below MRL			
Radiochemical Constituents							
Radon*	Varies	31	149	174	248	348	
Gross Alpha*	Varies	15	2.7	3.1	4.9	7.1	
Gross Beta*	Varies	12	4.2	6.6	6.3	8.4	
Ra-226*	Varies	2		> 50% of data below MRL			
Uranium**	Varies	0		> 50% of data below MRL			
Isotopes							
Oxygen***	N/A	43	-12.1	-10.9	-11.5	-10.8	
Hydrogen ***	N/A	43	-94.3	-85.0	-89.1	-83.9	

All units mg/L except where noted or * = pCi/L, ** = •g/L, and *** = 0/00 * ammonia only analyzed in samples from 39 sites

mg/L), may result from human activities (14 sites between 3.0 to 10 mg/L), and probably result from human activities (3 sites > 10 mg/L).²²

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

Constituent Covariation

The co-variation of constituent concentrations was determined to scrutinize the strength of the association. The results of each combination of constituents were examined for statistically-significant positive or negative correlations. A **positive correlation** occurs when, as the level of a constituent increases or decreases, the concentration of another constituent also correspondingly increases or decreases. A **negative correlation** occurs when, as the concentration of a constituent increases, the concentration of another constituent decreases, and vice-versa. A positive correlation indicates a direct relationship between constituent concentrations; a negative correlation indicates an inverse relationship.³⁸

Many significant correlations occurred among the 43 Lake Mohave basin sites (Pearson Correlation Coefficient test, $p < 0.05$). Two general groups of correlations were identified. Positive correlations occurred among calcium, magnesium, hardness, sulfate, iron, manganese, and ammonia; negative correlations with these constituents often occurred with pH. Positive correlations also occurred among sodium (Figure 14), potassium, chloride (Figure 14), arsenic, boron, and fluoride.

Other positive correlations occurred between TDS and the following constituents: SC, hardness, calcium, sodium, potassium, chloride, sulfate, and boron. Oxygen and hydrogen isotope values were negatively correlated with temperature, sodium, arsenic, and boron.

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

Spatial Variation

Analytical results were compared between the northern and southern basins to identify significant differences in concentrations of groundwater quality constituents. Significant concentration differences were found with only six constituents: oxygen, deuterium, boron, and fluoride were higher in the north basin; the opposite pattern was found with temperature and manganese (ANOVA test, ≤ 0.01 for oxygen, temperature, and boron, 0.05 for other constituents).

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.¹¹ This is accomplished by comparing oxygen-18 isotopes ($\bullet^{18}\text{O}$) and deuterium ($\bullet\text{D}$), an isotope of hydrogen, data to the Global Meteoric Water Line (GMWL). The GMWL is described by the linear equation:

$$\bullet\text{D} = 8\bullet^{18}\text{O} + 10$$

where $\bullet\text{D}$ is deuterium in parts per thousand (per mil, ‰), 8 is the slope of the line, $\bullet^{18}\text{O}$ is oxygen-18 ‰, and 10 is the y-intercept.¹¹ 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.¹¹ The LMWL created by $\bullet^{18}\text{O}$ and $\bullet\text{D}$ values for samples collected at sites in the MHV were compared to the GMWL. The $\bullet\text{D}$ and $\bullet^{18}\text{O}$ data lie to the right of the GMWL. 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.¹¹

Groundwater from arid environments is typically subject to evaporation, which enriches $\bullet\text{D}$ and $\bullet^{18}\text{O}$, resulting in a lower slope value (usually between 3 and 6) as compared to the slope of 8 associated with the GMWL.¹¹ The data for the arid MHV conform to

this theory, having a slope of 7.84, with the LMWL described by the linear equation:

$$\bullet D = 7.84^{18}O + 0.50$$

The MHV LMWL is higher than other nearby basins such as Detrital Valley (5.15) and Sacramento Valley (5.5) because of the impact of recharged Colorado River water.^{28, 29}

SOUTH BASIN GROUNDWATER COMPOSITION

General Summary

Groundwater in the South basin is *slightly alkaline*, *fresh*, and *moderately hard-to-very hard* as indicated by pH values and TDS and hardness concentrations. Levels of pH were *slightly alkaline* (above 7 SU) at the 33 sites measured.¹⁸ TDS concentrations were considered *fresh* (below 1,000 mg/L) at 17 sites, slightly saline (1,000 to 3,000 mg/L) 13 sites, and moderately saline (3,000 to 10,000 mg/L) at 3 sites.¹⁸ Hardness concentrations were divided into *soft* (below 75 mg/L) at 3 sites, *moderately hard* (75 – 150 mg/L) at 6 sites, *hard* (150 – 300 mg/L) at 9 sites, and *very hard* (above 300 mg/L) at 15 sites.¹³

Nitrate, TKN, ammonia, and total phosphorus were detected at more than 20 percent of the sites. Nitrate (as nitrogen) concentrations were divided into natural background (14 sites < 0.2 mg/L), may or may not indicate human influence (7 sites between 0.2 - 3.0 mg/L), may result from human activities (9 sites between 3.0 - 10 mg/L), and probably result from human activities (3 sites > 10 mg/L).²²

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

Constituent Covariation

Many significant correlations occurred among the 33 South basin sites (Pearson Correlation Coefficient test, $p < 0.05$). Several groups of correlations were identified:

- Positive correlations occurred between TDS and SC, hardness, turbidity, calcium,

sodium, bicarbonate, chloride, sulfate, nitrate, TKN, iron and manganese.

- Negative correlations occurred between fluoride and TDS, SC, hardness, turbidity, calcium, bicarbonate, sulfate, TKN, iron and manganese; a positive correlation occurred with pH-field.
- Positive correlations occurred between calcium and TDS, SC, hardness, turbidity, bicarbonate, chloride, sulfate, nitrate, TKN, iron and manganese.
- Positive correlations occurred between sodium and TDS, SC, turbidity, chloride, sulfate, TKN, iron, and manganese.
- Negative correlations occurred between pH-lab (Figure 15) and TDS, SC, hardness (Figure 15), turbidity, calcium, magnesium, bicarbonate, chloride, TKN, iron and manganese.

Isotope Comparison

The most *depleted*, or isotopically lighter waters are associated with groundwater sites that are recharged by the pre-dam Colorado River water. Slightly higher up the evaporation trajectory are groundwater sites recharged by post-dam Colorado River water. These sites form an evaporation trajectory as a result of time spent in reservoirs on the Colorado River. Isotopic data from the Colorado River obtained during this study are comparable to those obtained from previous studies.^{17, 26} Further up the evaporation trajectory are two sites whose strong sodium-chloride chemistry indicates they are likely producing water from the deep Bouse Formation, a marine brackish water sequence. The most enriched sites or isotopically heavier waters are associated with groundwater sites that are recharged by local precipitation (Figure 16).

Significant differences were found in the $\bullet D$ and $\bullet^{18}O$ between values of sites recharged by the pre-dam Colorado River (9 sites), post-dam Colorado River (10 sites), local precipitation (12 sites), and the Bouse Formation (2 sites) (ANOVA with Tukey Test, $p < 0.01$).

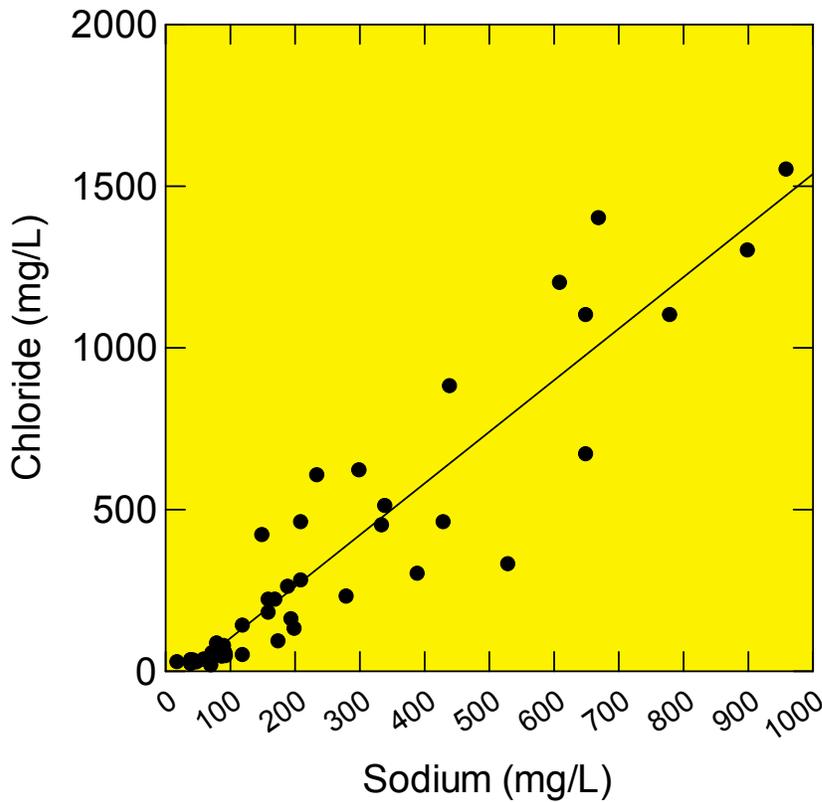


Figure 14 – This graph illustrates the strong relationship in the entire Lake Mohave basin (MHV) between sodium and chloride concentrations described by the equation, $y = 1.6x - 57$ (regression, $p \leq 0.01$). TDS concentrations in the basin are best predicted among major ions and cations by sodium concentrations while among anions, chloride is the best predictor (multiple regression analysis, $p = 0.01$).

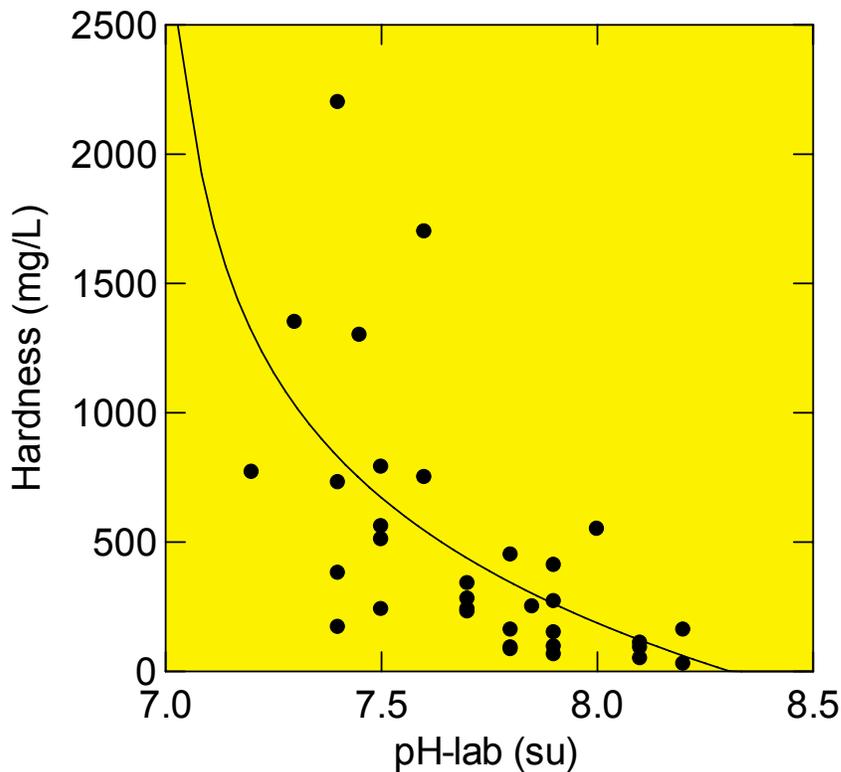


Figure 15 – This graph illustrates the relationship in the MHV South basin between pH-lab and hardness concentrations described by the equation, $y = -1123x + 9139$ (regression, $p \leq 0.01$). This negative correlation has been found in other Arizona groundwater basins and may be related to precipitation of calcite in response to increases in the pH.^{27, 28} Calcium, a major component of hardness, is also more soluble in acidic waters.

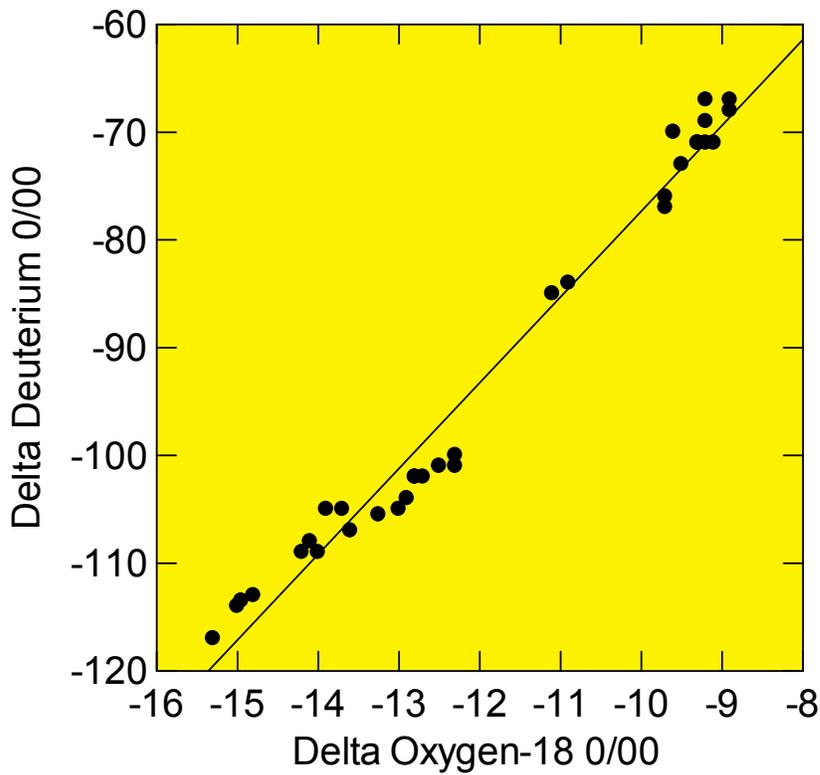


Figure 16 –This graph illustrates the oxygen-18 and deuterium values for the 33 sites sampled in the MHV South basin. Four clusters are apparent on the graph. Lowest on the evaporation trajectory are sites recharged with pre-dam Colorado River water, higher up are sites recharged with post-dam Colorado River water that form an evaporation trajectory, higher up are two sites tapping the Bouse Formation, and highest are sites recharged with local precipitation.¹⁷ Isotope values of these four groups are significantly different from one another (ANOVA with Tukey option, $p \leq 0.01$).

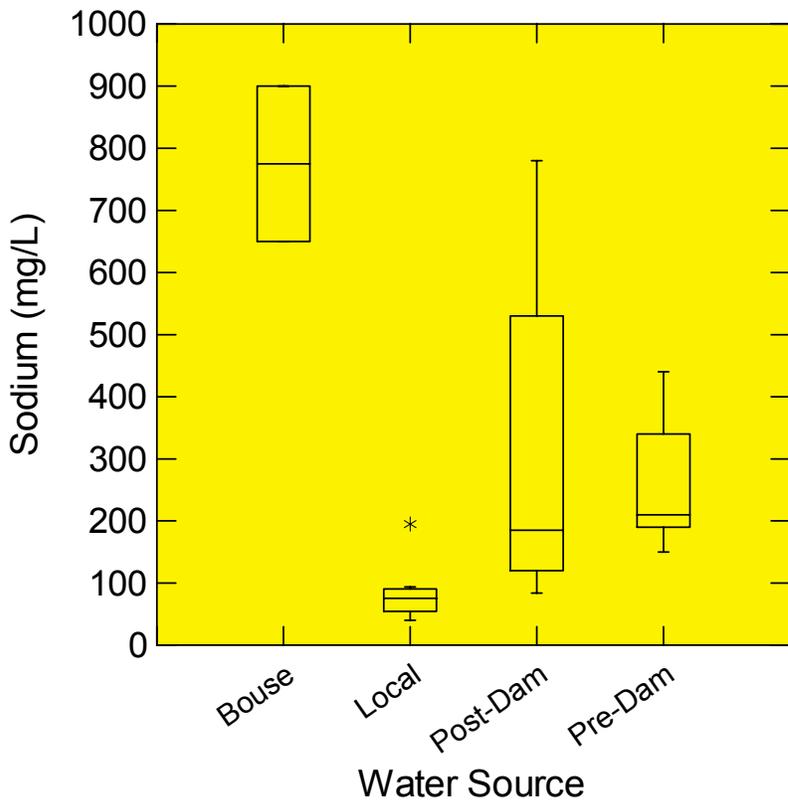


Figure 17 – This boxplot illustrates that sodium concentrations significantly differ between recharge sources in the MHV South basin (ANOVA with Tukey option, $p \leq 0.01$). Local precipitation recharge is significantly less than either pre-dam or post-dam Colorado River recharge or water from the Bouse Formation, a marine to brackish-water sequence.²³ Post-dam recharge is also significantly less than water from the Bouse Formation. There is no significant difference in sodium concentrations between pre-dam and post-dam Colorado River recharge and between pre-dam Colorado River recharge and the Bouse Formation.

