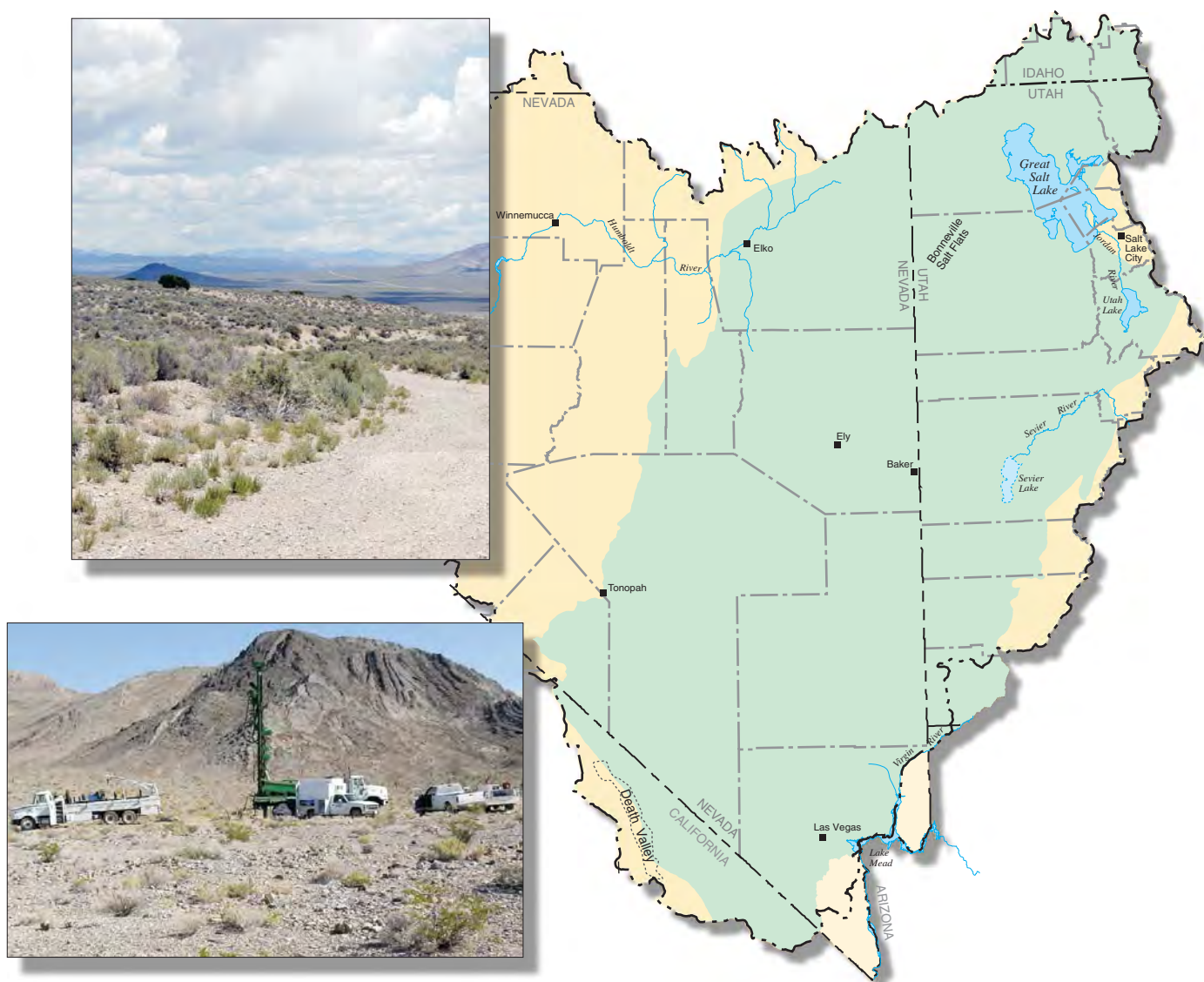


Ground-Water Quality in the Carbonate-Rock Aquifer of the Great Basin, Nevada and Utah, 2003



Scientific Investigations Report 2005-5232

**U.S. Department of the Interior
U.S. Geological Survey
National Water-Quality Assessment Program**

Cover: (Upper) View looking east into Coal Valley from the Coal Valley well, June 2003. (Lower) View looking north towards Desert Range at the DR-1 well, June 2003. Photographs taken by D.H. Schaefer.

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**U.S. Department of the Interior
U.S. Geological Survey
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U.S. Department of the Interior

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Carson City, Nevada 2006

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FOREWORD

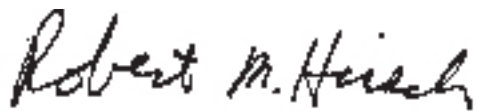
The U.S. Geological Survey (USGS) is committed to providing the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life and that facilitates effective management of water, biological, energy, and mineral resources (<http://www.usgs.gov/>). Information on the quality of the Nation's water resources is critical to assuring the long-term availability of water that is safe for drinking and recreation and suitable for industry, irrigation, and habitat for fish and wildlife. Population growth and increasing demands for multiple water uses make water availability, now measured in terms of quantity and quality, even more essential to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to support national, regional, and local information needs and decisions related to water-quality management and policy (<http://water.usgs.gov/nawqa>). Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities.

From 1991-2001, the NAWQA Program completed interdisciplinary assessments in 51 of the Nation's major river basins and aquifer systems, referred to as Study Units (<http://water.usgs.gov/nawqa/studyu.html>). Baseline conditions were established for comparison to future assessments, and long-term monitoring was initiated in many of the basins. During the next decade, 42 of the 51 Study Units will be reassessed so that 10 years of comparable monitoring data will be available to determine trends at many of the Nation's streams and aquifers. The next 10 years of study also will fill in critical gaps in characterizing water-quality conditions, enhance understanding of factors that affect water quality, and establish links between *sources* of contaminants, the *transport* of those contaminants through the hydrologic system, and the potential *effects* of contaminants on humans and aquatic ecosystems.

The USGS aims to disseminate credible, timely, and relevant science information to inform practical and effective water-resource management and strategies that protect and restore water quality. We hope this NAWQA publication will provide you with insights and information to meet your needs, and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

The USGS recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The NAWQA Program, therefore, depends on advice and information from other agencies—Federal, State, interstate, Tribal, and local—as well as nongovernmental organizations, industry, academia, and other stakeholder groups. Your assistance and suggestions are greatly appreciated.



Robert M. Hirsch
Associate Director for Water

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Conversion Factors and Datums

Multiply	By	To obtain
Length		
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
Flow rate		
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m ³ /yr)
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm ³ /yr)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$^{\circ}\text{C}=(^{\circ}\text{F}-32)/1.8$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929, (NAVD 29).

Horizontal coordinate information is referenced to the North American Vertical Datum of 1983 (NAVD 83).

Altitude, as used in this report, refers to distance above the vertical datum.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (μg/L).

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Abstract

The carbonate-rock aquifer of the Great Basin is named for the thick sequence of Paleozoic limestone and dolomite with lesser amounts of shale, sandstone, and quartzite. It lies primarily in the eastern half of the Great Basin and includes areas of eastern Nevada and western Utah as well as the Death Valley area of California and small parts of Arizona and Idaho. The carbonate-rock aquifer is contained within the Basin and Range principal aquifers, one of 16 principal aquifers selected for study by the U.S. Geological Survey's National Water-Quality Assessment Program.