Map 2 Groundwater Recharge Source

Legend

MHV Sample Sites

- North - Local Precipitation
- North - Deep Upwelling
- North - Local/Deep Mix
- South - Local Precipitation
- South - Bouse Formation
- South - Post-Dam Col. River
- ▲ South - Pre-Dam Col. River
- Towns

- - - Lake Mohave Groundwater Basin

— Roads

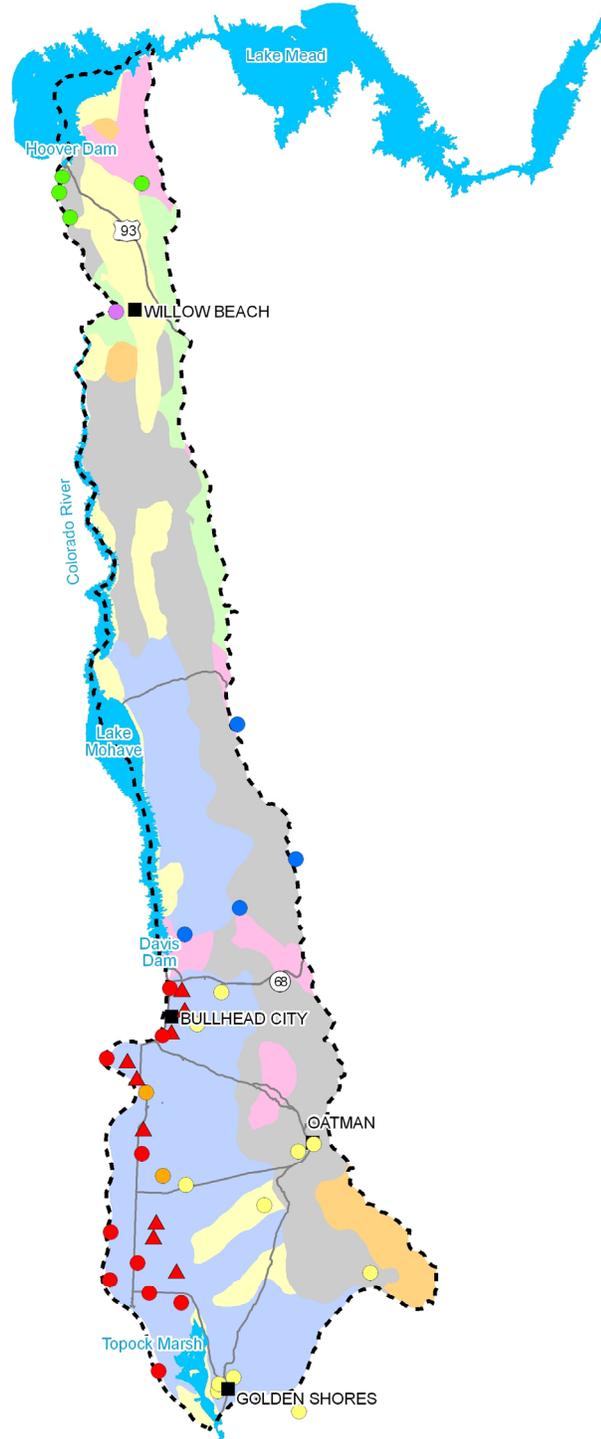
■ Lakes

Geology

- alluvium
- basalt
- granitic
- metamorphic
- sedimentary
- volcanic



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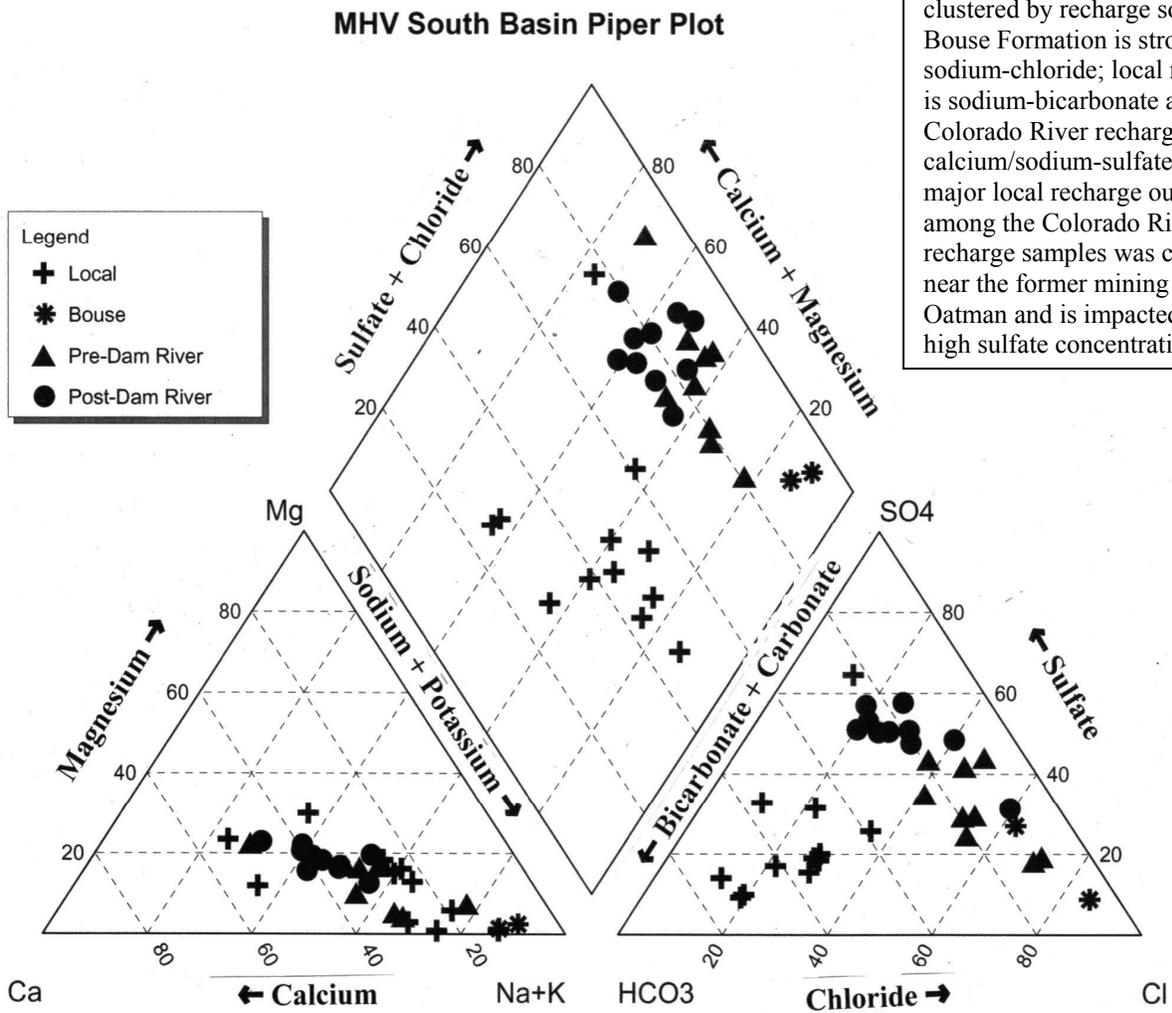


Figure 18 – The piper diagram of MHV South basin shows sample sites are predominantly clustered by recharge source: Bouse Formation is strongly sodium-chloride; local recharge is sodium-bicarbonate and Colorado River recharge is calcium/sodium-sulfate.²³The major local recharge outlier among the Colorado River recharge samples was collected near the former mining town of Oatman and is impacted by high sulfate concentrations.

Groundwater Chemistry

The chemical composition of the 33 sampled sites is illustrated using Piper trilinear diagrams.

- The cation triangle diagram (lower left in Figure 11) shows that the dominant (> 50 percent) cation is calcium at 2 sites, sodium at 19 sites, and mixed at 12 sites.
- The anion triangle diagram (lower right in Figure 11) shows that the dominant anion (> 50 percent) is bicarbonate at 6 sites, sulfate

at 8 sites, chloride at 8 sites, and mixed at 11 sites).

- The cation-anion diamond diagram (in center of Figure 11) shows that the groundwater chemistry is calcium-bicarbonate at 1 site, calcium-sulfate at 1 site, mixed-bicarbonate at 1 site, mixed-mixed at 4 sites, mixed-chloride at 2 sites, mixed-sulfate at 5 sites, sodium-bicarbonate at 4 sites, sodium-mixed at 7 sites, sodium-chloride at 6 sites, and sodium-sulfate at 2 sites.

Map 5 Groundwater Chemistry

Legend

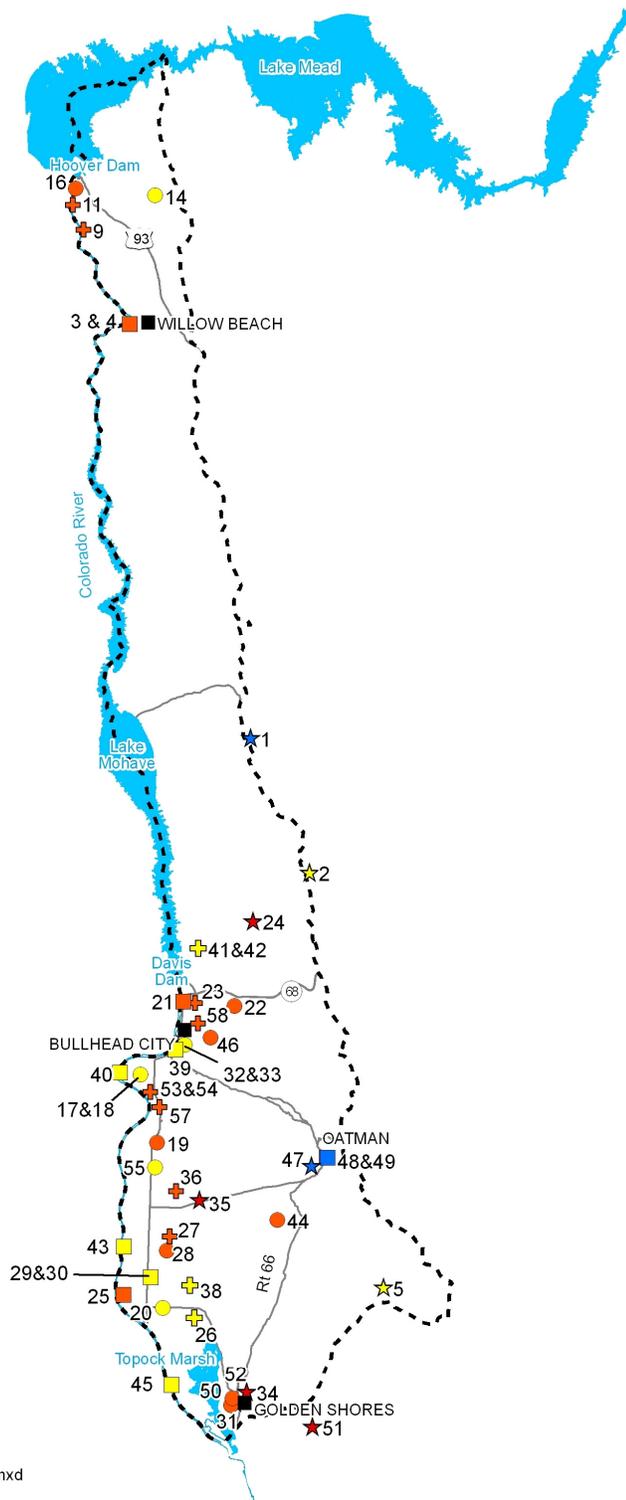
MHV Sample Sites

- ★ Calcium Bicarbonate
- Calcium Sulfate
- ☆ Mixed Bicarbonate
- ⊕ Mixed Chloride
- Mixed Sulfate
- Mixed Mixed
- ★ Sodium Bicarbonate
- ⊕ Sodium Chloride
- Sodium Sulfate
- Sodium Mixed
- Towns

- - - Lake Mohave Groundwater Basin
- Roads
- Streams
- Lakes



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Recharge Source Variation

For water quality comparison purposes, the MHV can be divided among recharge sources as interpreted from oxygen and hydrogen isotopes: pre-dam Colorado River recharge, post-dam Colorado River recharge, local recharge, and the Bouse Formation.

Analytical results were compared among these four recharge sources to identify significant differences in concentrations of groundwater quality constituents. Many significant concentration differences were found (Table 4) (Figure 17). Confidence intervals (95 percent) are provided by specific recharge sources for those constituents whose concentrations significantly differ (Table 5).

Analytical results were also compared between the pre-dam (before 1936) Colorado River recharge and post-dam (after 1936) Colorado River recharge to identify significant differences in concentrations of groundwater quality constituents. Several significant concentration differences were found which are summarized in Table 6, which also includes 95% confidence intervals for significantly different recharge sources (ANOVA test, ≤ 0.01) (Figure 18).

NORTH BASIN GROUNDWATER COMPOSITION

General Summary

Groundwater in the North basin is *slightly alkaline*, *fresh*, and *moderately hard-to-very hard* as indicated by pH values and TDS and hardness concentrations. Levels of pH were *slightly alkaline* (above 7 SU) at the 10 sites measured.¹⁸ TDS concentrations were considered *fresh* (below 1,000 mg/L) at 4 sites, *slightly saline* (1,000 to 3,000 mg/L) 5 sites, and *moderately saline* (3,000 to 10,000 mg/L) at 1 site.¹⁸ Hardness concentrations were divided into *soft* (below 75 mg/L) at 0 sites, *moderately hard* (75 to 150 mg/L) at 0 sites, *hard* (150 to 300 mg/L) at 4 sites, and *very hard* (above 300 mg/L) at 6 sites.¹³

Nitrate, TKN, and total phosphorus were detected at more than 20 percent of the sites. Nitrate (as nitrogen) concentrations were divided into natural background (1 site < 0.2 mg/L), may or may not indicate human influence (4 sites between 0.2 to 3.0 mg/L), may result from human activities (5 sites between 3.0 to 10 mg/L), and probably result from human activities (0 sites > 10 mg/L).²²

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

Groundwater Chemistry

The chemical composition of the 10 sampled sites is illustrated using Piper trilinear diagrams.

- The cation triangle diagram (lower left in Figure 19) shows that the dominant (> 50 percent) cation is calcium at 1 site, sodium at 6 sites, and mixed at 3 sites.
- The anion triangle diagram (lower right in Figure 19) shows that the dominant anion (> 50 percent) is bicarbonate at 3 sites, sulfate at 1 site, chloride at 4 sites, and mixed at 2 sites).
- The cation-anion diamond diagram (in the center of Figure 19) shows that the groundwater chemistry is calcium-bicarbonate at 1 site, mixed-bicarbonate at 1 site, mixed-mixed at 1 site, mixed-chloride at 1 site, sodium-bicarbonate at 1 site, sodium-mixed at 1 site, sodium-chloride at 3 sites, and sodium-sulfate at 1 site.

Spatial Variation

For water quality comparison purposes, the North basin can be divided into recharge sources as interpreted from oxygen and hydrogen isotopes. Three potential recharge sources were identified: local recharge, mixed local-Colorado River recharge, and mixed Colorado River-Bouse recharge. Analytical results were compared between these to identify significant differences in concentrations of groundwater quality constituents. Many significant concentration differences were found. TDS, SC, hardness, calcium, sodium, potassium, chloride, sulfate, arsenic, and boron were higher in mixed Colorado River-Bouse recharge than in local recharge (ANOVA test with Tukey option, $p \leq 0.05$). Oxygen-18 was higher in local recharge than in mixed Colorado River-Bouse recharge. Deuterium was higher in local recharge than in either mixed Colorado River-Bouse recharge or mixed local-Colorado River recharge (ANOVA test with Tukey option, $p \leq 0.05$).