Water samples from 30 ground-water sites (20 in Nevada and 10 in Utah) were collected in the summer of 2003 and analyzed for major anions and cations, nutrients, trace elements, dissolved organic carbon, volatile organic compounds (VOCs), pesticides, radon, and microbiology. Water samples from selected sites also were analyzed for the isotopes oxygen-18, deuterium, and tritium to determine recharge sources and the occurrence of water recharged since the early 1950s.

Primary drinking-water standards were exceeded for several inorganic constituents in 30 water samples from the carbonate-rock aquifer. The maximum contaminant level was exceeded for concentrations of dissolved antimony (6 $\mu\text{g/L}$) in one sample, arsenic (10 $\mu\text{g/L}$) in eleven samples, and thallium (2 $\mu\text{g/L}$) in one sample. Secondary drinking-water regulations were exceeded for several inorganic constituents in water samples: chloride (250 mg/L) in five samples, fluoride (2 mg/L) in two samples, iron (0.3 mg/L) in four samples, manganese (0.05 mg/L) in one sample, sulfate (250 mg/L) in three samples, and total dissolved solids (500 mg/L) in seven samples.

Six different pesticides or metabolites were detected at very low concentrations in the 30 water samples. The lack of VOC detections in water sampled from most of the sites is evidence that VOCs are not common in the carbonate-rock aquifer. Arsenic values for water range from 0.7 to 45.7 $\mu\text{g/L}$, with a median value of 9.6 $\mu\text{g/L}$. Factors affecting arsenic concentration in the carbonate-rock aquifer in addition to geothermal heating are its natural occurrence in the aquifer material and time of travel along the flow path.

Most of the chemical analyses, especially for VOCs and nutrients, indicate little, if any, effect of overlying land-use patterns on ground-water quality. The water quality in recharge areas for the aquifer where human activities are more intense may be affected by urban and/or agricultural land uses as evidenced by pesticide detections. The proximity of the

carbonate-rock aquifer at these sites to the land surface and the potential for local recharge to occur through the fractured rock likely results in the occurrence of these and other land-surface related contaminants in the ground water. Water from sites sampled near outcrops of carbonate-rock aquifer likely has a much shorter residence time resulting in a potential for detection of anthropogenic or land-surface related compounds. Sites located in discharge areas of the flow systems or wells that are completed at a great depth below the land surface generally show no effects of land-use activities on water quality. Flow times within the carbonate-rock aquifer, away from recharge areas, are on the order of thousands of years, so any contaminants introduced at the land surface that will not degrade along the flow path have not reached the sampled sites in these areas.

Introduction

In the Great Basin, a thick sequence of Paleozoic limestone and dolomite with lesser amounts of shale, sandstone, and quartzite forms a carbonate-rock aquifer. It lies primarily in the eastern half of the Great Basin and includes areas of eastern Nevada and western Utah, as well as the Death Valley area of California and small parts of Arizona and Idaho. The carbonate-rock aquifer of Nevada and Utah covers approximately 92,000 mi^2 of the Great Basin and is one of the larger regional aquifer systems in the country. Unlike other large regional aquifers, this aquifer is composed of several flow systems that integrate ground-water flow across multiple topographic basins. These aquifers generally are recharged in higher-altitude mountains and basins and discharge to large springs, usually associated with faults in lower-altitude basins. Few wells currently withdraw water from the carbonate-rock aquifer because of the great depth to the aquifer from land surface in many areas.

Although population density within the area overlying the carbonate-rock aquifer is generally low, the potential for increased use exists with two of the fastest growing cities in the western part of the United States located within or near the carbonate-rock aquifer borders (Las Vegas and Salt Lake City). From 1990 to 2000, the population in the western states increased by 10.4 million people, an increase of 19.7 percent (Perry and Mackun, 2001). The metropolitan areas of Las Vegas and Salt Lake City grew in population by about 83 and 40 percent, respectively. Increased use of ground water from this regional system is expected in the next few years because the anticipated large influx of new residents will require addi-

tional sources of drinking water. Increased use of the resource and changing land-use patterns may contribute to changes in the quality of water in the carbonate-rock aquifer.

Large quantities of ground water are stored in the carbonate-rock aquifer. The large aerial extent of the various flow systems, coupled with the substantial thickness of the carbonate section, could supply a vast quantity of ground water. Dettinger and others (1995, p. 71) estimated the volume of stored water in the carbonate-rock aquifer in southern Nevada to be on the order of 800 million acre-ft. Withdrawal of this water for municipal use may have adverse effects on the water availability of current users and affect ecological habitats associated with natural discharge from the aquifer system. More hydrologic, as well as chemical, information is needed on the carbonate-rock aquifer to better understand these effects.

The carbonate-rock aquifer is contained within the Basin and Range principal aquifers, one of 16 principal aquifers selected for study by the U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) Program. Water withdrawn from these 16 principal aquifers accounted for about 74 percent of the drinking water consumed in the Nation in 1990. The carbonate-rock aquifer was studied as part of the NAWQA program to assess its water quality and is part of the water-quality assessment of the Basin and Range principal aquifers.

Purpose and Scope

One of the purposes of the NAWQA Program is to describe the status of water quality in large, representative areas of the Nation's surface-water and ground-water resources and to provide a sound, scientific understanding of the primary natural and human factors affecting the quality of these resources (Gilliom and others, 1995).

The purpose of this report is to document the ground-water quality in the carbonate-rock aquifer of the Great Basin and describe how it relates to U.S. Environmental Protection Agency (USEPA) drinking-water standards. Water samples from 30 sites (20 in Nevada and 10 in Utah) were collected in the summer of 2003 and analyzed for major anions and cations, nutrients, trace elements, dissolved organic carbon (DOC), volatile organic compounds (VOCs), pesticides, radon, and microbiology. Water samples from selected sites also were analyzed for the isotopes of water [oxygen-18 (^{18}O), deuterium (^2H), and tritium (^3H)] to determine recharge sources and the occurrence of water recharged since the early 1950s.

The scope of this report includes presenting the water-quality dataset and relating the data to the ground-water flow systems documented in previous studies and the potential effects of overlying land use. It also includes comparative analyses from previous studies to view data in a regional context.

Acknowledgments

The authors thank the many people of several municipal, State, and Federal agencies that assisted in this endeavor. Of particular help were Stephen Acheampong and Jeff Johnson of the Southern Nevada Water Authority who were very interested in helping with the success of this project. The authors also thank the many employees of the Carson City and Las Vegas, Nevada, and Salt Lake City, Utah, offices of the USGS who worked long hours and drove countless miles to complete this work. Finally, the drillers with the Western Region Research Drilling Unit in Las Vegas are thanked. Drillers included Bob Roche, Roland Gonzales, Ray McKean, and Steve Crawford; their hard work is greatly appreciated.

Description of Study Area

The Basin and Range physiographic province (Fenneman and Johnson, 1946) is a large area in the western United States of mostly internal drainages. The Great Basin is in the northern part of the Basin and Range, and as discussed in this report includes about 140,000 mi², largely in Nevada and Utah (fig. 1). Smaller portions of the Great Basin extend into Arizona, California, Idaho, and Oregon. The Great Basin generally is characterized by parallel north-trending mountain ranges more than 50 mi long separated by broad alluvial basins. Most mountain ranges are 5 to 15 mi wide and offer local vertical relief from the adjoining basins of 1,000 to 5,000 ft. The crests of these mountain ranges are commonly 8,000 to 10,000 ft above sea level and altitudes of the basin floors range from below sea level in Death Valley to about 7,000 ft in central Nevada. The altitudes of most basin floors range from 4,000 to 6,000 ft.

About 260 hydrographic areas or subareas (commonly topographic basins) are recognized within the Great Basin area. Hydrographic areas are basic units used by State and local agencies for water-resources planning and management. They commonly include one topographic basin that contains a basin-fill aquifer. Many of the structural basins are topographically closed; however, others are interconnected by river systems, which terminate in major lakes or sinks. An area in the southeast part of the Great Basin drains to the Colorado River mostly as interbasin ground-water flow with little surface-water flow (Harrill and Prudic, 1998).

Although generally arid to semiarid, the climate of the study area is highly variable. The effect of a large range of latitude, the many mountain ranges, and large variations of altitude all play a part in the regions climatic variability. Mean annual precipitation in the valleys ranges from less than 5 in. in the south to about 16 in. in the north (Prudic and others, 1995, p. D7). Precipitation in the mountains generally ranges from 8 in. to more than 60 in. in some areas. Most of the precipitation occurs during the winter months and mountain

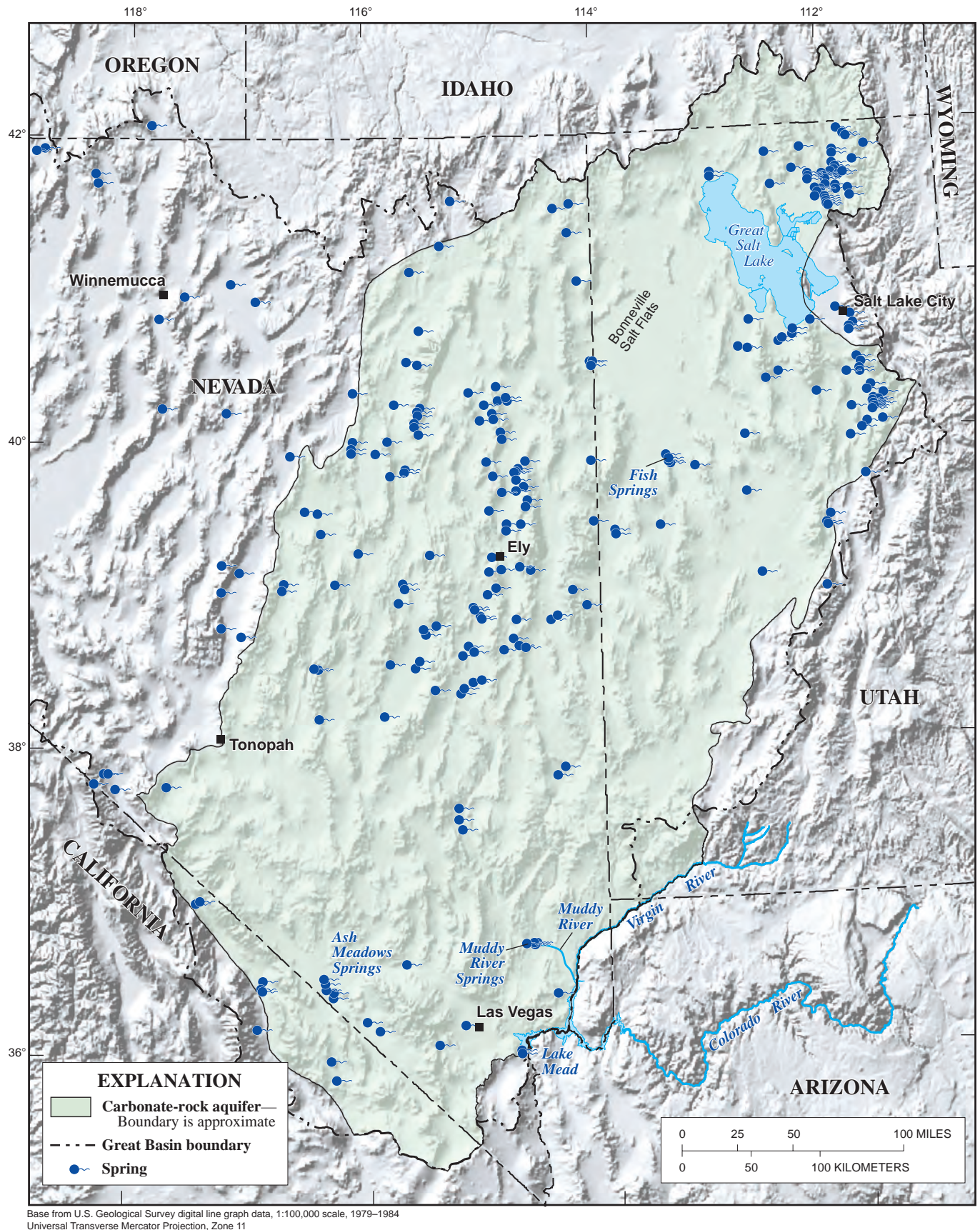


Figure 1. Selected features of the Great Basin and extent of the carbonate-rock aquifer.

snowpacks melt during spring and summer, which is the major component of ground-water recharge.

Mean annual temperature ranges from about -1.0°C in some northern valleys to about 60°C in the extreme southern valleys. The wide range between daily maximum and minimum temperatures is one of the characteristics of this area. The daily range exceeds 16°C in most valleys and can exceed 28°C in some valleys (Prudic and others, 1995, p. D9). The average length of the growing season in the principal areas of agriculture ranges from about 100 to 175 days, but can exceed 200 days in the extreme south. In the higher northern valleys it may be only 30 days. Alfalfa is the primary crop grown in the study area. Humidity in the study area also is generally quite low. This dryness coupled with abundant sunshine and light-to-moderate fairly constant winds causes high rates of evaporation.

Hydrogeology

The Great Basin has had a complex geologic history that includes major episodes of sedimentation, igneous activity, orogenic deformation, and continental rifting. The area experienced tectonic compression during parts of the Paleozoic and Mesozoic Eras resulting in thrust sequences of carbonate and clastic rocks ranging from about 0 to nearly 30,000-ft thick in eastern Nevada and western Utah. Known as the carbonate-rock province, these marine-deposited rocks underlie the eastern two-thirds of the Great Basin (fig. 1; Harrill and Prudic, 1998, fig. 4 and 5). Tectonic extension in the area began about 17 million years ago and involved normal faulting that resulted in the Basin and Range structure visible today (Stewart, 1980 p. 5).

The Great Basin of Nevada, Utah, and adjacent states contains two important aquifer systems, one composed of basin-fill aquifers and the other of the carbonate-rock aquifer. The basin-fill aquifers occur within the topographic basins and most are physically separated from each other by mountain ranges composed of consolidated rock. The carbonate-rock aquifer can extend across topographic basins and mountain blocks forming multibasin ground-water flow systems (Eakin, 1966).

The carbonate-rock aquifer is composed of thick sequences of Paleozoic and Mesozoic limestone and dolomite with lesser amounts of shale, sandstone, and quartzite. Secondary permeability has developed in these aquifers by fracturing, faulting, and to a lesser extent solution enlargement of fractures. Although the aquifer system contains layers of sandstone and quartzite that can be fractured and transmit water readily, it is generally referred to as the carbonate-rock aquifer (Plume and Carlton, 1988). The carbonate rocks are underlain by Precambrian metamorphic and granitic rocks and upper Precambrian to Middle Cambrian clastic sedimentary rocks. Figure 2 shows a representative stratigraphic section of the Paleozoic rocks as exposed in the Sheep Range in southern Nevada. They are overlain by Upper Paleozoic to Mesozoic

clastic sedimentary rocks, Cenozoic volcanic rocks, and Cenozoic basin-fill deposits. Rocks of the region are intruded by granitic rocks that range in age from late Mesozoic to Cenozoic. Carbonate rocks in this area may be up to 25,000-ft thick (Dettinger and others, 1995). Figure 3 shows a representative cross section through the carbonate aquifer in southern Nevada.