Table 4. Variation in Groundwater Quality Constituent Concentrations Among Four South Basin Aquifers Using Transformed Data with ANOVA and Tukey Tests

Constituent	Significance	Differences Among Aquifers
Oxygen-18	**	Local > Bouse > Post-Dam River > Pre-Dam River
Deuterium	**	Local > Bouse > Post-Dam River > Pre-Dam River
Temperature - f	**	Local & Bouse & Pre-Dam River > Post-Dam River ; Local > Pre-Dam River
pH - f	*	Local > Post-Dam River
pH - lab	**	Local > Pre-Dam River & Post-Dam River
SC - f	**	Pre-Dam River & Post-Dam River & Bouse > Local
SC - lab	**	Pre-Dam River & Post-Dam River & Bouse > Local
Turbidity	ns	-
TDS	**	Pre-Dam River & Post-Dam River & Bouse > Local
Bicarbonate	ns	-
Calcium	**	Pre-Dam River & Post-Dam River > Local
Magnesium	**	Pre-Dam River & Post-Dam River > Local
Hardness	**	Pre-Dam River & Post-Dam River > Local
Sodium	**	Bouse & Pre-Dam River & Post-Dam River > Local; Bouse > Post-Dam River
Potassium	ns	-
Chloride	**	Pre-Dam River & Post-Dam River & Bouse > Local
Sulfate	**	Pre-Dam River & Post-Dam River & Bouse > Local
Fluoride	**	Bouse > Pre-Dam River & Post-Dam River; Local > Post-Dam River
Nitrate (as N)	**	Local > Post-Dam River
TKN	*	Post-Dam River > Local
Ammonia ***	**	Post-Dam River > Local
Phosphorus, Total ***	*	Post-Dam River > Local
Arsenic***	**	Bouse > Pre-Dam River & Post-Dam River & Local
Boron	**	Bouse > Pre-Dam River & Post-Dam River & Local
Chromium ***	**	Local > Pre-Dam River & Post-Dam River
Iron***	**	Post-Dam River > Local & Pre-Dam River
Manganese ***	**	Post-Dam River > Local
Gross Alpha	**	Local > Pre-Dam River

ns = not significant

* = significant at p • 0.05

** = significant at p • 0.01

*** = less than 50% of samples above MRL

Table 5. Summary Statistics (95% Confidence Intervals) for Groundwater Quality Constituents With Significant Concentration Differences Among Four South Basin Aquifers

Constituent	Significant Differences	Bouse	Local	Pre-Dam River	Post-Dam River
Oxygen-18	**	-12.3 to -9.7	- 9.5 to - 9.1	-14.9 to -14.0	-13.1 to -12.5
Deuterium	**	-78 to -91	-72.9 to - 68.9	-114 to -107	-105 to -101
Temperature - f	**	25.6 to 29.2	29.6 to 35.2	25.6 to 29.2	22.0 to 25.3
pH - f	**	-	7.55 to 8.02	-	7.24 to 7.57
pH - lab	**	-	7.77 to 8.08	7.46 to 7.80	7.43 to 7.74
SC - f	**	- 3159 to 11047	312 to 1158	1589 to 2747	1288 to 4031
SC - lab	**	- 1768 to 9668	317 to 1150	1614 to 2853	1248 to 4258
Turbidity	ns	-	-	-	-
TDS	**	- 1997 to 6897	133 to 874	996 to 1710	825 to 2973
Bicarbonate	ns	-	-	-	-
Calcium	**	-	- 8 to 124	86 to 180	96 to 344
Magnesium	**	-	-2 to 33	18 to 57	30 to 101
Hardness	**	-	- 28 to 434	296 to 662	353 to 1315
Sodium	**	- 813 to 2363	54 to 106	187 – 352	126 – 492
Potassium	**	-	-	-	-
Chloride	**	-3017 to 4987	28 to 77	257 to 574	60 to 724
Sulfate	**	-1049 to 1619	- 58 to 327	215 to 461	328 to 1076
Fluoride	**	- 1.5 to 8.7	0.5 to 1.6	0.02 to 1.51	0.14 to 0.52
Nitrate (as N)	**	-	2.3 to 5.7	-	-0.2 to 1.0
TKN	ns	-	0.03 to 0.14	-	0.06 to 0.89
Ammonia	**	-	0.01	-	0 to 0.43
Phosphorus, Total	**	-	0.01	-	0.01 to 0.03
Arsenic	**	- 0.445 to 0.558	0.003 to 0.026	0.00 to 0.01	0 to 0.01
Boron	ns	0.67 to 0.80	0.16 to 0.27	0.18 – 0.34	0.15 – 0.29
Chromium	ns	-	0.008 to 0.018	0.005	0.005
Iron	ns	-	0.00 – 0.19	0.04 to 0.14	0.09 to 1.46
Manganese	ns	-	- 0.12 to 0.41	-	0.18 – 1.28
Gross Alpha	ns	-	2.9 to 7.5	0.05	-

Table 6. Variation in Groundwater Quality Constituent Concentrations Between Pre-Dam and Post-Dam Colorado River Recharge Using Transformed Data with ANOVA Test

Constituent	Significance	Differences Among Recharge	Pre-Dam River 95% CIs	Post-Dam River 95% CIs
Oxygen-18	**	Post-Dam River > Pre-Dam River	-14.9 to -14.0	-13.1 to -12.5
Deuterium	**	Post-Dam River > Pre-Dam River	-114 to -107	-105 to -101
Temperature - f	**	Pre-Dam River > Post-Dam River	25.6 to 29.2	22.0 to 25.3
pH - f	ns	-		
pH - lab	ns	-		
SC - f	ns	-		
SC - lab	ns	-		
Turbidity	ns	-		
TDS	ns	-		
Bicarbonate	*	Post-Dam River > Pre-Dam River	147 - 249	187 - 451
Calcium	ns	-		
Magnesium	ns	-		
Hardness	ns	-		
Sodium	ns	-		
Potassium	ns	-		
Chloride	ns	-		
Sulfate	*	Post-Dam River > Pre-Dam River	215 to 461	328 to 1076
Fluoride	ns	-		
Nitrate (as N)	ns	-		
TKN	*	Post-Dam River > Pre-Dam River	0.04 to 0.17	0.06 to 0.89
Ammonia ***	ns	-		
Phosphorus, T***	ns	-		
Arsenic***	ns	-		
Boron	ns	-		
Chromium ***	ns	-		
Iron***	*	Post-Dam River > Pre-Dam River	0.04 to 0.14	0.09 to 1.46
Manganese ***	ns	-		
Gross Alpha	ns	-		

ns = not significant

* = significant at p • 0.05

** = significant at p • 0.01

*** = less than 50% of samples above MRL

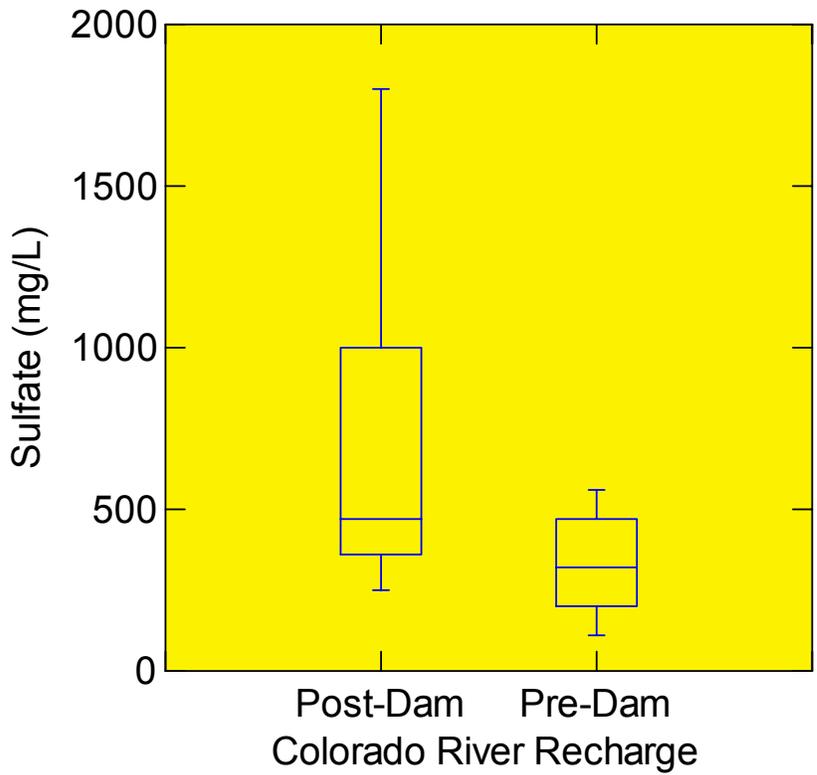


Figure 19 – Sulfate concentrations are significantly higher in post-dam (after 1936) Colorado River recharge than in pre-dam (before 1936) Colorado River recharge in the MHV South basin (ANOVA test, ≤ 0.01) as visually shown in this box plot diagram. The lower sulfate concentrations in pre-dam Colorado River recharge suggest that its source was largely infiltration of dilute flood water.¹⁷ Large floods, such as occurred in 1983, have been rare since the construction of storage dams along the Colorado River.

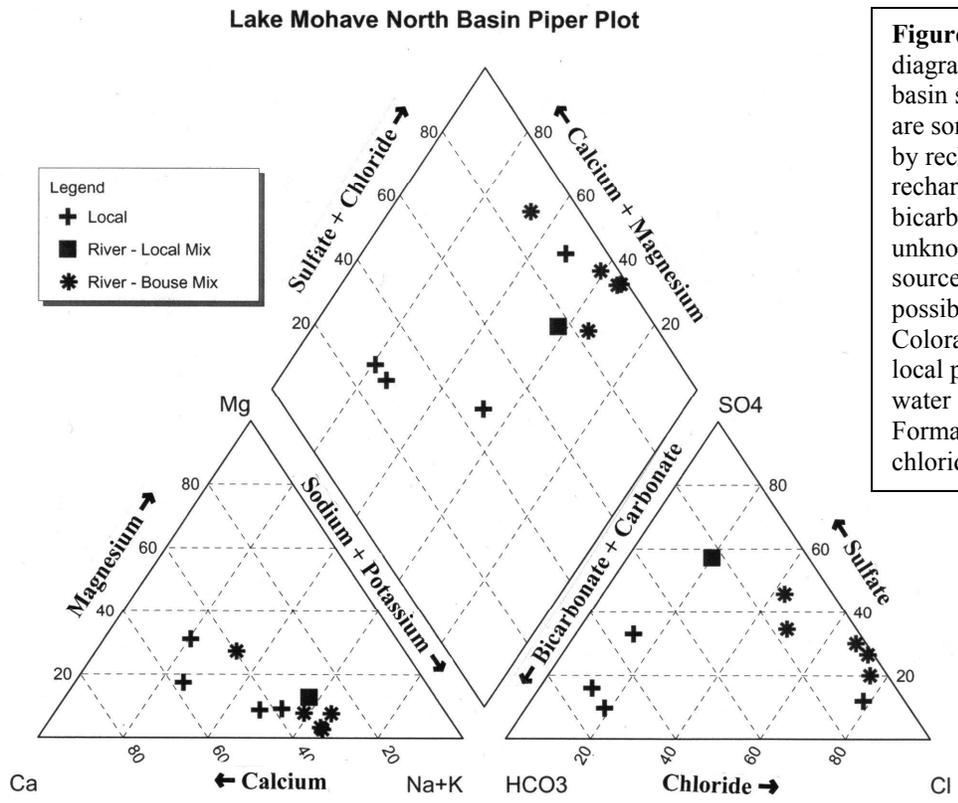


Figure 20 – The piper diagram of MHV North basin shows sample sites are somewhat clustered by recharge source: local recharge is calcium-bicarbonate, while other unknown recharge sources conjectured to be possible mixes of Colorado River water, local precipitation, and water from the Bouse Formation, are mixed-chloride-sulfate.

APPLICATION TO PREVIOUS STUDIES

Four previous groundwater quality studies conducted by ADEQ in various parts of the MHV South basin can be further interpreted as to their recharge source based upon the results of this study.^{14, 31, 32} These ADEQ studies were conducted in Bullhead City (1987-89), Bullhead City and Northern Mohave Valley (1994), Golden Shores (1996), and North Central Mohave Valley (1997) to investigate potential septic system impacts to groundwater. In addition, Colorado River data was also evaluated. The 1987-89, 1994 and 1997 studies were published by ADEQ; the unpublished results of the 1996 study have been included in Appendices C, D and E. For these studies, samples for physical parameters, major ions, nutrients, and trace elements were collected at each site. The 1987-89 consisted of 33 wells, the 1994 study consisted of 52 wells, the 1996 of 19 wells, and the 1997 study of 42 wells.

Although no isotope samples were collected for these studies, based on correlations between water chemistry and isotope values, it is possible to

interpolate the recharge source of any sample from these studies based upon its water chemistry plotted on a Piper trilinear diagram. For example, the vast majority of the 33 samples collected in 1987-89 appear to be composed chiefly of Colorado River recharge with two samples composed of water from the Bouse Formation (Figure 21). The 1994 data shows the vast majority of the 52 samples collected appear to be composed chiefly of Colorado River recharge, three samples appear to be composed of local recharge, and one sample appears to be composed of water from the Bouse Formation (Figure 22). In contrast, the 19 samples collected in 1996 in the Golden Shores area appear to be largely recharged from local precipitation, with several samples recharged from Colorado River water while two others appear to be a mixture of these two sources (Figure 23). The 42 samples collected in 1997 appear to consist of Colorado River recharge with one sample composed of water from the Bouse Formation (Figure 24). Finally, Colorado River data show that post-dam flows are generally an average between pre-dam high and low flows (Figure 25).

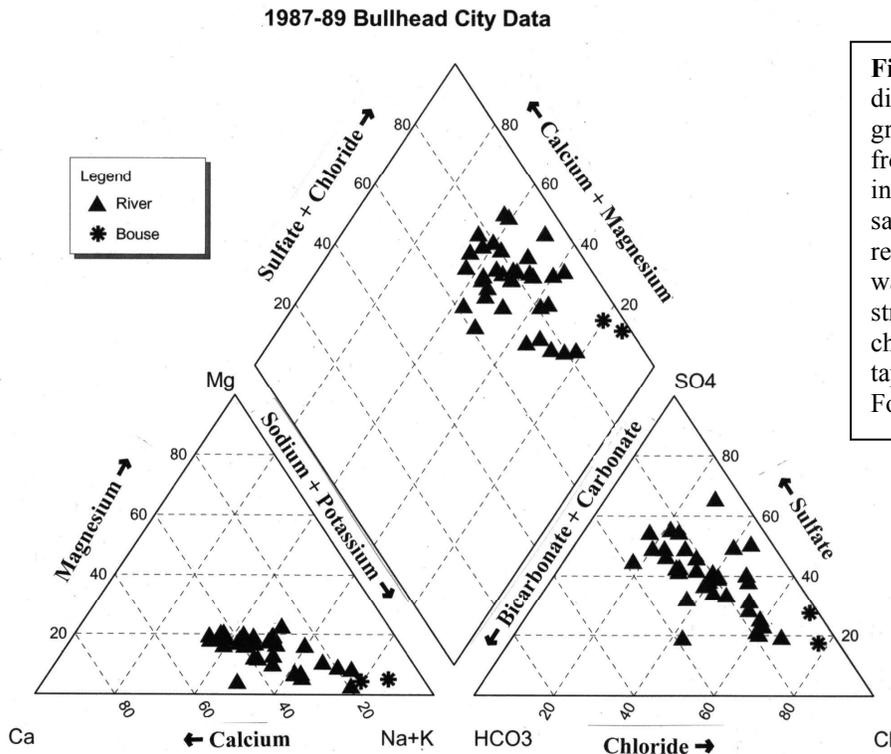


Figure 21 – The piper diagram of 1987-89 groundwater quality data from the Bullhead City area indicates the majority of samples likely were of recharged Colorado River water.¹⁴ Two samples with strong sodium-chloride chemistry are probably tapping water in the Bouse Formation.

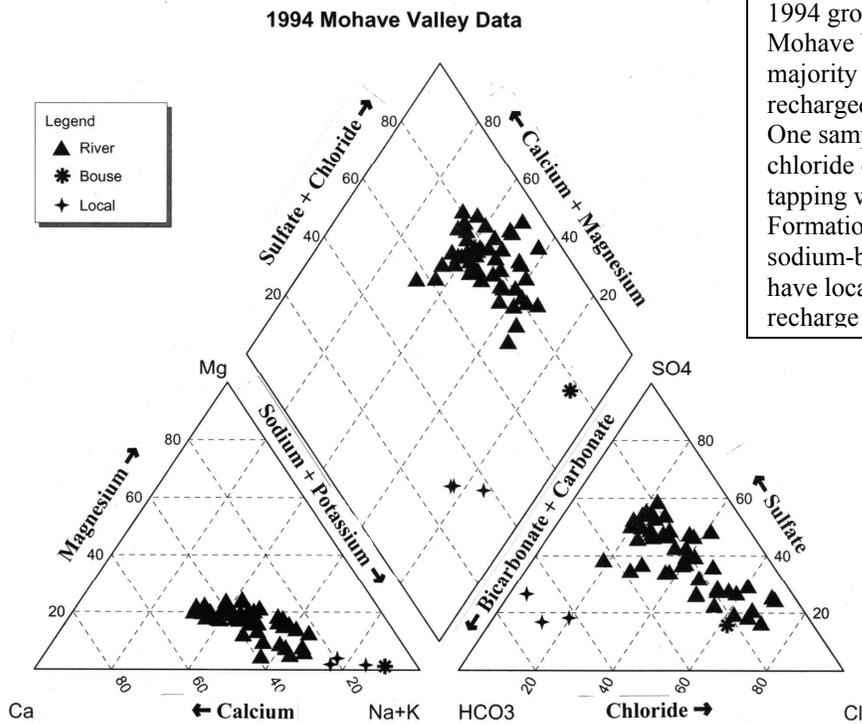


Figure 22 – The piper diagram of 1994 groundwater quality data from Mohave Valley indicates the majority of samples likely were of recharged Colorado River water.³¹ One sample with strong sodium-chloride chemistry is probably tapping water in the Bouse Formation. Three samples of strong sodium-bicarbonate chemistry likely have local precipitation as their recharge source.

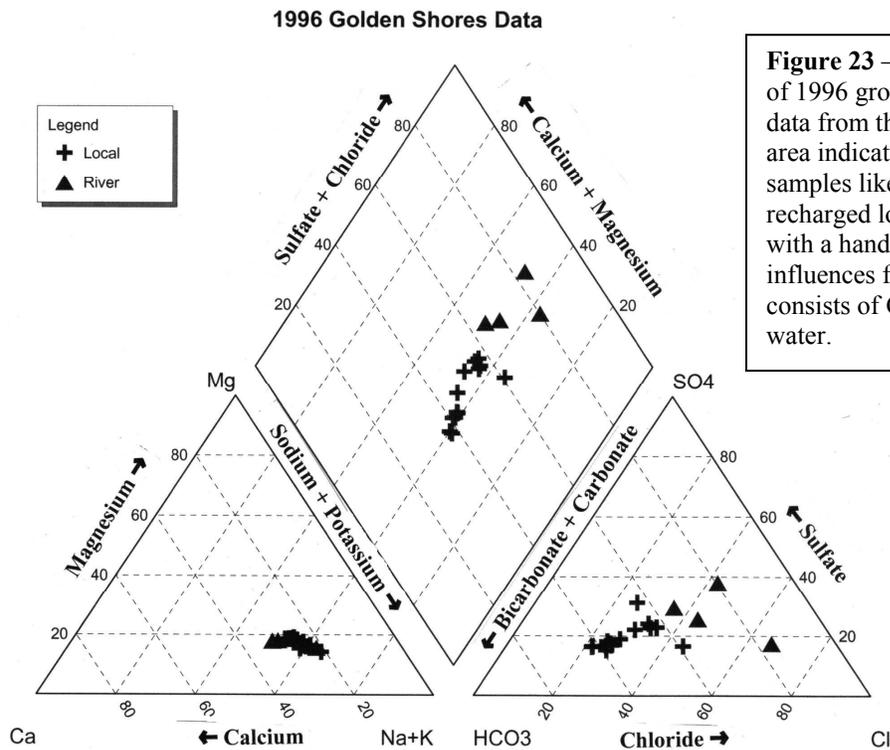


Figure 23 – The piper diagram of 1996 groundwater quality data from the Golden Shores area indicates the majority of samples likely were of recharged local precipitation with a handful of sites showing influences from recharge that consists of Colorado River water.