Carbonate rocks typically are more permeable than the adjacent volcanic and igneous rocks. This is generally due to secondary permeability developed by dissolution of carbonate minerals along faults, fractures, and bedding planes. Because of these factors, ground water in most cases moves more easily through carbonate rocks. The ability of carbonate rocks to store and transmit water differs throughout the area; transmissivities vary from $13\text{ ft}^2/\text{d}$ in undeformed areas to more than $130,000\text{ ft}^2/\text{d}$ in areas where rocks are intensely deformed and fractured (Thomas and others, 1986; Dettinger and others, 1995).

Carbonate-rock units can form extensive aquifers that store and transmit large quantities of water along faults and fracture systems that extend through several basins and ranges. Discharge from these regional aquifers is manifested by large springs and in some areas extensive wetlands. Non-carbonate rocks generally are less permeable and can act as barriers to flow and confining units for the carbonate rocks. Basin-fill deposits generally overlie the carbonate-rock units, and in most cases are more permeable than carbonate rocks, and also are capable of storing and transmitting large quantities of ground water. In some places these basin-fill deposits are assumed to be hydraulically connected to adjacent and underlying carbonate rocks, resulting in a continuous flow system bounded by non-carbonate rocks and structural features. Figure 4 shows a generalized hydrogeologic section through a carbonate-rock aquifer and overlying basin-fill deposits.

Based on water-level information and ground-water budgets for individual topographic basins, Harrill and Prudic (1998) identified 17 major ground-water flow systems within the carbonate-rock province (fig. 5). The flow systems within the aquifer each have their own recharge and discharge areas and structural controls, and the water quality within any given flow system can be considerably different from a nearby or adjacent flow system.

Ground-Water Recharge, Flow, and Discharge

Recharge to the carbonate-rock aquifer occurs mostly in the surrounding mountain ranges originating primarily as snow at high altitudes. Water recharging the carbonate rocks in the mountains may travel through or beneath several basins and ranges before reaching a discharge area (fig. 4). Some ground water may be discharged in topographically low areas along the flow path. Thus, a carbonate-rock aquifer may contain several discharge areas along the flow path upgradient from the terminal discharge area.




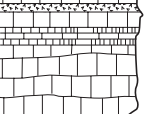
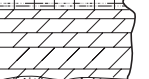

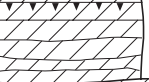
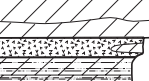

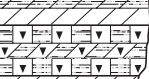

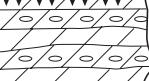
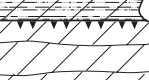
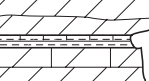




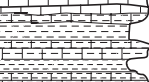
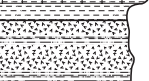
SYS- TEM	GROUP, FORMATION, MEMBER		LITHOLOGY	THICK- NESS, IN FEET	DESCRIPTION
Mississippian	Indian Springs Formation			100	Rusty shale, very poorly exposed
	Joana Limestone			820	Dark gray crinodal limestone, with prominent cherty zone
	Pilot Shale			50	Shaly limestone, with thin basal quartzite and bedded chert
Devonian	Devils Gate Limestone			1,440	Limestone, dark gray to blue gray; upper middle part with interbedded clean quartzite; lower middle part with abundant stromataphorids; thin silty dolomite at base
	Nevada Formation	Upper Member		640	Dolomite, laminated, dark to light gray
		Oxyoke Canyon Sandstone-Beacon Peak Dolomite		160	Sandstone, sandy dolomite, cherty dolomite, and silty dolomite
Silurian	Laketown Dolomite			980	Dolomite, light gray, thin bedded, with some chert
Ordovician	Ely Springs Dolomite			460	Dolomite, black, massive
	Eureka Quartzite			160	Quartzite, mostly white and vitreous with minor dolomite
	Antelope Valley Limestone	Aysees Member		910	Silty, light gray dolomite in upper part; massive, dark gray dolomite in lower part
		Ranger Mountains Member		420	Silty, crepe-weathering limestone and dolomite
		Paiute Ridge Member		590	Silty dolomite and minor limestone
		Lower Pogonip Group Undifferentiated			1,060
	Cambrian	Nopah Formation	Upper Member		890
Dunderberg Shale				100	Shale and shaly limestone
Bonanza King Formation		Banded Mountain Member		1,340	Dolomite and limestone, color-banded, mottled, laminated, ledge-forming; silty limestone at base
		Papoose Lake Member		1,610	Dolomite and limestone, mottled, burrowed, laminated
Carrara Formation			870	Interbedded shale and limestone	
Wood Canyon Formation			660	Dark colored siltstone and quartzite	
Pre-cambrian	Stirling Quartzite			?	Light colored quartzite and conglomerate

Figure 2. Paleozoic-rock section as exposed in the Sheep Range, Nevada (from Dettinger and others, 1995, fig. 2).