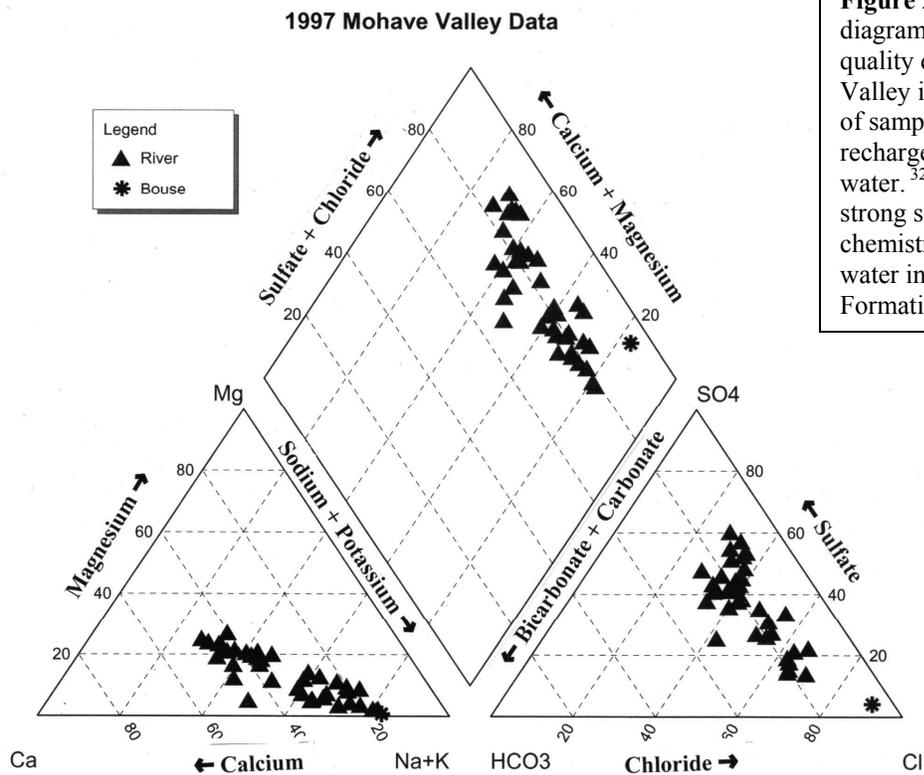


Figure 24 – The piper diagram of 1997 groundwater quality data from Mohave Valley indicates the majority of samples likely were of recharged Colorado River water.³² One sample with strong sodium-chloride chemistry is probably tapping water in the Bouse Formation.

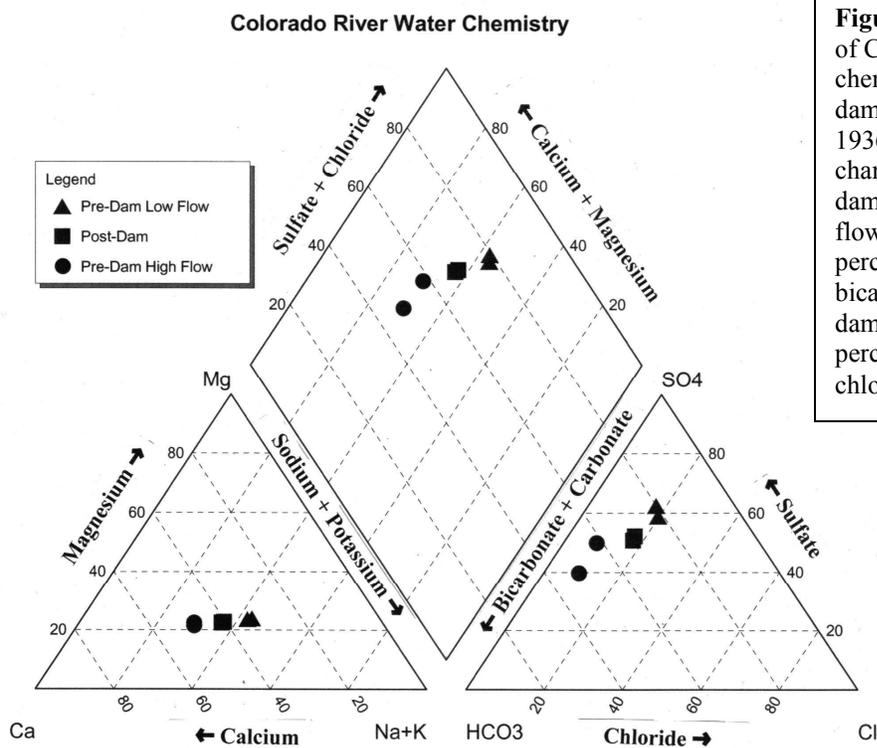


Figure 25 – The piper diagram of Colorado River water chemistry illustrates that post-dam flows, which began around 1936, moderate the chemistry changes characteristic of pre-dam river flows. Pre-dam high flows tended to have a higher percentage of calcium and bicarbonate; in contrast, pre-dam flows had a higher percentage of sodium-chloride/sulfate.

CONCLUSIONS

In many parts of the MHV, groundwater appears to be suitable for domestic use although both basins and all four recharge sources have groundwater quality concerns, based on the results of ADEQ sampling. Only 21 percent of the 43 groundwater samples met all health and aesthetic standards; however, 65 percent met all health standards.

Groundwater recharged by local precipitation found in upland areas outside the floodplain is generally preferred for domestic or municipal use because of much lower salinity concentrations. However, this recharge source has the drawback of having arsenic concentrations occasionally exceeding the health-based standards that will take effect in 2006, except around the Golden Shores area. In contrast, groundwater recharged by Colorado River water has a lower frequency of health-based water quality standard exceedances and does not appear to have been impacted by perchlorate concentrations regularly detected in the river water. However, this source's much higher salinity concentrations sometimes cause well owners not to use this resource for domestic purposes. The water from the Bouse Formation is characterized by both high salinity concentrations and health and aesthetics-based exceedances.

Limited time-trend analyses conducted at sites previously sampled in 1969-70, 1994, 1996 and 1998 reveal constituent concentrations to be generally stable with greater variation found over longer time periods.^{8, 9, 17, 31} Whether this variation reflects actual change in groundwater quality or is the result of different sampling and laboratory techniques is uncertain. However, looking broadly at all the time-trend data, there is no clear increasing trend with any particular constituent. Therefore, it seems likely that any variation is the result of site-specific conditions or different sampling and laboratory regimes.

Many of the health-based exceedances, such as arsenic and fluoride, found in the MHV basin appear to be the result of naturally occurring geochemical processes. Nitrate however, typically results from human activities such as wastewater disposal practices. Limited time-trend analysis reveals constituent concentrations such as nitrate to be generally stable. This likely indicates that providing sewers to portions of the study area as recommended by ADEQ and local governments has decreased nitrogen loading to the groundwater. In addition, although not addressed specifically by this report, ADEQ continues to monitor the Golden Shores area

for any chromium impacts from the Pacific Gas and Electric Topock compressor station located in San Bernardino County, California.

South Basin

The South basin of the MHV stretches from granite bedrock barrier where Davis Dam is situated to Topock and includes Mohave Valley.⁶ There is intensive water development in the South basin stemming from municipal, domestic and irrigation uses especially in floodplain areas near the Colorado River. Although development is slowly occurring in upland areas, fewer samples sites are available in areas outside the floodplain.

In contrast to the focus on nitrate in earlier hydrologic studies completed in various portions of the South basin (1987-89, 1994, 1996 and 1998), arsenic appears to be the constituent that most often exceeds health-based water quality standards, especially with the MCL reduced from 0.05 mg/L to 0.01 mg/L effective in 2006.^{14, 30, 31} Arsenic exceedances may be occurring because of a long groundwater residence time which allows for more contact with rock surfaces.²⁶

Stable hydrogen and oxygen isotopes are useful for establishing the origin of groundwater in areas where waters of different origin, age, and evolution are present such as in the MHV where snowmelt from regions of higher altitude and latitude produce river water that recharges the floodplain and eventually mixes with groundwater derived from local rainfall.¹⁷ Data from this study, along with other recent groundwater studies that have included isotopic sampling will be of assistance in complimenting the 1994 "accounting surface" method to determine if a well withdraws water whose source is the Colorado River.³⁶ Of the 33 sites sampled, based on oxygen and hydrogen isotope values, 9 sites consisted of recharged, pre-dam Colorado River water, 10 sites consisted of recharged, post-dam Colorado River water, 12 sites consisted of recharged local precipitation, and 2 sites consisted of water from the Bouse Formation. The water quality characteristics of each recharge source will be described below.

Of the 12 sites consisting of recharged local precipitation, 7 sites had no water quality exceedances, 4 sites had health-based water quality exceedances (arsenic at 4 sites, nitrate at 1 site), and 1 site had aesthetic-based exceedances. Arsenic exceedances were found mostly the northern and central upland areas with no exceedances found in the Golden Shores area. The site with aesthetic

exceedances was near Oatman and the elevated TDS, sulfate, iron, and manganese are likely related to the extensive historic mining activity in the area.

The 12 local precipitation recharge sites generally consist of *fresh* water (TDS < 1,000 mg/L), with a sodium-bicarbonate chemistry.¹⁸ Temperature, pH, nitrate, and chromium were higher at sites recharged by local precipitation than from pre/post-dam Colorado River water (ANOVA with Tukey test, $p \leq 0.05$). TDS, sodium, chloride, sulfate, calcium, magnesium, and hardness were lower at sites recharged by local precipitation than by pre/post-dam Colorado River water and Bouse Formation (except for last three constituents). The acceptable water quality of local recharge was predicted in earlier hydrologic studies because of the rock types composing the mountains.²³ Included among these 12 sites is an artesian well (MHV-51) that is slightly outside the MHV in the Sacramento Valley basin. This well was sampled because of its unique hydrologic characteristics and because the groundwater boundary between the two basins is a surface water divide that does not impede groundwater flow. This well was cited as in previous studies as producing water from and below the Bouse Formation and fanglomerate.²³

Of the 2 sites consisting of Bouse Formation water, both had health-based and aesthetics-based water quality exceedances. The 2 sites generally consist of *slightly-saline* water (TDS > 1,000 mg/L) with a strong sodium-chloride chemistry.¹⁸ Arsenic, boron, and fluoride were higher at Bouse Formation sites than from recharged pre/post-dam Colorado River water or local precipitation (ANOVA with Tukey test, $p \leq 0.05$).

The 10 sites consisting of recharged, post-dam Colorado River water (after 1936) generally were wells located in the floodplain in proximity to the current river channel. Of the 10 sites, 1 site had a health-based water quality exceedance (arsenic), and all 10 sites had aesthetic-based exceedances (TDS and sulfate at 10 sites, manganese at 8 sites, iron at 6 sites, and chloride at 3 sites).

The 10 sites generally consist of *slightly-saline* water (TDS > 1,000 mg/L) that sometimes is moderately-saline (TDS between 3,000 and 10,000) with a mixed-sulfate chemistry.¹⁸ TKN, ammonia, total phosphorus, iron, and manganese were higher at sites recharged by post-dam Colorado River water than at sites recharged by local precipitation (ANOVA with Tukey test, $p \leq 0.05$). These patterns may indicate that, in contrast to the usual oxidizing groundwater

environment in Arizona, reducing conditions driven by the oxygen demand presented by decomposing soil organic carbon are present in Mohave Valley along the Colorado River.²⁶ An anaerobic sub-surface environment in parts of Mohave Valley was noted in previous groundwater studies.²³

The 9 sites consisting of recharged, pre-dam Colorado River water (before 1936) generally were wells located in the floodplain distant from the current river channel. Of the 9 sites, 3 sites had health-based water quality exceedances (arsenic at 2 sites, nitrate at 1 site), and all 9 sites had aesthetic-based exceedances (TDS at 9 sites, chloride at 8 sites, sulfate at 6 sites, manganese at 4 sites, and fluoride at 1 site). The 9 sites generally consist of *slightly-saline* water (TDS > 1,000 mg/L) with sodium-chloride chemistry.¹⁸

When only comparing pre-dam and post-dam Colorado River recharge, oxygen-18, deuterium, total alkalinity, bicarbonate, sulfate, TKN, and iron were significantly higher in post-dam Colorado River recharge than in pre-dam Colorado River recharge; in contrast, temperature was significantly higher in pre-dam Colorado River water than in post-dam Colorado River recharge (ANOVA, $p \leq 0.05$). The elevated bicarbonate concentrations in the post-dam Colorado River recharge probably result from dissolution of carbonate materials.²⁶ This process allows bicarbonate concentrations averaging 150 mg/L in Colorado River water to increase to 730 mg/L in groundwater recharged by Colorado River water.

Variations in pre-dam and post-dam Colorado River recharge are related to changes in the water regime caused by Hoover Dam impounding water beginning in 1936. Previous to this, spring floods typically contained 200-300 mg/L TDS, mostly calcium and bicarbonate, and the sulfate concentration always exceeded the chloride concentration. During low-flow periods in fall and winter, the Colorado River often contained 1,500 mg/L TDS. The composition was mostly calcium and sulfate, although considerable sodium and chloride were sometimes present. Since then, below Hoover Dam, the downstream seasonal variation virtually ended. TDS concentrations have ranged between 606–813 mg/L.²³

North Basin

The North basin of the MHV stretches from the Hoover Dam area along the west flank of the Black Mountains to the Colorado River south to the granite bedrock barrier that is located near Davis Dam. Most of this basin is located within the Lake Mead

National Recreation Area and there is little water development. As such, samples were able to be collected from only 10 sites of which four were wells and six were springs. Of the six spring sites, four were thermal springs located along the Colorado River close to Hoover Dam.

Only limited groundwater characterizations can be made of the North basin from this limited sampling. Generally groundwater appears to be suitable for domestic purposes in much of the basin. Of the 10 sites sampled, two sites near the crest of the Black Mountains met all health and aesthetic water quality standards, three sites (two near Davis Dam, one near the crest of the Black Mountains) had only aesthetic water quality exceedances, and five sites along the Colorado River immediately south of Hoover Dam all had health and aesthetic water quality standards. The health-based exceedances were all from elevated arsenic concentrations while aesthetics-based exceedances included chloride, fluoride, sulfate, and TDS. Previous studies indicate that water of the best chemical quality probably will be obtained from the more permeable beds because the contact surface is smaller, there are fewer exchangeable ions than in the finer units, and, during withdrawal, the water will be in contact with the alluvial material for a shorter time; therefore, it is suggested that the thick silt and clay units be sealed off.⁸

Volcanic rocks yield moderate quantities (around 1000 acre-feet per year) of water to at least six hot springs along a 5-mile stretch of the Colorado River below Hoover Dam.⁸ These thermal springs issue from fractures in volcanic rocks, the highly mineralized water that issues from these springs probably is not representative of the chemical quality of the water in the volcanic rocks. The source of the saline water that issues from the hot springs along the Colorado River is unknown, but the springs existed prior to the construction of Hoover Dam.⁸ Isotope values for these thermal springs are difficult to interpret. These thermal springs had elevated concentrations of several constituents that make them poor choices for domestic supplies.

Well No. 2 at the Willow Beach Campground obtains moderate quantities of water from the younger alluvium. Pump tests indicated a high rate of recharge from Lake Mohave, which appears to be partially supported by isotope values.⁸ The Katherine Gold Mine is in fractured granite and consists of a main shaft about 700 feet deep and several thousand feet of horizontal levels, stopes, and interconnecting excavations with a static water level at about the same altitude as the lake surface.⁹ However, no

significant hydraulic connection was found to exist between the lake and the mine, a finding which was supported by isotope values from this study.⁹ Water from the Katherine Mine is highly mineralized and has an objectionable taste.⁹ This study found that although no health-based standards were exceeded, aesthetic water quality exceedances did occur for TDS, chloride, and fluoride as well as extremely hard water (570 mg/L).

Study Design and Data Evaluation

The 43 groundwater sample sites were generally selected using a modified grid-based, random site-selection approach. This method allowed the spatial distribution of sample sites throughout the MHV although some areas particularly north of Davis Dam and in mountainous areas were not sampled because of a combination of remote, rugged terrain and a corresponding lack of groundwater sample sites. Quality assurance procedures were followed and quality control samples were collected to ensure the validity of groundwater quality data. Analysis of equipment blank samples indicated systematic contamination of SC-lab and turbidity; however, the extent of contamination by these parameters was not considered significant.