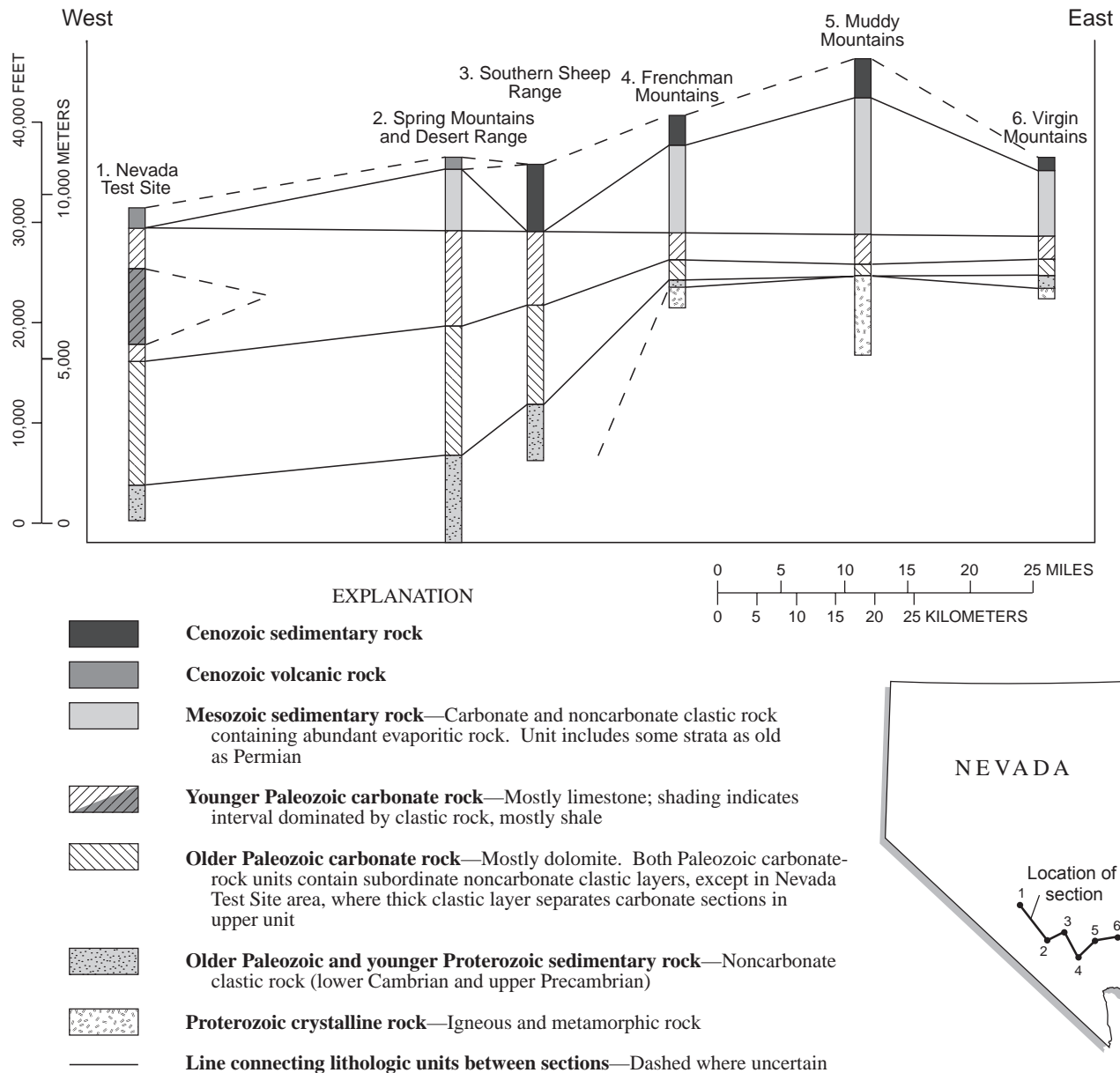


Figure 3. Generalized cross section through the carbonate-rock aquifer in southern Nevada (from Dettinger and others, 1995, fig. 3).

Water leaves the carbonate-rock aquifer by evaporating from areas where ground water is near the land surface, transpiring through plants, discharging at springs, leaking into overlying and underlying aquifers, and in a few cases, discharging into rivers or streams.

Evapotranspiration is the largest source of ground-water discharge in the Great Basin (Harrill and Prudic, 1998, p. A25). A regional ground-water flow model of the carbonate-rock province was constructed as part of the Great Basin Regional Aquifer-System Analysis (RASA) study (Prudic and others, 1995). Discharge by evapotranspiration was simulated at an estimated 1,213,000 acre-ft/yr. An additional 211,000

acre-ft/yr is estimated to discharge from regional springs, much of which is lost to evaporation. Figure 5 shows the location of major evapotranspiration areas in the carbonate-rock province in relation to this study's sampling sites.

An example of a carbonate-rock aquifer is the Colorado flow system in eastern Nevada. This flow system encompasses 34 hydrographic areas with an overall area of 16,300 mi². Recharge to the flow system occurs as snowmelt from the higher mountain ranges of individual hydrographic areas. During the spring the water seeps into the permeable bed-rock or flows off into adjacent valleys where it can seep into the basin-fill deposits. Depending on the location, ground

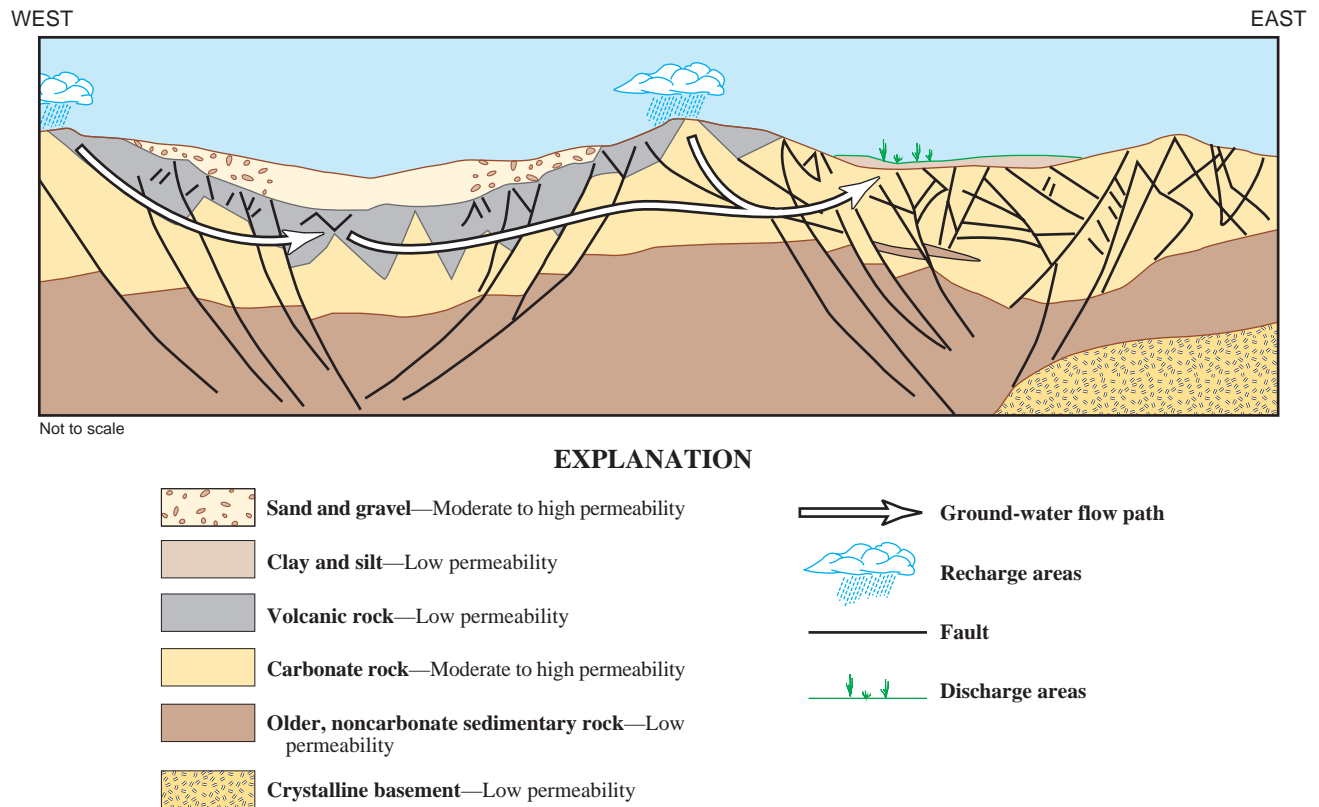


Figure 4. Generalized hydrogeologic section through the carbonate-rock aquifer and overlying basin-fill deposits (from Dettinger and others, 1995, fig. 4).

water can stay within basin-fill deposits in the basins or move into the underlying carbonate rock. Ground water within the Colorado flow system generally moves downgradient to one or more discharge areas. Because ground water flows from areas of high head toward areas of lower head at rates that are dependent on the permeability of the aquifer, the path the ground water follows may be circuitous. Ground-water flow also may reach great depths because of the thickness of the carbonate-rock aquifer in some areas. The ultimate discharge area for the Colorado flow system is the Muddy River springs area in southern Nevada (near the Pederson site; fig. 5) with an annual discharge of about 36,000 acre-ft/yr (Dettinger and others, 1995, table 8).

Study Design and Methods

This study was designed to provide an indication of the water-quality conditions in the carbonate-rock aquifer of the Great Basin. The 30 sampling locations consisted of existing wells or springs distributed throughout the area. Ground-water development within the area is not widespread at present because the carbonate-rock aquifer generally is deep below the land surface. However, increasing population growth in both Nevada and Utah, coupled with scarce additional water

resources, has made use of the water in the carbonate-rock aquifer more economically feasible.