Analysis of the four full duplicate samples and one partial duplicate sample revealed excellent correlations of less than 12 percent except for turbidity (16 percent) and TKN (31 percent). The three split samples generally had more variability but still only exceeded a maximum difference of 10 percent with potassium (18 percent), zinc (39 percent), and TKN (49 percent). TKN exhibited the largest maximum difference, a pattern found in other ADEQ groundwater studies due to the difficulty by laboratories in analyzing this constituent.^{27, 28}

Data validation was also examined in five QA/QC correlations that affirmed the acceptability of the groundwater quality data for further analysis. Only the field pH – lab pH correlation was not significant (regression analysis, $p < 0.05$). The non-significance of this QA/QC correlation is likely due to the short 15 minute holding time associated with lab pH measurement that was exceeded with each sample.²⁵

Data analysis for this study was conducted using Systat software.³⁸ Spatial variations in constituent concentrations were investigated using the parametric Analysis of Variance (ANOVA) test with the Tukey test. Correlations among constituent concentrations were analyzed using the Pearson Correlation Coefficient test.³⁸

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- ¹ Arizona Department of Commerce Website, 2005, Community profile – Bullhead City, Arizona [<http://www.commerce.state.az.us/Communities/default.asp>], accessed 6/15/05.
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Appendix A. Data for Sample Sites, Lake Mohave Basin, 2003

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Basin / Source
1st Field Trip, January 14-17, 2003 - Towne & Boettcher (Equipment Blank, MHV-6)									
MHV-1	B(24-21)23cdb submersible	35°30'35.13" 114°29'32.71"	651165	22151	Lost Cabin Well	Inorganic, Radiochem Radon, O, H isotopes	80'	22'	North Local
MHV-2	B(22-20)09aaa	35°18'51.786" 114°24'49.84"	--	21920	Burns Spring	Inorganic, Radiochem O, H isotopes	--	--	North Local
MHV-3/4	B(29-22)29dca submersible	35°51'57.639" 114°39'43.765"	629087	22384	Willow B. #2 Well	Inorganic, Radiochem Radon, O, H isotopes	68'	16'	North Mix
MHV-5	B(17-19)04abb	34°53'39.238" 114°18'17.034"	--	20978	Lwr Warm Springs	Inorganic O, H isotopes	--	--	South Local
2nd Field Trip, March 3-7, 2003 - Towne & Boettcher (Equipment Blanks, MHV-7,8,22 & 23)									
MHV-9	B(30-23)26bcc	35°57'38.600" 114°43'27.760"	--	60593	Upper AZ Hot Spring	Inorganic, Radiochem Radon, O, H isotopes	--	--	North Mix
MHV-10	B(30-23)26bcc	35°57'38.600" 114°43'27.760"	--	60593	Lower AZ Hot Spring	Inorganic O, H isotopes	--	--	North Mix
MHV-11/12	B(30-23)15cbd	--	--	60605	Lost Man Hot Spring	Inorganic, Radiochem O, H isotopes	--	--	North Mix
MHV-13	sample below Hoover Dam	--	--	--	Colorado River	O, H isotopes	--	--	--
MHV-14	B(30-22)10caa	35°59'52.876" 114°38'09.718"	--	60594	Horsethief Spring	Inorganic O, H isotopes	--	--	North Mix
MHV-15	sample below Horsethief Spr	--	--	--	Horsethief Canyon	O, H isotopes	--	--	--
MHV-16	B(30-23)10caa	36°00'07.549" 114°44'09.280"	--	22415	Sugarloaf Spring	Inorganic O, H isotopes	--	--	North Mix
MHV-17/18	B(20-22)19adc submersible	35°06'07.804" 114°36'50.295"	646219	60591	Moon Well	Inorganic O, H isotopes	74'	50"	South Pre-Dam
MHV-19	B(19-22)14bdc submersible	35°02'01.548" 114°35'27.018"	528687	60592	Horvath Well	Inorganic, Perchlorate Radon, O, H isotopes	174'	147'	South Pre-Dam
MHV-20	B(17-22)13bba submersible	34°51'55.232" 114°34'34.834"	--	62187	YoneyAuto Well #2	Inorganic, Perchlorate O, H isotopes	90'	11'	South Post-Dam
MHV-21	B(21-21)30bdb submersible	35°10'40.811" 114°33'52.634"	512128	48690	Davis Camp Well	Inorganic, Radon O, H isotopes	150'	45'	South Post-Dam
3rd Field Trip, April 23-25th, 2003 - Towne & Boettcher (Equipment Blank, MHV-31)									
MHV-22	B(21-21)27add submersible	35°10'16.057" 114°30'59.235"	805519	21806	Well #7	Inorganic, Radiochem Radon, O, H isotopes Perchlorate	1300'	930'	South Local
MHV-23	B(21-21)29bca submersible	35°10'38.643" 114°32'58.491"	608741	46093	Well #2	Inorganic, Radon O, H isotopes	340'	--	South Pre-Dam
MHV-24	B(22-21)25cbc submersible	35°15'46.579" 114°28'52.829"	528496	60958	Wall Well	Inorganic, Radiochem Radon, O, H isotopes	420'	220'	North Local
MHV-25	B(17-22)09bad submersible	34°52'38.958" 114°37'31.174"	616521	21007	Lucas Well	Inorganic, Perchlorate Radon, O, H isotopes	70'	14'	South Post-Dam
MHV-26	B(17-21)17cad submersible	34°51'23.767" 114°32'12.056"	577939	60965	Nance Well	Inorganic, Radon O, H isotopes	85'	14'	South Post-Dam
MHV-27	B(18-22)13cdd turbine	34°56'19.937" 114°34'15.086"	617628	46269	Irrigation Well	Inorganic O, H isotopes	--	--	South Pre-Dam
MHV-28	B(18-22)25bba turbine	35°55'25.602" 114°34'25.115"	558408	21239	Irrigation Well	Inorganic O, H isotopes	--	--	South Pre-Dam
MHV-29/30	B(18-22)35cdc submersible	34°53'45.191 114°35'31.901"	537129	60969	Yoney Well	Inorganic, Perchlorate Radon, O, H isotopes	85'	15'	South Post-Dam

Appendix A. Data for Sample Sites, Lake Mohave Basin, 2003 Continued

Sample #	Cadastral/ Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Basin / Source
4th Field Trip, June 4-6th, 2003 - Towne & Boettcher									
MHV-31	B(16-21)15dca submersible	34°46'04.783" 114°29'14.783"	507868	48400	Burman Well	Inorganic, Perchlorate Radon, O, H isotopes	280'	162'	South Local
MHV32/33	B(20-21)07bbb submersible	35°08'02.441" 114°33'37.687"	632703	48607	Tri-State Refuse Well	Inorganic, Perchlorate O, H isotopes Radiochem	250'	200'	South Pre-Dam
MHV-34	B(16-21)11dca submersible	34°46'57.415" 114°28'08.099"	629200	61357	Well #3	Inorganic, Radon O, H isotopes	500'	280'	South Local
MHV-35	B(18-21)05bdb submersible	34°58'37.932" 114°32'09.648"	808210	21179	Harrison Well	Inorganic, Radiochem Radon, O, H isotopes	485'	340'	South Local
MHV-36	B(19-22)36ddb submersible	34°59'07.076" 114°33'53.741"	536851	61359	Jordan Well	Inorganic, Radon O, H isotopes	210'	165'	South Bouse
MHV-37	Colorado River at Needles, CA					Perchlorate O, H isotopes			
MHV-38	B(17-21)05bcc submersible	34°53'21.959" 114°32'37.081"	617200	20980	Desert Lawn Well	Inorganic, Perchlorate Radon, O, H isotopes	124'	88'	South Pre-Dam
MHV-39	B(20-22)12cdd submersible	35°07'43.729" 114°34'17.737"	507943	48621	River City RV Well	Inorganic, Radon O, H isotopes	170'	45'	South Post-Dam
MHV-40	B(20-23)24bad submersible	35°06'11.732" 114°38'22.142"	509401	46090	Tipton Well	Inorganic, Perchlorate Radon, O, H isotopes	60'	15'	South Post-Dam
MHV-41/42	B(21-21)05cba submersible	35°13'59.103" 114°32'53.858"	806514	21811	Katherine Mine Well	Inorganic, Radiochem Radon, O, H isotopes	700'	308'	North Local
MHV-43	B(18-22)21cdb submersible	34°55'35.095" 114°37'35.774"	603947	45999	King St. Well	Inorganic, Perchlorate Radon, O, H isotopes	120'	12'	South Post-Dam
MHV-44	B(18-20)07daa submersible	34°57'32.818" 114°26'18.196"	584937	61395	Rodman Well	Inorganic, Radiochem Radon, O, H isotopes	955'	860'	South Local
MHV-45	B(16-22)12bdd submersible	34°47'10.957" 114°33'41.495"	627157	46111	Havasu NWR Well	Inorganic, Perchlorate Radon, O, H isotopes	53'	10'	South Post-Dam
MHV-46	B(20-21)05ddd submersible	35°08'32.609" 114°31'45.184"	557919	61396	AM Waterworks	Inorganic, Radiochem Radon, O, H isotopes	1073'	632'	South Local
5th Field Trip, June 25-27th, 2003 - Towne & Boettcher (Equipment Blank, MHV-56)									
MHV-47	B(19-20)22dbb submersible	35°00'56.98" 114°23'55.01"	555937	61820	Angled Well	Inorganic, Radiochem Radon, O, H isotopes	260'	100'	South Local
MHV-48/49	B(19-20)23bac submersible	35°01'27.54" 114°22'46.39"	535054	56293	Oatman Well	Inorganic, Radiochem Radon, O, H isotopes	480'	260'	South Local
MHV-50	B(16-21)15aca submersible	34°46'31.077" 114°29'10.758"	629199	55133	Well #1	Inorganic, Radon O, H isotopes	250'	140'	South Local
MHV-51	B(16-20)06dda artesian	34°44'58.51" 114°23'11.50"	553210	61821	Artesian Well	Inorganic, Radiochem Radon, O, H, Perc	890'	--	South Local
MHV-52	B(16-21)15dda submersible	34°46'31.077" 114°29'10.758"	629730	48391	Kuska Well	Inorganic, Perchlorate Radon, O, H isotopes	230'	160'	South Local
MHV-53/54	B(20-22)29bc submersible	35°05'07.88" 114°36'03.51"	637323	46085	Hansen Well	Inorganic, Perchlorate Radon, O, H isotopes	120'	100'	South Pre-Dam
MHV-55	B(19-22)26bbb submersible	35°00'29.05" 114°35'30.65"	649765	48564	Sens Well	Inorganic, Perchlorate Radon, O, H isotopes	90'	75'	South Post-Dam
MHV-57	B(20-22)35cdd submersible	35°04'13.72" 114°35'20.98"	505714	21642	Larry=s Auto Well	Inorganic, Perchlorate Radon, O, H isotopes	125'	65'	South Bouse
6th Field Trip, June 9-10th, 2004 - Towne & Carpenter & Christiana									
MHV-58	B(21-21)32cda submersible	35°09'25.491" 114°32'43.364"	589061	63595	N. Mohave #9	Inorganic, Perchlorate O, H isotopes	675'	340'	South Pre-Dam

Appendix B. Groundwater Quality Data, Lake Mohave Basin, 2003

Site #	MCL Exceedances	Temp (°C)	pH-field (su)	pH-lab (su)	SC-field (•S/cm)	SC-lab (•S/cm)	TDS (mg/L)	Hardness (mg/L)	Hard (cal) (mg/L)	Turbidity (ntu)
MHV-1		24.3	7.39	7.6	698	660	430	280	280	0.09
MHV-2		19.9	8.23	8.1	416	440	290	170	180	0.06
MHV-3/4	TDS, SO ₄ , As*	24.5	7.81	7.55	1254	1300	845	280	290	0.075
MHV-5	As	22.2	7.93	8.2	502	510	340	160	170	7.8
MHV-9	TDS, SO ₄ , Cl, F, As*	39.2	7.53	7.4	4218	4400	2800	740	760	0.02
MHV-10	TDS, SO ₄ , Cl, As*	20.7	7.74	7.5	4452	4900	3000	920	950	0.25
MHV-11/12	TDS, SO ₄ , Cl, F, As*	13.9	8.03	8.31	5695	6200	4050	1200	1200	0.03
MHV-14	TDS, SO ₄ , Cl	7.6	7.28	7.6	3651	3900	2700	1500	1400	1.9
MHV-16	TDS, SO ₄ , Cl, F, As*	17.9	7.36	8.1	2697	3000	1800	490	490	0.04
MHV-17/18	TDS, SO ₄ , Cl, NO ₃	25.2	7.80	7.4	2656	2900	1900	730	750	0.23
MHV-19	TDS, SO ₄ , Cl, Mn	26.3	7.79	7.7	2099	2200	1400	240	250	1.1
MHV-20	TDS, SO ₄ , Cl, Mn, Fe	23.7	7.26	7.4	6020	6600	4900	2200	2200	32
MHV-21	TDS, SO ₄ , Mn	21.9	7.77	7.7	1414	1500	990	340	350	0.70
MHV-22	F, As*	37.0	8.02	8.2	514	530	330	28	30	0.04
MHV-23	TDS, Cl	29.8	7.12	7.4	1853	1900	1100	380	390	0.08
MHV-24	TDS	31.3	7.09	7.8	976	1000	640	250	240	0.04
MHV-25	TDS, SO ₄ , Mn, Fe	22.2	7.26	7.5	2236	2300	1500	560	510	1.2
MHV-26	TDS, SO ₄ , Cl, As* Mn, Fe	23.7	7.13	7.6	5698	6000	3800	1700	1600	23
MHV-27	TDS, SO ₄ , Cl, Mn	25.3	7.49	8.0	2631	2800	1600	550	580	1.2
MHV-28	TDS, SO ₄ , Cl, Mn	23.8	7.56	7.8	1796	1900	1100	450	420	1.2
MHV-29/30	TDS, SO ₄ , Cl, Mn, Fe	23.4	7.54	7.45	4120	4300	3100	1300	1250	14.5
MHV-31		30.4	7.67	8.1	585	570	330	110	110	0.05
MHV32/33	TDS, SO ₄ , Cl	29.6	7.27	7.5	2231	2200	1400	790	835	0.57
MHV-34		33.0	7.75	7.9	575	560	330	95	97	ND
MHV-35	As*	32.6	8.23	8.1	457	440	270	49	52	0.15
MHV-36	TDS, Cl, F, As*	29.9	7.57	7.7	4503	4400	2800	230	230	0.08
MHV-38	TDS, SO ₄ , Cl, As* Mn	27.0	7.19	7.6	3669	3700	2100	750	760	0.97
MHV-39	TDS, SO ₄	26.8	7.23	7.5	1800	1800	1200	510	520	0.12
MHV-40	TDS, SO ₄ , Mn	23.5	7.70	7.9	946	950	590	270	270	0.24
MHV-41/42	TDS, Cl, F	31.8	7.10	7.6	2464	2460	1410	570	570	0.61
MHV-43	TDS, SO ₄ , Fe, Mn	21.9	7.49	7.9	1334	1300	820	410	420	1.6

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, Lake Mohave Basin, 2003BContinued

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)
MHV-1	87	16	44	0.75	260	320	ND	32	56
MHV-2	44	17	19	3.7	150	180	ND	27	19
MHV-3/4	81	21	175	6.7	150	180	ND	91.5	355
MHV-5	36	19	40	5.6	170	210	ND	33	23
MHV-9	280	14	650	13	35	43	ND	1100	550
MHV-10	310	43	610	12	98	120	ND	1200	430
MHV-11/12	420	25.5	960	18	98	106	ND	1550	935
MHV-14	340	140	300	36	240	290	ND	620	900
MHV-16	160	27	430	9.6	220	270	ND	460	440
MHV-17/18	200	60.5	335	6.25	180	220	ND	450	560
MHV-19	67	20	390	4.5	210	260	ND	300	470
MHV-20	580	170	780	9.3	450	550	ND	1100	1800
MHV-21	99	24	200	5.1	190	230	ND	130	360
MHV-22	12	ND	94	4.2	125	150	ND	46	42
MHV-23	120	21	210	11	110	130	ND	460	160
MHV-24	76	11	120	1.7	270	330	ND	49	160
MHV-25	130	56	280	14	210	260	ND	230	700
MHV-26	430	120	670	9.4	320	390	ND	1400	1000
MHV-27	140	55	340	6.6	230	280	ND	510	380
MHV-28	110	35	210	4.1	230	280	ND	280	320
MHV-29/30	335	98	530	9.7	600	730	ND	330	1350
MHV-31	28	10	73	4.8	140	170	ND	55	47
MHV32/33	230	63.5	150	5.9	97.5	120	ND	420	520
MHV-34	25	8.5	78	4.4	150	180	ND	54	39
MHV-35	16	3	71	4.4	120	146	ND	17	67
MHV-36	71	13	900	6.8	120	150	ND	1300	180
MHV-38	190	70	440	5.8	160	200	ND	880	320
MHV-39	140	42	170	4.6	200	240	ND	220	500
MHV-40	79	18	91	3.0	130	160	ND	77	260
MHV-41/42	190	23	235	8.45	115	130	ND	605	125
MHV-43	110	34	120	4.4	170	210	ND	140	360

Appendix B. Groundwater Quality Data, Lake Mohave Basin, 2003^BContinued

Site #	Nitrate-Nitrite-N (mg/L)	Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Total Phosphorus (mg/L)	SAR (value)	Irrigation Quality
MHV-1	1.8	1.8	ND	ND	-	0.024	1.1	C2-S1
MHV-2	4.3	4.3	ND	0.11	-	ND	0.6	C2-S1
MHV-3/4	5.75	5.75	ND	ND	-	0.022	4.4	C3-S1
MHV-5	5.4	5.4	ND	ND	-	0.027	1.3	C2-S1
MHV-9	0.78	0.78	ND	0.16	ND	ND	10.3	C4-S3
MHV-10	4.2	4.2	ND	<i>0.33</i>	ND	ND	8.6	C4-S2
MHV-11/12	0.26	0.26	ND	0.32	ND	ND	11	C4-S3
MHV-14	2.0	2.0	ND	<i>1.5</i>	0.085	0.021	3.5	C4-S1
MHV-16	0.087	0.087	ND	<i>0.30</i>	ND	ND	8.3	C4-S2
MHV-17/18	13	13	ND	ND	ND	ND	5.4	C4-S2
MHV-19	0.021	0.021	ND	<i>0.084</i>	0.051	ND	10.7	C3-S2
MHV-20	ND	ND	ND	<i>1.7</i>	0.72	0.037	7.3	C4-S2
MHV-21	0.025	0.025	ND	0.093	ND	ND	4.7	C3-S1
MHV-22	4.7	4.7	ND	<i>0.17</i>	ND	ND	7.5	C2-S1
MHV-23	2.6	2.6	ND	<i>0.058</i>	ND	ND	4.6	C3-S1
MHV-24	7.4	7.4	ND	ND	ND	ND	3.4	C3-S1
MHV-25	ND	ND	ND	<i>0.20</i>	0.084	<i>0.037</i>	5.2	C4-S2
MHV-26	ND	ND	ND	<i>1.3</i>	0.80	<i>0.031</i>	7.4	C4-S2
MHV-27	ND	ND	ND	<i>0.20</i>	0.073	<i>0.020</i>	6.2	C4-S2
MHV-28	ND	ND	ND	<i>0.28</i>	0.18	<i>0.025</i>	4.5	C3-S1
MHV-29/30	0.028	0.028	ND	0.74	0.27	0.029	6.7	C4-S2
MHV-31	3.1	3.1	ND	ND	ND	ND	3.0	C2-S1
MHV32/33	3.1	3.1	ND	0.115	ND	ND	2.3	C3-S1
MHV-34	2.0	2.0	ND	ND	ND	ND	3.4	C2-S1
MHV-35	1.5	1.5	ND	ND	ND	ND	4.3	C2-S1
MHV-36	0.40	0.40	ND	0.059	ND	ND	25.8	C4-S4
MHV-38	ND	ND	ND	0.098	0.029	ND	6.9	C4-S2
MHV-39	1.2	1.2	ND	0.057	ND	ND	3.2	C3-S1
MHV-40	ND	ND	ND	0.15	0.072	ND	2.4	C3-S1
MHV-41/42	3.3	3.3	ND	0.37	ND	ND	4.4	C4-S2
MHV-43	ND	ND	ND	0.28	0.14	0.031	2.6	C3-S1

bold = constituent level exceeds Primary or Secondary MCL

italics = constituent exceeded holding time

Appendix B. Groundwater Quality Data, Lake Mohave Basin, 2003^BContinued

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)
MHV-1	ND	ND	ND	ND	0.14	ND	ND	ND	0.96
MHV-2	ND	ND	ND	ND	ND	ND	ND	ND	0.47
MHV-3/4	ND	0.025*	ND	ND	0.695	ND	0.0105	ND	0.80
MHV-5	ND	0.065	ND	ND	0.14	ND	ND	ND	0.72
MHV-9	ND	0.047*	ND	ND	1.1	ND	0.016	ND	2.2
MHV-10	ND	0.014*	0.11	ND	0.84	ND	0.040	ND	1.1
MHV-11/12	ND	0.0225*	0.049	ND	1.65	ND	ND	ND	3.1
MHV-14	ND	ND	ND	ND	0.90	ND	ND	ND	0.65
MHV-16	ND	0.012*	ND	ND	0.78	ND	ND	ND	2.4
MHV-17/18	ND	ND	ND	ND	0.35	ND	ND	ND	ND
MHV-19	ND	ND	ND	ND	0.28	ND	ND	ND	1.8
MHV-20	ND	ND	ND	ND	0.29	ND	ND	ND	ND
MHV-21	ND	ND	ND	ND	0.26	ND	ND	ND	0.60
MHV-22	ND	0.025*	ND	ND	0.23	ND	0.020	ND	3.5
MHV-23	ND	ND	ND	ND	0.19	ND	ND	ND	0.45
MHV-24	ND	ND	ND	ND	0.21	ND	ND	ND	0.97
MHV-25	ND	ND	ND	ND	0.23	ND	ND	ND	0.92
MHV-26	ND	0.019*	ND	ND	0.28	ND	ND	ND	ND
MHV-27	ND	ND	ND	ND	0.29	ND	ND	ND	ND
MHV-28	ND	ND	ND	ND	0.15	ND	ND	ND	0.26
MHV-29/30	ND	ND	ND	ND	0.41	ND	ND	ND	ND
MHV-31	ND	ND	0.12	ND	0.12	ND	0.022	ND	0.88
MHV32/33	ND	ND	ND	ND	0.105	ND	ND	ND	ND
MHV-34	ND	ND	ND	ND	0.22	ND	0.011	ND	ND
MHV-35	ND	0.013*	ND	ND	0.37	ND	ND	ND	0.92
MHV-36	ND	0.017*	ND	ND	0.73	ND	ND	ND	4.0
MHV-38	ND	0.015*	ND	ND	0.31	ND	ND	ND	ND
MHV-39	ND	ND	ND	ND	0.20	ND	ND	ND	0.29
MHV-40	ND	ND	0.10	ND	0.11	ND	ND	ND	0.39
MHV-41/42	ND	ND	ND	ND	0.30	ND	ND	ND	2.65
MHV-43	ND	ND	0.12	ND	0.13	ND	ND	ND	0.33

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, Lake Mohave Basin, 2003--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)
MHV-1	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-2	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-3/4	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-5	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-9	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-10	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-11/12	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-14	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-16	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-17/18	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-19	0.20	ND	0.089	ND	ND	ND	ND	ND	ND
MHV-20	2.5	ND	2.1	ND	ND	ND	ND	ND	0.25
MHV-21	ND	ND	0.12	ND	ND	ND	ND	ND	ND
MHV-22	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-23	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-24	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-25	0.30	0.0076	0.29	ND	ND	ND	ND	ND	ND
MHV-26	1.9	ND	1.6	ND	ND	ND	ND	ND	ND
MHV-27	0.13	ND	0.58	ND	ND	ND	ND	ND	ND
MHV-28	0.18	ND	0.36	ND	ND	ND	ND	ND	ND
MHV-29/30	2.0	ND	1.7	ND	ND	ND	ND	ND	ND
MHV-31	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV32/33	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-34	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-35	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-36	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-38	ND	ND	0.88	ND	ND	ND	ND	ND	ND
MHV-39	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-40	ND	ND	0.51	ND	ND	ND	ND	ND	ND
MHV-41/42	ND	ND	ND	ND	ND	ND	ND	ND	0.15
MHV-43	0.42	ND	0.66	ND	ND	ND	ND	ND	ND

bold = constituent level exceeds Primary or Secondary MCL

Appendix B. Groundwater Quality Data, Lake Mohave Basin, 2003--Continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Ra-226 (pCi/L)	Uranium (ug/L)	Perc (ug/L)	$\delta^{18}\text{O}$ (‰)	δD (‰)	Chemistry Type
MHV-1	174	13.7	--	0.2+/-0.1	--	--	- 9.6	- 73	calcium-bicarbonate
MHV-2	--	1.2	< 4.7	--	--	--	- 8.8	- 69	mixed-bicarbonate
MHV-3/4	135	3.0	<3.2	--	--	--	- 10.6	- 84.5	sodium-sulfate
MHV-5	--	--	--	--	--	--	- 9.2	- 69	mixed-bicarbonate
MHV-9	449	1.4	10.6	--	--	--	- 10.9	- 86	sodium-chloride
MHV-10	--	--	--	--	--	--	- 9.7	- 78	sodium-chloride
MHV-11/12	--	4.2	10.3	--	--	--	- 10.7	- 85	sodium-chloride
MHV-13						--	- 12.4	- 100	--
MHV-14	--	--	--	--	--	--	- 12.1	- 92	mixed-mixed
MHV-15						--	- 5.2	- 42	--
MHV-16	--	--	--	--	--	--	- 10.2	- 82	sodium-mixed
MHV-17/18	--	--	--	--	--	--	- 14.0	- 109	mixed-mixed
MHV-19	128	--	--	--	--	ND	- 14.2	- 109	sodium-mixed
MHV-20	--	--	--	--	--	ND	- 13.0	- 105	mixed-mixed
MHV-21	130	--	--	--	--	--	- 12.5	- 101	sodium-sulfate
MHV-22	198	6.2	--	--	--	ND	- 9.7	- 77	sodium-mixed
MHV-23	120	--	--	--	--	--	- 13.9	- 105	sodium-chloride
MHV-24	112	11.1	--	--	--	--	- 9.3	- 71	sodium-bicarbonate
MHV-25	38	--	--	--	--	ND	- 12.9	- 104	sodium-sulfate
MHV-26	80	--	--	--	--	--	- 12.3	- 101	mixed-chloride
MHV-27	--	--	--	--	--	--	- 15.0	- 114	sodium-chloride
MHV-28	--	--	--	--	--	--	- 14.8	- 113	sodium-mixed
MHV-29/30	34	--	--	--	--	ND	- 13.25	- 105.5	mixed-sulfate
MHV-31	192	--	--	--	--	ND	- 9.2	- 67	sodium-mixed
MHV32/33	--	< LLD	7.8	--	--	ND	- 14.95	- 113.5	mixed-mixed
MHV-34	195	--	--	--	--	--	- 9.3	- 71	sodium-bicarbonate
MHV-35	136	2.9	4.5	--	--	--	- 9.1	- 71	sodium-bicarbonate
MHV-36	188	--	--	--	--	--	- 11.1	- 85	sodium-chloride
MHV-37	--	--	--	--	--	4.4	- 12.3	- 99	--
MHV-38	441	--	--	--	--	ND	- 13.7	- 105	mixed-chloride
MHV-39	279	--	--	--	--	--	- 12.7	- 102	mixed-sulfate
MHV-40	254	--	--	--	--	ND	- 12.8	- 102	mixed-sulfate
MHV-41/42	< 29	2.4	1.3	--	--	--	- 8.7	- 68	mixed-chloride
MHV-43	138	--	--	--	--	ND	- 12.8	- 102	mixed-sulfate

bold = Primary MCL Exceedance

LLD = Lower Limit of Detection

italics = constituent exceeded holding time

Appendix B. Groundwater Quality Data, Lake Mohave Basin, 2003--Continued

Site #	MCL Exceedances	Temp (°C)	pH-field (su)	pH-lab (su)	SC-field (•S/cm)	SC-lab (•S/cm)	TDS (mg/L)	Hardness (mg/L)	Hard (cal) (mg/L)	Turbidity (ntu)
MHV-44	NO ₃ , As*	38.1	7.58	7.9	612	600	370	65	68	ND
MHV-45	TDS, SO ₄ , Fe, Mn	21.0	7.51	7.7	958	980	590	280	300	2.0
MHV-46		37.1	7.76	7.8	616	600	370	84	90	ND
MHV-47		27.6	7.80	7.8	489	520	320	160	160	0.10
MHV-48/49	TDS, SO ₄ , Mn, Fe	30.5	7.16	7.3	2833	2800	2350	1350	1300	5.4
MHV-50		32.5	8.11	7.9	721	740	450	150	150	0.12
MHV-51		34.7	8.18	7.8	434	440	280	91	90	0.12
MHV-52		32.9	8.19	8.1	479	490	300	91	89	0.45
MHV-53/54	TDS, Cl, F, As*	29.8	7.75	7.85	1434	1500	925	250	230	0.095
MHV-55	TDS, SO ₄	28.5	7.16	7.2	2069	1800	1500	770	820	0.15
MHV-57	TDS, SO ₄ , Cl, NO ₃ , F, As	33.7	7.61	7.5	3385	3500	2100	240	220	0.40
MHV-58	TDS	29.6	7.52	7.4	1143	1000	650	170	180	0.42

bold = constituent level exceeds Primary or Secondary MCL

Appendix B. Groundwater Quality Data, Lake Mohave Basin, 2003--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)
MHV-44	27	ND	93	4.9	140	170	ND	55	52
MHV-45	77	26	84	4.2	150	180	ND	73	250
MHV-46	33	2	88	3.7	130	160	ND	44	85
MHV-47	53	7.2	40	0.70	170	207	ND	21	31
MHV-48/49	385	103	195	5.75	400	490	ND	160	1095
MHV-50	35	14	80	5.6	130	160	ND	85	83
MHV-51	21	9.0	49	5.5	140	170	ND	26	17
MHV-52	21	8.8	60	4.5	140	170	ND	35	37
MHV-53/54	78.5	8.3	190	5.7	140	170	ND	260	200
MHV-55	220	65	160	6.3	200	240	ND	220	440
MHV-57	81	5.1	650	6.3	160	200	ND	670	390
MHV-58	62	5.6	160	7.0	100	120	ND	180	110

bold = constituent level exceeds Primary or Secondary MCL

Appendix B. Groundwater Quality Data, Lake Mohave Basin, 2003--Continued

Site #	Nitrate-Nitrite-N (mg/L)	Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Ammonia (mg/L)	Total Phosphorus (mg/L)	SAR (value)	Irrigation Quality
MHV-44	10	10	<i>ND</i>	0.072	ND	ND	4.9	C2-S1
MHV-45	ND	ND	<i>ND</i>	0.12	0.026	ND	2.1	C3-S1
MHV-46	3.6	3.6	<i>ND</i>	0.054	ND	ND	4.0	C2-S1
MHV-47	7.3	7.3	<i>ND</i>	ND	ND	ND	1.4	C2-S1
MHV-48/49	0.037	0.037	<i>ND</i>	0.21	ND	ND	2.3	C4-S1
MHV-50	4.2	4.2	<i>ND</i>	0.088	ND	ND	2.9	C2-S1
MHV-51	3.9	3.9	<i>ND</i>	ND	ND	ND	2.3	C2-S1
MHV-52	2.2	2.2	<i>ND</i>	0.26	ND	ND	2.8	C2-S1
MHV-53/54	5.7	5.7	<i>ND</i>	0.084	ND	<i>ND</i>	5.4	C3-S1
MHV-55	2.6	2.6	<i>ND</i>	0.089	ND	<i>ND</i>	2.4	C3-S1
MHV-57	15	15	<i>ND</i>	0.073	ND	<i>ND</i>	18.9	C4-S4
MHV-58	0.091	0.091	<i>ND</i>	ND	ND	ND	5.2	C3-S1

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

Appendix B. Groundwater Quality Data, Lake Mohave Basin, 2003--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)
MHV-44	ND	0.033*	ND	ND	0.31	ND	ND	ND	0.80
MHV-45	ND	ND	0.12	ND	0.12	ND	ND	ND	0.30
MHV-46	ND	ND	ND	ND	0.24	ND	0.018	ND	1.1
MHV-47	ND	ND	ND	ND	ND	ND	ND	ND	0.86
MHV-48/49	ND	ND	ND	.00054	0.32	ND	ND	ND	0.46
MHV-50	ND	ND	ND	ND	0.24	ND	0.012	ND	0.76
MHV-51	ND	ND	ND	ND	0.13	ND	0.029	ND	1.2
MHV-52	ND	ND	ND	ND	0.20	ND	0.016	ND	0.95
MHV-53/54	ND	0.018*	ND	ND	0.435	ND	ND	ND	2.8
MHV-55	ND	ND	ND	ND	0.18	ND	ND	ND	0.14
MHV-57	ND	0.096	ND	ND	0.74	ND	ND	ND	3.2
MHV-58	ND	ND	ND	ND	0.21	ND	ND	ND	1.2

bold = constituent level exceeds Primary or Secondary MCL

Appendix B. Groundwater Quality Data, Lake Mohave Basin, 2003--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)
MHV-44	ND	0.022	ND	ND	ND	ND	ND	ND	0.55
MHV-45	0.45	ND	0.27	ND	ND	ND	ND	ND	ND
MHV-46	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-47	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-48/49	0.57	ND	1.45	ND	ND	ND	ND	ND	0.075
MHV-50	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-51	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-52	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-53/54	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-55	ND	ND	ND	ND	ND	ND	ND	ND	ND
MHV-57	ND	ND	ND	0.0017	ND	ND	ND	ND	ND
MHV-58	ND	ND	ND	ND	ND	ND	ND	ND	ND

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

Appendix B. Groundwater Quality Data, Lake Mohave Basin, 2003--Continued

Site #	Radon-222 (pCi/L)	Alpha (pCi/L)	Beta (pCi/L)	Ra-226 (pCi/L)	Uranium (ug/L)	Perc (ug/L)	$\delta^{18}\text{O}$ (‰)	δD (‰)	Chemistry Type
MHV-44	408+/- 43	6.2 +/- 0.9	6.3 +/- 1.1	< LLD	--	--	- 9.7	- 76	sodium-mixed
MHV-45	125+/-16	--	--	--	--	ND	- 12.3	- 100	mixed-sulfate
MHV-46	550+/-57	3.1 +/- 0.7	6.9 +/- 1.1	--	--	--	- 9.5	- 73	sodium-mixed
MHV-47	191+/-23	2.7 +/- 0.6	1.5 +/- 1.0	--	--	--	- 9.2	- 71	calcium-bicarbonate
MHV-48/49	404+/-43	9.5 +/- 0.8	9.7 +/- 1.8	0.2 +/- 0	--	--	- 9.3	- 71	calcium-sulfate
MHV-50	85+/-13	--	--	--	--	--	- 8.9	- 68	sodium-mixed
MHV-51	590+/-61	5.9 +/- 0.8	9.2 +/- 1.2	< LLD	--	ND	-9.6	- 70	sodium-bicarbonate
MHV-52	<29	--	--	--	--	ND	- 8.9	- 67	sodium-bicarbonate
MHV-53/54	144+/-18	--	--	--	--	ND	- 14.1	- 108	sodium-chloride
MHV-55	1464+/-148	--	--	--	--	ND	- 13.6	- 107	mixed-mixed
MHV-57	253+/-28	--	--	--	--	ND	- 10.9	- 84	sodium-chloride
MHV-58	--	--	--	--	--	ND	-15.3	- 117	sodium-chloride