Site Selection

Sampling locations were selected from existing wells identified from the USGS National Water Information System (NWIS) database or from drillers' logs submitted to State agencies in both Nevada and Utah. Wells that were selected had an open interval within the carbonate-rock aquifer. No preference was given to sampling specific formations within the carbonate-rock sequence; wells in the province are too few to allow any discretion. Selected springs discharging from carbonate-rock aquifer were chosen because of a lack of existing wells in those areas. Sites also were chosen based on their location in regard to the 17 flow systems within the carbonate-rock province. Twenty sites were sampled in Nevada and ten sites were sampled in Utah based on the areal extent of the carbonate-rock aquifer in each state. Although not all of the flow systems were sampled, the sampled sites do provide a reasonable areal distribution across the province. Figure 5 shows the location of the 30 sampling sites and table 1 lists characteristics of the sites sampled for this study. Priorities for sampling wells were based on several criteria:

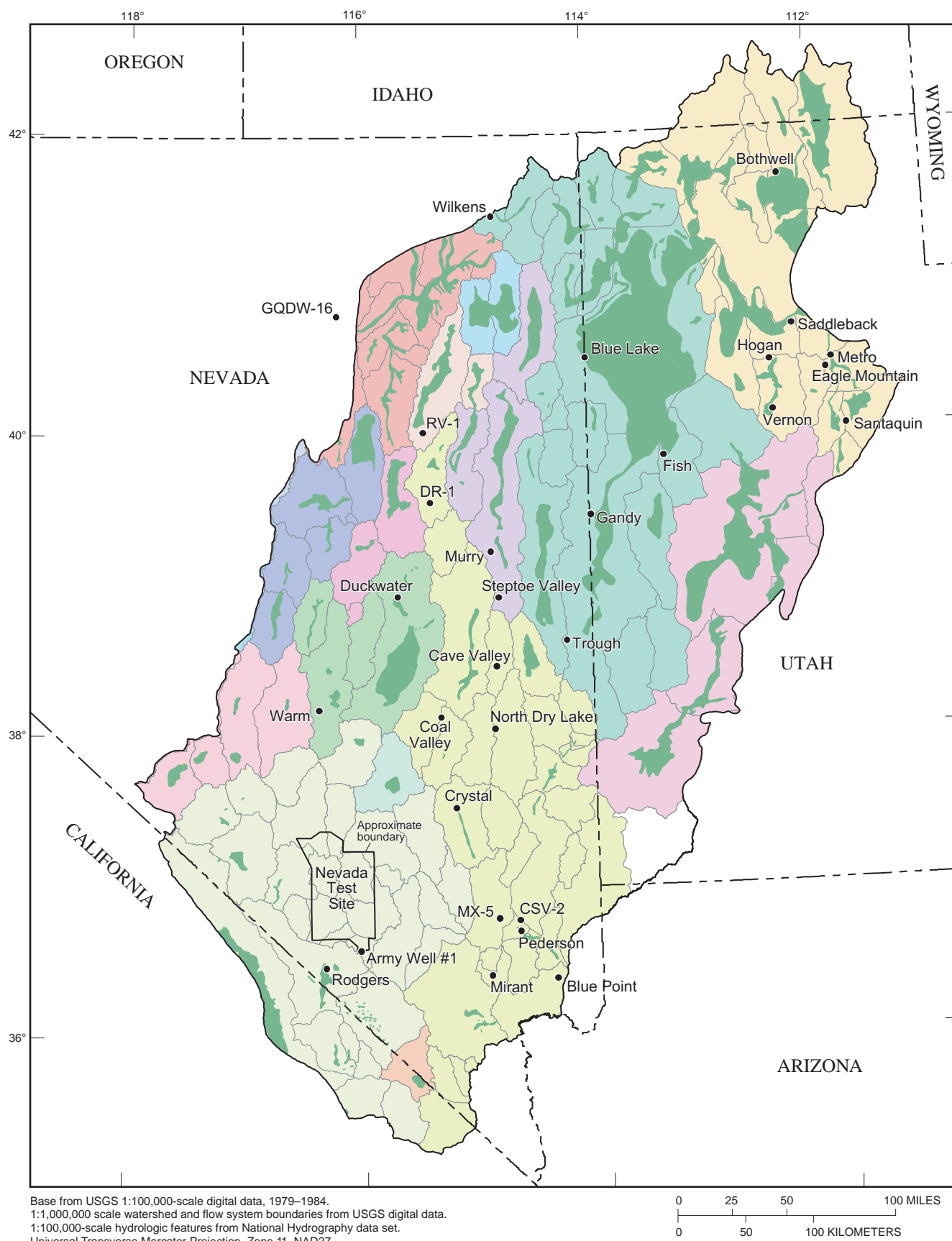


Figure 5. Carbonate-rock aquifer, evapotranspiration areas, and sample sites.

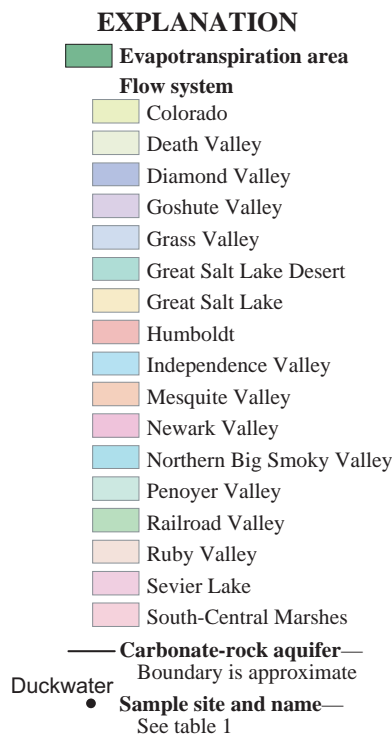


Figure 5. Carbonate-rock aquifer, evapotranspiration areas, and sample sites—Continued.

- 1) the well was completed in the carbonate-rock aquifer,
- 2) the well had an existing pump or could be pumped with available equipment,
- 3) the well was reasonably easy to sample and permission to sample could be obtained, and
- 4) the well fit within a broad spatial distribution of sites across the carbonate-rock province.

Based on some of these criteria, the wells chosen were grouped into three types. The first group included wells that had an existing pump. These generally were production wells, such as Army well #1 (table 1) just to the south of the Nevada Test Site (fig. 5). The well was completed in 1956 and has provided the water supply for the Nevada Test Site operations since that time. Because the well is fairly old, there are several historical analyses that can give an indication of water-quality changes with time.

The second group includes wells that did not have a dedicated pump. These wells were sampled using a submersible pump installed for sampling. Many of the large-diameter wells sampled for this study were wells drilled by the U.S. Air Force in the early 1980s as part of the MX missile program in Nevada and Utah. These test wells were drilled to assess the availability of water in the carbonate-rock and basin-fill aquifers to support a large missile system. These wells were not drilled in connection with any type of contaminated site remediation and existing inorganic, trace, and isotopic chemical analyses exist from the early 1980s for many of these wells. The MX test wells generally were drilled in areas where depth to water exceeded 500 ft. More information on the MX test wells can be found in Bunch and Harrill (1984) and Tumbusch and Schaefer (1996).

The third group includes wells and springs that were sampled with portable sampling pumps, and a flowing well that had enough head to move water through the sampling equipment. Well points and screens were placed in spring orifices well below the water surface to isolate the sample from the atmosphere.

Sample Collection

The sites were sampled in accordance with USGS ground-water sampling protocols (Koterba and others, 1995). All wells were purged of at least three borehole volumes and until the field parameters (temperature, pH, specific conductance, dissolved oxygen, and turbidity) stabilized for five successive measurements made at least five minutes apart. Sampling began as soon as field measurements stabilized. All instrumentation used to collect field data were calibrated daily. Additional information on sample collection procedures can be found at the USGS national field manual site: <http://water.usgs.gov/owq/FieldManual/>.