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

Appendix C. Data for Sample Sites, Golden Shores, 1996

Site #	Cadastral / Pump Type	Latitude - Longitude	ADWR #	ADEQ #	Site Name	Samples Collected	Well Depth	Water Depth	Basin / Source
1 st Field Trip, April 23-25, 1996 – Hains									
GS-1	B(16-21)15dda submersible	34°46'16.363" 114°28'58.354"	629730	48391	Kuska Well	Inorganic	230'	160'	623'
GS-2/3	B(16-21)15bdd submersible	34°46'19.722" 114°29'05.530"	500887	48356	Francis Well	Inorganic	250'	-	621'
GS-4	B(16-21)15bda submersible	34°46'25.914" 114°28'59.028"	505670	48353	Hill Well	Inorganic	263'	175'	621'
GS-5	B(16-21)15ccc submersible	34°45'52.556" 114°29'42.985"	504302	48385	Zegler Well	Inorganic	155'	67'	523'
GS-6	B(16-21)15cbc submersible	35°46'07.296" 114°29'54.384"	501091	48374	Little Well	Inorganic	120'	80'	535'
GS-7	B(16-21)15cca submersible	34°46'10.250" 114°29'09.362"	503071	48392	Romine Well	Inorganic	260'	163'	615'
GS-8	B(16-21)15dad submersible	34°46'06.640" 114°28'57.544"	507173	48396	Rasmussen Well	Inorganic	-	-	624'
GS-9	B(16-21)15bbd submersible	34°46'34.628" 114°29'44.394"	503603	55132	Garner Well	Inorganic	-	-	-
GSB10	B(16-21)15c submersible	34°46'15.119" 114°29'28.082"	630094	55135	Reynolds Well	Inorganic	205'	140'	-
GS-11/12	B(16-21)15aaa submersible	34°46'10.266" 114°29'21.589"	502692	48399	Hennington Well	Inorganic	234'	155'	609'
GS-13	B(16-21)15dda Submersible	34°46'03.898" 114°28'56.296"	507275	48404	Mellette Well	Inorganic	276'	170'	626'
GS-14	B(16-21)15dcc Submersible	34°45'54.043" 114°29'21.636"	507518	48403	B. Scott Well	Inorganic	220'	95'	549'
GS-15	B(16-21)15dad Submersible	34°46'00.024" 114°29'35.600"	502683	48387	Sorenson Well	Inorganic	155'	118'	572'
GS-16	B(16-21)15bdc submersible	34°46'21.262" 114°29'40.554"	503210	55134	Spiegel Well	Inorganic	220'	130'	-
GS-17	B(16-21)15aad Submersible	34°46'29.980" 114°29'02.249"	611520	48354	Wolfe Well	Inorganic	220'	190'	623'
GS-18	B(16-21)11dda submersible	34°46'53.154" 114°28'20.685"	503510	48343	King Well	Inorganic	-	-	715'
GS-19	B(16-21)11aab submersible	34°47'27.586" 114°28'05.682"	503795	48332	Powers Well	Inorganic	415'	270'	716'
GS-20/21	B(16-21)11 Submersible	34°47'03.590" 114°28'08.329"	629198	48335	GS Well #2	Inorganic	500'	270'	719'
GS-22	B(16-21)15aca submersible	34°46'31.077" 114°29'10.758"	629199	55133	GS Well #1	Inorganic	250'	140'	-

Appendix D. Groundwater Quality Data, Golden Shores, 1996

Site #	MCL Exceedances	Temp (°C)	pH-field (su)	pH-lab (su)	SC-field (•S/cm)	SC-lab (•S/cm)	TDS (mg/L)	Hardness (mg/L)	Turbidity (ntu)
GS-1	As*	28	7.84	7.78	-	-	288	88	0.04
GS-2/3		29	7.71	6.99	-	-	326	107	0.02
GS-4		31	7.58	6.92	-	-	336	109	0.02
GS-5		29	7.77	7.38	-	-	329	107	0.10
GS-6	TDS, SO ₄ , Cl,	28	7.24	7.39	-	-	1370	399	0.24
GS-7		30	7.74	7.90	-	-	305	101	0.08
GS-8		30	7.65	8.14	-	-	318	111	0.03
GS-9	TDS, Cl	29	7.60	7.80	-	-	744	294	0.14
GSB10	As*	27	8.05	7.80	-	-	324	109	0.06
GS-11/12	As*	29	7.72	7.75	-	-	292	93	0.05
GS-13		30	7.67	7.79	-	-	366	133	0.05
GS-14		30	7.84	7.80	-	-	317	103	0.07
GS-15		30	7.79	7.61	-	-	379	134	0.15
GS-16		31	7.63	7.63	-	-	474	172	0.01
GS-17		31	7.61	7.79	-	-	309	103	ND
GS-18		32	7.69	7.73	-	-	491	188	0.04
GS-19		32	7.74	7.77	-	-	365	131	0.16
GS-20/21		31	7.75	7.55	-	-	425	119	0.02
GS-22		31	7.89	7.88	-	-	407	144	ND

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 D. Groundwater Quality Data, Golden Shores, 1996--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)
GS-1	21.1	9.2	64.2	-	141	172	ND	35.3	36
GS-2/3	27.0	10.4	71.1	-	149	182	ND	47.4	43.8
GS-4	26.8	11.3	73.9	-	150	183	ND	48.3	43.3
GS-5	27.6	10.0	71.7	-	149	182	ND	45.7	45.4
GS-6	93.3	40.5	309	-	202	246	ND	312	376
GS-7	25.2	10.0	68.3	-	142	173	ND	43.1	38.8
GS-8	26.4	11.8	65.1	-	133	162	ND	48.2	44.8
GS-9	75.4	27.4	149	-	104	127	ND	300	106
GSB10	26.0	11.3	66.8	-	111	135	ND	59.3	54.1
GS-11/12	22.9	9.2	65.1	-	143	174	ND	35.5	35.9
GS-13	33.5	13.4	72.9	-	138	168	ND	60.0	60.3
GS-14	26.8	9.6	69.4	-	141	172	ND	46.2	39.7
GS-15	32.1	14.0	82.0	-	125	153	ND	52.8	86.4
GS-16	44.0	17.8	97.8	-	119	145	ND	120	94.7
GS-17	25.0	11.0	69.4	-	148	181	ND	46.2	36.5
GS-18	51.7	17.7	94.8	-	132	161	ND	96.4	107
GS-19	32.3	13.5	74.4	-	128	156	ND	66.2	67.1
GS-20/21	30.1	12.2	105	-	134	163	ND	108	54.0
GS-22	35.7	15.3	84.8	-	135	165	ND	78.5	69.5

bold = constituent level exceeds Primary or Secondary MCL

Appendix D. Groundwater Quality Data, Golden Shores, 1996--Continued

Site #	Nitrate-Nitrite-N (mg/L)	Nitrate-N (mg/L)	Nitrite-N (mg/L)	TKN (mg/L)	Chemistry Type	SAR (value)	Irrigation Quality
GS-1	1.79	-	-	ND	sodium-bicarbonate	2.9	C2-S1
GS-2/3	2.39	-	-	ND	sodium-bicarbonate	2.9	C2-S1
GS-4	1.91	-	-	ND	sodium-bicarbonate	3.0	C2-S1
GS-5	2.16	-	-	ND	sodium-bicarbonate	3.0	C2-S1
GS-6	3.94	-	-	ND	sodium-mixed	6.7	C4-S1
GS-7	2.33	-	-	ND	sodium-bicarbonate	2.9	C2-S1
GS-8	3.07	-	-	ND	sodium-bicarbonate	2.6	C2-S1
GS-9	0.74	-	-	ND	sodium-chloride	3.7	C3-S1
GSB10	2.21	-	-	ND	sodium-mixed	2.7	C2-S1
GS-11/12	1.97	-	-	ND	sodium-bicarbonate	2.9	C2-S1
GS-13	4.19	-	-	ND	sodium-mixed	2.7	C2-S1
GS-14	3.11	-	-	ND	sodium-bicarbonate	2.9	C2-S1
GS-15	4.96	-	-	ND	sodium-mixed	3.0	C2-S1
GS-16	1.07	-	-	ND	sodium-mixed	3.1	C3-S1
GS-17	2.56	-	-	ND	sodium-bicarbonate	2.9	C2-S1
GS-18	4.86	-	-	ND	sodium-mixed	2.9	C3-S1
GS-19	1.78	-	-	ND	sodium-mixed	2.8	C2-S1
GS-20/21	1.26	-	-	ND	sodium-mixed	4.0	C2-S1
GS-22	3.81	-	-	0.10	sodium-mixed	3.0	C2-S1

Appendix D. Groundwater Quality Data, Golden Shores, 1996--Continued

Site #	Aluminum (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)
GS-1	ND	0.011*	ND	-	-	ND	0.014	ND	1.06
GS-2/3	ND	ND	ND	-	-	ND	0.016	ND	0.87
GS-4	ND	ND	ND	-	-	ND	0.014	ND	0.85
GS-5	ND	ND	ND	-	-	ND	0.015	ND	0.91
GS-6	ND	ND	ND	-	-	ND	ND	ND	1.24
GS-7	ND	ND	ND	-	-	ND	0.016	ND	0.98
GS-8	ND	ND	ND	-	-	ND	0.021	ND	0.98
GS-9	ND	ND	0.10	-	-	ND	ND	ND	0.56
GSB10	ND	0.012*	ND	-	-	ND	0.011	ND	0.92
GS-11/12	ND	0.011*	ND	-	-	ND	0.014	ND	1.02
GS-13	ND	ND	ND	-	-	ND	0.024	ND	0.94
GS-14	ND	ND	ND	-	-	ND	0.020	ND	1.07
GS-15	ND	ND	ND	-	-	ND	0.022	ND	1.01
GS-16	ND	ND	ND	-	-	ND	ND	ND	0.76
GS-17	ND	ND	ND	-	-	ND	0.013	ND	0.84
GS-18	ND	ND	ND	-	-	ND	0.014	ND	0.72
GS-19	ND	ND	ND	-	-	ND	ND	ND	0.78
GS-20/21	ND	ND	ND	-	-	ND	ND	ND	0.87
GS-22	ND	ND	ND	-	-	ND	0.012	ND	0.87

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 D. Groundwater Quality Data, Golden Shores, 1996--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)
GS-1	ND	ND	ND	ND	-	ND	ND	-	ND
GS-2/3	ND	ND	ND	ND	-	ND	ND	-	ND
GS-4	ND	ND	ND	ND	-	ND	ND	-	ND
GS-5	ND	ND	ND	ND	-	ND	ND	-	ND
GS-6	ND	ND	ND	ND	-	0.006	ND	-	ND
GS-7	ND	ND	ND	ND	-	ND	ND	-	ND
GS-8	ND	ND	ND	ND	-	ND	ND	-	ND
GS-9	ND	ND	ND	ND	-	ND	ND	-	ND
GSB10	ND	ND	ND	ND	-	ND	ND	-	ND
GS-11/12	ND	ND	ND	ND	-	ND	ND	-	ND
GS-13	ND	ND	ND	ND	-	ND	ND	-	ND
GS-14	ND	ND	ND	ND	-	ND	ND	-	ND
GS-15	ND	ND	ND	ND	-	ND	ND	-	ND
GS-16	ND	ND	ND	ND	-	ND	ND	-	ND
GS-17	ND	ND	ND	ND	-	ND	ND	-	ND
GS-18	ND	ND	ND	ND	-	ND	ND	-	ND
GS-19	ND	ND	ND	ND	-	ND	ND	-	ND
GS-20/21	ND	ND	ND	ND	-	ND	ND	-	ND
GS-22	ND	ND	ND	ND	-	ND	ND	-	ND

bold = constituent level exceeds Primary or Secondary MCL

Appendix E. Summary Statistics for 1996 Golden Shores Groundwater Quality Data

Constituent	Minimum Reporting Limit (MRL)	Number of Samples Over MRL	Lower 95% Confidence Interval	Median	Mean	Upper 95% Confidence Interval
Physical Parameters						
Temperature (°C)	N/A	19	29.2	30.0	29.9	30.6
pH-field (su)	N/A	19	7.63	7.72	7.71	7.79
Turbidity (ntu)	0.01	19	0.04	0.05	0.07	0.10
General Mineral Characteristics						
Total Alkalinity	2.0	19	128	138	138	148
Hardness-lab	10.0	19	107	111	145	182
TDS	10.0	19	309	336	430	551
Major Ions						
Calcium	5.0	19	27	28	36	45
Magnesium	1.0	19	11	12	15	18
Sodium	5.0	19	65	73	92	120
Bicarbonate	2.0	19	157	168	168	180
Chloride	1.0	19	48	53	87	126
Sulfate	10.0	19	39	54	76	113
Nutrients						
Nitrate (as N)	0.02	19	2.1	2.3	2.6	3.2
Trace Elements						
Chromium	5.0	14	0.010	0.014	0.013	0.016
Fluoride	10.0	19	0.84	0.91	0.91	0.98

All units mg/L except where noted with physical parameters

APPENDIX F. INVESTIGATION METHODS

Various groundwater sites were sampled by the ADEQ Ambient Groundwater Monitoring Program to characterize regional groundwater quality in the MHV. Samples were collected at all sites for inorganic (physical parameters, major ions, nutrients, and trace elements) and hydrogen and oxygen isotope analyses. At select sites, samples were also collected for radiochemistry, radon, and perchlorate analyses. No bacteria sampling was conducted because microbiological contamination problems in groundwater are often transient and subject to a variety of changing environmental conditions including soil moisture content and temperature.¹⁶

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.¹⁹

Sampling in the MHV 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.¹⁹ 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.⁷ Other factors such as casing access to determine groundwater depth and construction information were preferred but not essential.

If registered wells were unavailable for sampling, springs or unregistered wells were randomly selected for

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

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

- Amount of groundwater quality data already available;
- Extent to which impacted groundwater is known or believed likely to occur; and
- Hydrologic complexity and variability of the basin.¹⁹

Sample Collection

The personnel who designed the MHV 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)² and the Field Manual For Water Quality Sampling.⁷ While these sources should be consulted as references to specific sampling questions, a brief synopsis of the procedures involved in collecting a groundwater sample is provided.

After obtaining permission from the owner to sample the well, the water level was measured with a sounder if the casing had access for a probe. The volume of water needed to purge the well three bore-hole volumes was calculated from well log and on-site information. Physical parameters - temperature, pH, and specific conductivity - were monitored at least every five minutes using a YSI multi-parameter instrument. To assure obtaining fresh water from the aquifer, typically after three bore volumes had been pumped and the physical parameters were stabilized within 10 percent, a sample representative of the aquifer was collected from a point as close to the wellhead as possible. In certain instances, it was not possible to purge three bore volumes. In these cases, at least one bore volume was evacuated and the physical parameters had stabilized within 10 percent.

Sample bottles were filled in the following order:

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

Radon samples were collected in two unpreserved, 40-ml clear glass vials. Radon samples were carefully filled and sealed so that no headspace remained.¹⁵

Perchlorate samples were collected in a 1-liter polyethylene bottle and were not preserved.¹⁵

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

- Samples to be analyzed for dissolved metals were filtered into bottles and preserved with 5 ml nitric acid (70 percent). An on-site positive pressure filtering apparatus with a 0.45 micron (μm) pore size groundwater capsule filter was used.
- Samples to be analyzed for nutrients were collected in bottles and preserved with 2 ml sulfuric acid (95.5 percent).
- Samples to be analyzed for other parameters were unpreserved.²⁵

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

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

Samples were kept at 4⁰C with ice in an insulated cooler, with the exception of the isotope and radiochemistry samples. Chain of custody procedures were followed in sample handling. Samples for this study were collected during five field trips between January and June, 2003. One additional sample was collected in June 2004.

Laboratory Methods

The inorganic analyses for this study were conducted by the Arizona Department of Health Services (ADHS) Laboratory in Phoenix, Arizona. Inorganic sample splits analyses, as well as perchlorate analyses, were conducted by Del Mar Laboratory in Phoenix, Arizona. A complete listing of inorganic parameters, including laboratory method, EPA water method, and Minimum Reporting Level (MRL) for each laboratory is provided in Table 7.

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

Radiochemistry samples were analyzed by either the Radiation Safety Engineering, Inc. Laboratory or the Arizona Radiation Agency Laboratory in Phoenix. The following EPA SDW protocols were used: Gross alpha was analyzed, and if levels exceeded 5 pCi/L, then radium-226 was measured. If radium-226 exceeded 3 pCi/L, radium-228 was measured. If gross alpha levels exceeded 15 pCi/L initially, then radium-226/228 and total uranium were measured.