The large diameter, deep wells without dedicated pumps were sampled using a 6-in. diameter, 20 horsepower submersible pump set in the well by the USGS Western Region Research Drilling Unit. The pump was lowered into the well

Table 1. Selected characteristics of sites sampled in the carbonate-rock aquifer system

[Well identification number is the site number used in the U.S. Geological Survey National Water Information System. Flow system: GSL, Great Salt Lake; GSLD, Great Salt Lake Desert; COLS, south part of Colorado; COLN, north part of Colorado; DV, Death Valley; GV, Goshute Valley; RR, Railroad Valley; HUM, Humboldt; RUBY, Ruby Valley. Water use: N, industrial; I, irrigation; P, production; U, unused; U (MX), well drilled for MX missile program and is unused; E, electricity generation; D, dewatering. How sampled: 1, well had existing pump; 2, 6-inch diameter submersible pump set with drill rig; 3, 2-inch diameter submersible pump; 4, flowing. Well depth: includes depth of 2-inch diameter polyvinyl chloride casing installed in spring orifices for sampling purposes. Symbols: R, reported.—, not applicable]

Sampled site name	Site type	Site identification number	Sample date	Flow system	Water use	How sampled	Altitude of land surface (feet)	Well depth (feet below land surface)	Depth to top of open interval (feet below land surface)	Depth to bottom of open interval (feet below land surface)	Water level below land surface (feet)
Army Well #1	well	363530116021401	5/29/2003	DV	P	1	3,153	1,253	1,050	1,150	1,052
Blue Lake	spring	402956114024001	5/27/2003	GSLD	U	3	4,260	2	1	2	—
Blue Point	spring	362321114252601	6/5/2003	COLS	U	3	1,549	10	5	10	5
Bothwell	well	414023112180701	6/3/2003	GSL	U	3	4,524	278	240	277	244
Cave Valley	well	382807114521001	7/10/2003	COLN	U (MX)	2	6,008	460	210	435	220
Coal Valley	well	380758115204601	6/25/2003	COLN	U (MX)	2	5,560	1,837	118	1,837	798
Crystal	spring	373155115135801	6/3/2003	COLN	I	3	3,810	6	1	6	1
CSV-2	well	364650114432001	7/8/2003	COLS	U	2	2,186	478	95	478	394
DR-1	well	363332115244001	6/17/2003	COLS	U	2	3,579	930	870	930	815
Duckwater	spring	385604115415101	8/7/2003	RR	U	3	5,500	10	5	10	2
Eagle Mountain	well	402236111575101	6/4/2003	GSL	P	1	4,918	980	510	940	R 428
Fish	spring	395027113234001	5/29/2003	GSLD	U	3	4320	5	4	5	—
Gandy	spring	392737114021201	5/28/2003	GSLD	I	3	5,237	3	2	3	—
GQDW-16	well	404759116115401	8/26/2003	HUM	D	1	5,160	1,484	640	1,400	590
Hogan	well	402645112265101	6/2/2003	GSL	P	1	5,245	710	664	704	R 470
Metro	well	402636111545101	5/12/2003	GSL	N	4	4,600	1,030	710	1,010	R -184
Mirant	well	362507114572701	6/4/2003	COLS	E	1	2,566	1,979	1,197	1,979	754
Murry	spring	391345114535501	8/5/2003	GV	P	3	6,600	15	10	15	5
MX-5	well	364741114532801	5/28/2003	COLS	U (MX)	1	2,170	628	125	628	352
North Dry Lake	well	380531114534201	6/19/2003	COLN	U (MX)	2	5,560	2,395	347	1,395	850
Pederson	spring	364235114425401	7/30/2003	COLS	U	3	1,800	10	5	10	2
Rodgers	spring	362835116192101	7/29/2003	DV	U	3	2,275	15	10	15	1
RV-1	well	400119115274802	9/10/2003	RUBY	U	3	6,132	350	335	345	129
Saddleback	well	404040112143301	5/14/2003	GSL	P	1	4,620	1,020	400	1,000	R 185
Santaquin	well	400026111484301	5/20/2003	GSL	N	1	4,758	432	264	432	R 232
Steptoe Valley	well	385521114503601	7/16/2003	GV	U (MX)	2	7,320	948	500	948	428
Trough	spring	383744114160901	8/6/2003	GSLD	U	3	6,056	5	1	5	1
Vernon	well	400652112261801	5/13/2003	GSL	I	1	5,413	800	634	800	174
Warm	spring	381115116222101	7/31/2003	RR	U	3	5,549	25	20	25	15
Wilkens	spring	412703114500601	8/27/2003	GSLD	U	3	5,865	5	1	5	1

using 2-in. diameter galvanized pipe with the electrical cable for the pump taped to the outside of the pipe as the pump was lowered. The pump generally was set well below the water surface in cased wells but above any perforations. However, most of the wells sampled had open-hole completions, meaning that the well was only cased to the top of the carbonate rock. For these wells, the pump was installed in the uncased portion open to the carbonate rock. At the surface, the pipe was elbowed away from the well for discharge with a gate valve and a spigot attached as the sampling line. An in-line flow meter was installed to measure discharge.

For wells that had an existing pump, the discharge pipe from the pump to the surface was assumed to be made of galvanized steel. A Teflon sampling line was connected, in most cases, to a spigot on the discharge line. The portable pumps used to sample wells and springs were constructed of stainless steel and Teflon and the sampling equipment was connected directly to a Teflon discharge line. Portable pumps were placed well below the water surface in the well but above perforations.

Sample Analysis

Samples collected for this study were analyzed at the USGS National Water-Quality Laboratory (NWQL) for inorganic and organic constituents including major ions, radon, DOC, selected nutrients, trace elements, pesticides and VOCs (appendix 1). Analytical methods used for major ions and trace elements primarily were inductively coupled plasma/mass spectrometry, atomic adsorption spectrometry, or ion chromatography, and are described in Fishman and Friedman (1989), Fishman (1993), and Faires (1993). Nutrient concentrations were determined by colorimetry (Fishman, 1993; Patton and Truitt, 1992). DOC was analyzed by using ultraviolet-promoted persulfate oxidation and infrared spectrometry (Brenton and Arnett, 1993), and radon was analyzed using liquid scintillation (American Society for Testing and Materials, 1996). Water samples were analyzed for 47 pesticides by using capillary column gas chromatography/mass spectrometry (GCMS; Zaugg and others, 1995) and for 85 VOCs by using purge and trap capillary column GCMS (Conner and others, 1998). Alkalinity and bicarbonate concentration were determined on-site by incremental titration of filtered sample water with sulfuric acid. Samples were examined for total coliform and *Escherichia coli* (*E. coli*) bacteria in the field by use of a membrane-filtration method (U.S. Environmental Protection Agency, 2002a).

Analyses of the stable isotopes of water (^2H and ^{18}O) were done at the USGS Stable Isotope Laboratory in Reston, Virginia. The ^2H analysis uses a hydrogen equilibration method (Coplen and others, 1991), and the oxygen-18 analysis uses a carbon dioxide equilibration technique (Epstein and Mayeda, 1953). Analytical uncertainties for delta deuterium (δD or $\delta^2\text{H}$) and delta oxygen-18 ($\delta^{18}\text{O}$) values are 2 and 0.2 per mil, respectively. The USGS Isotope Tracers Project

Laboratory in Menlo Park, California analyzed eight samples for tritium using electrolytic enrichment and liquid scintillation (Thatcher and others, 1977). The other four samples were analyzed by the University of Utah Department of Geology and Geophysics, Tritium and Noble Gases Laboratory in Salt Lake City Utah using the helium ingrowth method (Bayer and others, 1989).