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

Sample Numbers

Forty-three (43) groundwater sites were sampled for the study. Two surface water sites and one precipitation event were also sampled for isotope analyses only. Various numbers and types of samples were collected and analyzed:

- 43 - inorganic
- 46 - hydrogen and oxygen isotopes
- 31 - radon
- 18 - perchlorate
- 15 - radiochemistry

Table 7. ADHS/Del Mar Laboratory Methods Used for the Lake Mohave Basin Study

Constituent	Instrumentation	ADHS / Del Mar Water Method	ADHS / Del Mar Minimum Reporting Level
Physical Parameters and General Mineral Characteristics			
Alkalinity	Electrometric Titration	SM232OB	2 / 5
SC (•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 ^{15, 25}

Table 7. ADHS/Del Mar Laboratory Methods Used for the Lake Mohave Basin 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 ^{15,25}

APPENDIX G. 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 MHV study. The design of the QA/QC plan was based on recommendations included in the *Quality Assurance Project Plan (QAPP)*² and the *Field Manual For Water Quality Sampling*.⁷ The types and numbers of QC samples collected for this study are as follows:

- Inorganic: (4 duplicates, 1 partial filter duplicate, 3 splits, 4 full blanks and 2 partial filter blanks).
- Isotope: (5 duplicates).

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

Blanks - Equipment blanks for inorganic analyses were collected to ensure adequate decontamination of sampling equipment, and that the filter apparatus and/or de-ionized water were not impacting the groundwater quality sampling.⁷ Equipment blank samples for major ion and nutrient analyses were collected by filling unpreserved and sulfuric acid preserved bottles with de-ionized water. Equipment blank samples for trace element analyses were collected with de-ionized water that had been filtered into nitric acid preserved bottles. Partial equipment blanks were collected by filling unpreserved bottles with de-ionized water. The ADHS laboratory then filtered the sample water into nitric acid preserved bottles. Only metal concentrations were analyzed from partial equipment blanks.

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.¹⁹ As such, SC-lab and turbidity were considered to be affected by systematic contamination; however, the extent of contamination was not considered significant.

SC was detected in all five full equipment blanks while turbidity was also detected three full equipment blanks.

For SC, equipment blanks had a mean (3.3 $\mu\text{S}/\text{cm}$) which was less than 1 percent of the SC mean concentration for the study. The SC detections may be explained in two ways: water passed through a de-ionizing exchange unit will normally have an SC value of at least 1 $\mu\text{S}/\text{cm}$, and carbon dioxide from the air can dissolve in de-ionized water with the resulting bicarbonate and hydrogen ions imparting the observed conductivity.²⁵ Similarly for turbidity, equipment blanks had a mean level (0.05 ntu) less than 1 percent of the turbidity median level for the study. Testing indicates turbidity is present at 0.01 ntu in the de-ionized water supplied by the ADHS laboratory, and levels increase with time due to storage in ADEQ carboys.²⁵

One other constituent, nitrate at 0.25 mg/L, was detected in the one blank but did not appear to significantly impact sampling results.

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.⁷ Duplicate samples were collected from sampling sites that were believed to have elevated constituent concentrations as judged by field SC values. Four duplicate samples were collected in this study.

Analytical results indicate that of the 23 constituents that had concentrations above the MRL, the maximum variation between duplicates was less than 12 percent (Table 8). The only exceptions were turbidity (16%) and TKN (31%). Not unexpectedly, TKN exhibited the largest maximum difference, a pattern which has been found in other ADEQ ambient groundwater studies and is due to the difficulty in analyzing this constituent.^{15, 25} The median variation between duplicates was less than 5 percent except that turbidity had a 10% variation. The majority of constituents had a maximum variation of less than 5% and a median variation less than 1%.

Analytical results for the five isotope duplicates conducted by the Laboratory of Isotope Geochemistry at the University of Arizona indicated the maximum variation between both oxygen and hydrogen duplicates was less than 1 percent.

Table 8. Summary Results of MHV Duplicate Samples from the ADHS Laboratory

Parameter	Number	Difference in Percent			Difference in Concentrations		
		Minimum	Maximum	Median	Minimum	Maximum	Median
Physical Parameters and General Mineral Characteristics							
Alkalinity, Total	4	0 %	3 %	0 %	0	5	0
SC (•S/cm)	4	0 %	0 %	0 %	0	0	0
Hardness	4	0 %	4 %	0 %	0	20	0
pH-field (su)	4	0 %	3 %	0 %	0	0.5	0
TDS	4	0 %	2 %	0 %	0	30	0
Turbidity (NTU)	4	7 %	16 %	10 %	0.01	3	0.03
Major Ions							
Bicarbonate	4	0 %	0 %	0 %	0	0	0
Calcium	5	0 %	5 %	0 %	0	30	0
Magnesium	5	0 %	2 %	1 %	0	4	1
Sodium	5	0 %	3 %	0 %	0	10	0
Potassium	5	0 %	1 %	0 %	0	0.2	0
Chloride	4	0 %	1 %	0 %	0	1	0
Sulfate	4	0 %	10 %	0 %	0	100	0
Nutrients							
Nitrate (as N)	4	0 %	11 %	0 %	0	0.1	0
TKN	3	4 %	31 %	5 %	0.01	0.08	0.05
Ammonia	1	2 %	2 %	2%	0.01	0.01	0.01
Phosphorus, total	1	5 %	5 %	5%	0.003	0.003	0.003
Trace Elements							
Arsenic	2	0 %	0 %	0 %	0	0.011	0
Boron	5	0 %	5 %	1 %	0	0.01	0.01
Chromium	1	5 %	5 %	5 %	0.001	0.001	0.001
Fluoride	3	0 %	2 %	0 %	0	0.03	0
Iron	1	0 %	0 %	0%	0	0	0
Manganese	1	0 %	0 %	0%	0	0	0

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

Note: In one duplicate, total phosphorus was 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.⁷ Three inorganic split samples were collected and analytical results were evaluated by examining the variability in constituent concentrations in terms of absolute levels and as the percent difference.

Analytical results indicate that of the 36 constituents examined, only 20 had concentrations above MRLs for both ADHS and Del Mar laboratories (Table 9). The maximum difference between split constituent only exceeded 10 percent for potassium (18%), zinc (39%), and TKN (49%). As usual, TKN exhibited the largest maximum difference, a pattern which has been found in other ADEQ ambient groundwater studies and is due to the difficulty in analyzing this constituent.^{15, 25}

Based on the results of blanks, duplicates and the split sample collected for this study, no significant QA/QC problems were apparent with the groundwater quality collected for this study. This conclusion is supported by the acceptable QA/QC results for other groundwater basins sampled concurrently with the Lake Mohave study (2003) including Meadview (2000-2003)³⁰ and Detrital Valley (2002).²⁹

ADEQ Time Trend Comparison

For additional QA/QC measurements, four sites sampled as part of the 1969-70 USGS study, three wells sampled as part of the 1994 Bullhead City and Northern Mohave Valley study, two wells that were sampled as part of the 1996 Golden Shores study, and two wells sampled in 1998 as part of Lower Colorado River valley isotope study were resampled in 2003.^{8, 9, 17, 31}

The four sites originally sampled in by the U.S. Geological Survey in 1969-70 include a windmill (MHV-1), two public water supply wells (MHV-3/4) and MHV-40/41, and a thermal spring (MHV-9).^{8, 9} Only physical parameters, major ions, and fluoride were able to be compared between studies. Analytical results of the 1969-70/2003 data indicate that of the 11 constituents examined, the minimum difference between sample constituents was typically less than 3 percent while the maximum difference was typically less than 25 percent except for bicarbonate (35%) and sulfate (90%)(Table 10).

The three wells originally sampled in 1994 include two municipal wells (MHV-22 and MHV-43) and one domestic (MHV-40).³¹ These consisted of two wells pumping recharged Colorado River water and one well (MHV-22) pumping recharged local precipitation.

Analytical results of the 1994/2003 data indicate that of the 16 constituents examined, the minimum difference between sample constituents was typically less than 3 percent while the maximum difference was typically less than 30 percent except for arsenic (35%) and chloride (45%)(Table 11).

The two wells originally sampled in 1996 include a shallow domestic well (MHV-52) and a municipal supply well (MHV-50) both pumping recharged local precipitation. Analytical results of the 1996/2003 data indicate that of the 14 constituents examined, the minimum difference between sample constituents was typically less than 5 percent while the maximum difference was typically less than 10 percent except for nitrate (37%) and gross alpha (84%)(Table 12).

The two wells originally sampled in 1998 include a municipal supply well (MHV-50) and an artesian well (MHV-51).¹⁷ Analytical results of isotope samples collected in 1998 compared with 2003 data at two sites indicated less than 1 percent difference.¹⁷

Data Validation

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

Cation/Anion Balances - In theory, water samples exhibit electrical neutrality. Therefore, the sum of milliequivalents per liter (meq/L) of cations must equal the sum of meq/L of anions. However, this neutrality rarely occurs due to unavoidable variation inherent in all water quality analyses. Still, if the cation/anion balance is found to be within acceptable limits, it can be assumed there are no gross errors in concentrations reported for major ions.²⁰

Overall, cation/anion balances of MHV 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 \bullet S/cm for groundwater up to several thousand mg/L.²⁰ Groundwater in which the ions are mostly bicarbonate and chloride will have a multiplication factor near the lower end of this range and groundwater high in sulfate may reach or even exceed the higher number. The relationship of TDS to SC becomes undefined for groundwater either with very high and low concentrations of dissolved solids.²⁰

Table 9. Summary Results of MHV 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	3	0 %	4 %	0	10	ns
SC (•S/cm)	3	2 %	4 %	120	200	ns
Hardness	3	0 %	4 %	0	100	ns
pH (su)	3	0 %	1 %	0.03	0.23	ns
TDS	3	1 %	6 %	100	180	ns
Turbidity (NTU)	1	4 %	4 %	0.4	0.4	ns
Major Ions						
Calcium	3	0 %	1 %	0	10	ns
Magnesium	3	0 %	7 %	0	14	ns
Sodium	3	2 %	6 %	10	100	ns
Potassium	3	12 %	18 %	2.1	6	ns
Chloride	3	3 %	6 %	20	100	ns
Sulfate	3	4 %	10 %	10	210	ns
Nutrients						
Nitrate as N	3	0 %	3 %	0	0.2	ns
TKN	1	49 %	49 %	0.37	0.37	ns
Trace Elements						
Arsenic	1	2 %	2 %	0.001	0.001	ns
Boron	1	9 %	9 %	0.3	0.3	ns
Fluoride	3	2 %	7 %	0.06	0.4	ns
Iron	1	4 %	4 %	0.04	0.04	ns
Manganese	1	3 %	3 %	0.1	0.1	ns
Zinc	2	16 %	39 %	0.024	0.117	ns

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

Table 10. Summary Results of 1969-70 / 2003 ADEQ Well Sampling Comparison

Constituents	Number	Difference in Percent		Difference in Levels		Significance
		Minimum	Maximum	Minimum	Maximum	
Physical Parameters and General Mineral Characteristics						
SC-lab (•S/cm)	4	1 %	13 %	11	570	ns
Hardness	4	1 %	21 %	6	150	ns
pH-lab (su)	4	0 %	4 %	0	0.6	ns
TDS	4	1 %	11 %	12	450	ns
Major Ions						
Calcium	4	3 %	19 %	5	50	ns
Magnesium	4	3 %	22 %	1	12	ns
Sodium/Potassium	4	3 %	9 %	3	63	ns
Bicarbonate	4	1 %	35 %	6	140	ns
Chloride	4	3 %	17 %	2	210	ns
Sulfate	4	1 %	90 %	10	119	ns
Trace Elements						
Fluoride	4	2 %	12 %	0.04	0.6	ns

All units are mg/L except as noted with certain physical parameters
 ns = No significant (p • 0.05) difference between samples
 The four ADEQ sample sites are MHV-1, MHV-3/4, MHV-9 and MHV-41/42

Table 11. Summary Results of 1994 / 2003 ADEQ Well Sampling Comparison

Constituents	Number	Difference in Percent		Difference in Levels		Significance
		Minimum	Maximum	Minimum	Maximum	
Physical Parameters and General Mineral Characteristics						
Alkalinity, total	3	1 %	4 %	2	10	ns
Hardness	3	9 %	29 %	22	69	ns
pH-lab (su)	3	1 %	3 %	0.2	0.5	ns
TDS	3	2 %	9 %	10	116	ns
Major Ions						
Calcium	3	7 %	26 %	7	17	ns
Magnesium	3	0 %	12 %	0	6	ns
Sodium	3	1 %	9 %	3	21	ns
Bicarbonate	3	2 %	3 %	5	11	ns
Chloride	3	3 %	45 %	5	29	ns
Sulfate	3	3 %	21 %	13	123	ns
Nutrients						
Nitrate as N	3	0 %	6 %	0	0.64	ns
Trace Elements						
Arsenic	3	0 %	35 %	0	0.013	ns
Barium	3	0 %	13 %	0	0.03	ns
Fluoride	3	1 %	11 %	0.03	0.1	ns
Iron	3	0 %	6 %	0	0.5	ns
Manganese	3	0 %	14 %	0	0.16	ns

All units are mg/L except as noted with certain physical parameters
 ns = No significant ($p < 0.05$) difference between samples
 The three ADEQ sample sites are MHV-22, MHV-40 and MHV-43

Table 12. Summary Results of 1996 / 2003 ADEQ Well Sampling Comparison

Constituents	Number	Difference in Percent		Difference in Levels		Significance
		Minimum	Maximum	Minimum	Maximum	
Physical Parameters and General Mineral Characteristics						
Alkalinity, total	2	1 %	2 %	1	5	ns
Hardness	2	2 %	2 %	3	6	ns
pH-lab (su)	2	0 %	2 %	0.02	0.32	ns
TDS	2	2 %	5 %	12	43	ns
Major Ions						
Calcium	2	0 %	1 %	0.1	0.7	ns
Magnesium	2	2 %	4 %	0.4	1.3	ns
Sodium	2	3 %	3 %	4.2	4.8	ns
Bicarbonate	2	1 %	2 %	2	5	ns
Chloride	2	0 %	4 %	0.3	6.5	ns
Sulfate	2	1 %	9 %	1	13.5	ns
Nutrients						
Nitrate as N	2	5 %	37 %	0.39	2.11	ns
Trace Elements						
Fluoride	2	5 %	7 %	0.11	0.11	ns
Radiochemistry						
Gross α (pCi/L)	1	84%	84%	25	25	ns
Gross beta (pCi/L)	1	87%	87%	17	17	ns

All units are mg/L except as noted with certain physical parameters
 ns = No significant ($p < 0.05$) difference between samples
 The two ADEQ sample sites are MHV-50 and MHV-52

Note: Arsenic was detected in the 1996 sample collected from Kruska Well at 0.011 mg/L and not detected above the MRL of 0.01 mg/L in 2003. Other constituents such as phenolphthalein alkalinity, barium, cadmium, copper, iron, lead, manganese, mercury, selenium, silver, and zinc were not detected in any of the samples.

Hardness - Concentrations of laboratory-measured and calculated values were significantly correlated (regression analysis, $p < 0.01$). Hardness concentrations were calculated using the following formula: $[(\text{Calcium} \times 2.497) + (\text{Magnesium} \times 4.118)]$.

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, $p < 0.01$).

pH - The pH value is closely related to the environment of the water and is likely to be altered by sampling and storage.²⁰ As such, the pH values measured in the field using a YSI meter at the time of sampling were not significantly correlated with laboratory pH values (regression analysis, $p < 0.05$).

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

Statistical Considerations

Various methods were used to complete the statistical analyses for the groundwater quality data of this study. All statistical tests were conducted on a personal computer using SYSTAT software.³⁸

Data Normality: Data associated with 32 constituents were tested for non-transformed normality using the Kolmogorov-Smirnov one-sample test with the Lilliefors option.¹⁰ Results of this test revealed that 5 of the 32 constituents (temperature, pH-field, pH-lab, gross alpha, and gross beta) were normally distributed.

The results of log-transformed test revealed that 18 of the 32 constituents were normally distributed. Most of the physical parameters and major ions were normally distributed while nutrients and trace elements were generally not normally distributed.

Spatial Relationships: The parametric analysis of variance (ANOVA) test in conjunction with the Tukey test was applied to investigate the hypothesis that constituent concentrations from

groundwater sites having different sources of water were the same. The ANOVA tests the equality of two or more means in experiments involving one continuous dependent variable and one categorical independent variable.³⁸ 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 basins (North and South) and recharge sources (Bouse Formation, pre-dam Colorado River, post-dam Colorado River, and local precipitation).

The ANOVA test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.¹⁸ However, the ANOVA test was applied to ammonia, arsenic, chromium, iron and manganese even though the results were not considered statistically valid in order to highlight possible significant differences. Highlights of these statistical tests are summarized in the groundwater quality section. The ANOVA test was not calculated for trace parameters or nutrients rarely detected such as antimony, barium, beryllium, cadmium, copper, lead, mercury, nickel, selenium, silver, total phosphorus, TKN, thallium, zinc, phenolphthalein alkalinity, carbonate, and nitrite.

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

The Pearson correlation coefficient varies between -1 and +1, with a value of +1 indicating that a variable can be predicted perfectly by a positive linear function of the other, and vice versa. A value of -1 indicates a perfect inverse or negative relationship. The results of the Pearson Correlation Coefficient test were then subjected to a probability test to determine which of the individual pair wise correlations were significant.³⁸ The Pearson test is not valid for data sets with greater than 50 percent of the constituent concentrations below the MRL.¹⁸ Consequently, Pearson Correlation Coefficients were not calculated for the same constituents as in spatial relationships.