Quality Assurance

Quality control included submitting field-blank samples, replicate samples, and spiked samples for analysis with the ground-water samples. Additional quality control included analysis of laboratory surrogate recoveries for pesticides and VOCs in each ground-water sample. Because sampling was divided between Nevada and Utah field crews, quality control samples were split between the two crews. Quality-control samples for the 30 sites included 2 equipment blanks (analyzed for all constituents, 1 for each study unit); 3 field blanks for DOC, VOCs, and trace elements; and 2 field blanks for major ions, nutrients, and pesticides. Replicates included two sets for major ions, nutrients, radon, VOCs, and pesticides and three sets for DOC and trace elements. Spikes included two field-spiked pesticide samples and one lab-spiked VOC sample.

Field and equipment blanks showed that most constituents in ground-water samples were not contaminated by the sampling equipment, although VOC contamination likely occurred during sampling. Two VOCs (trichloromethane and toluene) were detected at concentrations less than the minimum reporting level in one of the field-blank samples. Toluene was detected at concentrations less than the reporting level in ground water sampled at eight sites and possibly is the result of sample vial contamination or emissions from the incomplete combustion of gasoline used to power the generator. Therefore, the occurrence of toluene in these ground-water samples probably is the result of contamination during sampling.

Toluene was measured at relatively large concentrations in all six of the ground-water samples collected using the 6-in. diameter submersible pump. Other VOCs were detected in water from five of these sites, mostly gasoline-related hydrocarbons. This probably is due to contamination of the drop pipe or the submersible pump as they were transported by truck between well sites. Measures were taken to wash the pipe on a regular basis, but the remoteness of some of the well sites made this difficult. The occurrence of fuel-related VOCs in the ground-water samples may be from the atmosphere or from the pumping equipment rather than the aquifer and caution should be used when interpreting these data.

A relatively large concentration of DOC was measured in one field-blank sample (16.7 mg/L), but DOC concentrations in all but one of the ground-water samples were less than 1.0 mg/L. Because most of the environmental samples had low concentrations, they are assumed to be uncontaminated on the

basis of the field-blank data. Pesticides were not detected in any of the equipment- or field-blank samples.

The trace element lead was detected in one field-blank sample at a concentration in the range of those measured in the ground-water samples. Therefore, the ground-water data for lead may be biased. Aluminum was detected in a field-blank sample at a concentration much larger than those measured in the ground-water samples. Concentrations measured for aluminum in sample sites are assumed to be uncontaminated.

Sequential replicate ground-water samples give indication that laboratory and field methods are consistent. Concentrations from replicate samples were within 10 percent for all constituents except for dissolved nitrite plus nitrate expressed as N. The difference was small (0.05 mg/L) between the two nitrite plus nitrate values.

Spike solutions containing known concentrations of target compounds were added to replicate ground-water samples to determine analyte recovery in the sample matrix. Recovery of most of the target compounds was within 25 percent of the amount present in the unspiked sample plus the amount added in the spike solution. Recovery of the 47 spiked pesticide compounds ranged from 41 to 205 percent with a mean of 106 percent. Recovery of the 85 spiked VOCs ranged from 67 to 129 percent with a mean of 97 percent.

Ground-Water Quality

Some of the constituents analyzed as part of this study have drinking-water standards set by the USEPA (U.S. Environmental Protection Agency, 2002b). The maximum contaminant level (MCL) is the maximum concentration of a contaminant permissible in a public-water system. Secondary drinking water regulations (SDWR) are non-enforceable guidelines that generally are for constituents that can affect the aesthetic qualities of drinking water.

Results from the sampling of the 20 Nevada sites can be found in Stockton and others (2004, p. 586), results from the 10 Utah sites can be found in Tibbetts and others (2004, p. 448).

Occurrence of Inorganic and Organic Chemicals

The carbonate-rock aquifer in the eastern Great Basin is composed primarily of limestone and dolomite. Water chemistry in recharge areas and the upgradient portions of these aquifers is dominated by calcium, magnesium, and bicarbonate ions (fig. 6). As water flows through the carbonate-rock aquifer the dominant geochemical processes that occur are dissolution, ion exchange, and precipitation of minerals; mixing of waters; and geothermal heating due to deep circulation (Thomas and others, 1997, p. C22). These processes generally result in increased sodium, sulfate, and chloride concentrations in water from the downgradient parts of the carbonate-rock flow systems.

Total dissolved-solids (TDS) concentration in water sampled from the carbonate-rock aquifer ranged from 144 to 5,120 mg/L with a median value of 389 mg/L. The three largest TDS concentrations are for water discharging from springs in distal parts of regional flow systems. The three smallest concentrations are for water sampled from sites in or near recharge areas for the carbonate-rock aquifer.

Primary drinking-water standards were exceeded for several inorganic constituents in water from the carbonate-rock aquifer (U. S. Environmental Protection Agency, 2002b). The USEPA MCL was exceeded for concentrations of dissolved antimony (MCL is 6 µg/L) in 1 sample, arsenic (MCL is 10 µg/L) in 11 samples, and thallium (MCL is 2 µg/L) in one sample. Secondary drinking-water regulations were exceeded for several inorganic constituents in water samples. The USEPA SDWR was exceeded for concentrations of chloride (standard is 250 mg/L) in five samples, fluoride (standard is 2 mg/L) in two samples, iron (standard is 0.3 mg/L) in four samples, manganese (standard is 0.05 mg/L) in one sample, sulfate (standard is 250 mg/L) in three samples, and TDS (standard is 500 mg/L) in seven samples.

Radon activities in water from 28 sampled sites ranged from 30 to 1,720 pCi/L with a median value of 475 pCi/L. Activities exceeded the USEPA proposed MCL of 300 pCi/L in 75 percent (21 of 28) of the samples. Radon occurs naturally as a gas that is soluble in ground water and is released through radioactive decay from rocks containing uranium. Because of a short half-life of 3.8 days, radon generally is detected near its source. The three highest radon activities are from springs located in recharge areas of the carbonate-rock aquifer.

Values of pH varied from 6.4 to 8.8, but usually were between 7.2 and 7.5 with a median of 7.4. Dissolved-oxygen concentrations ranged from 0.2 to 8.0 mg/L with a median value of 2.6 mg/L. Specific conductance ranged from 290 to 9,030 µS/cm with a median value of 660 µS/cm.

DOC ranged from less than the detection level (<0.3 mg/L) to 4.6 mg/L with a median estimated value of 0.3 mg/L. Dissolved nitrite plus nitrate was detected in about 87 percent of the samples (26 of 30) and concentrations as N ranged from an estimated 0.05 mg/L to 3.38 mg/L with a median value of 0.31 mg/L. The MCL for nitrate is 10 mg/L. Nitrate concentrations in the carbonate-rock aquifer generally are low because of the depth and subsequent isolation of the aquifer from the land surface. The two sites sampled with nitrate concentrations greater than 2 mg/L may have received water that has been affected by activities occurring at the land surface.

The 47 pesticides and selected pesticide metabolites (degradation products of pesticides) analyzed as part of this study are listed in appendix 1. Six different pesticides or metabolites were detected at very small concentrations in the water samples including atrazine, deethylatrazine (CIAT, a metabolite of atrazine), carbofuran, prometon, tebuthiuron, and terbacil. All of these compounds, except for carbofuran, are herbicides or are degraded from herbicides used to control vegetation.

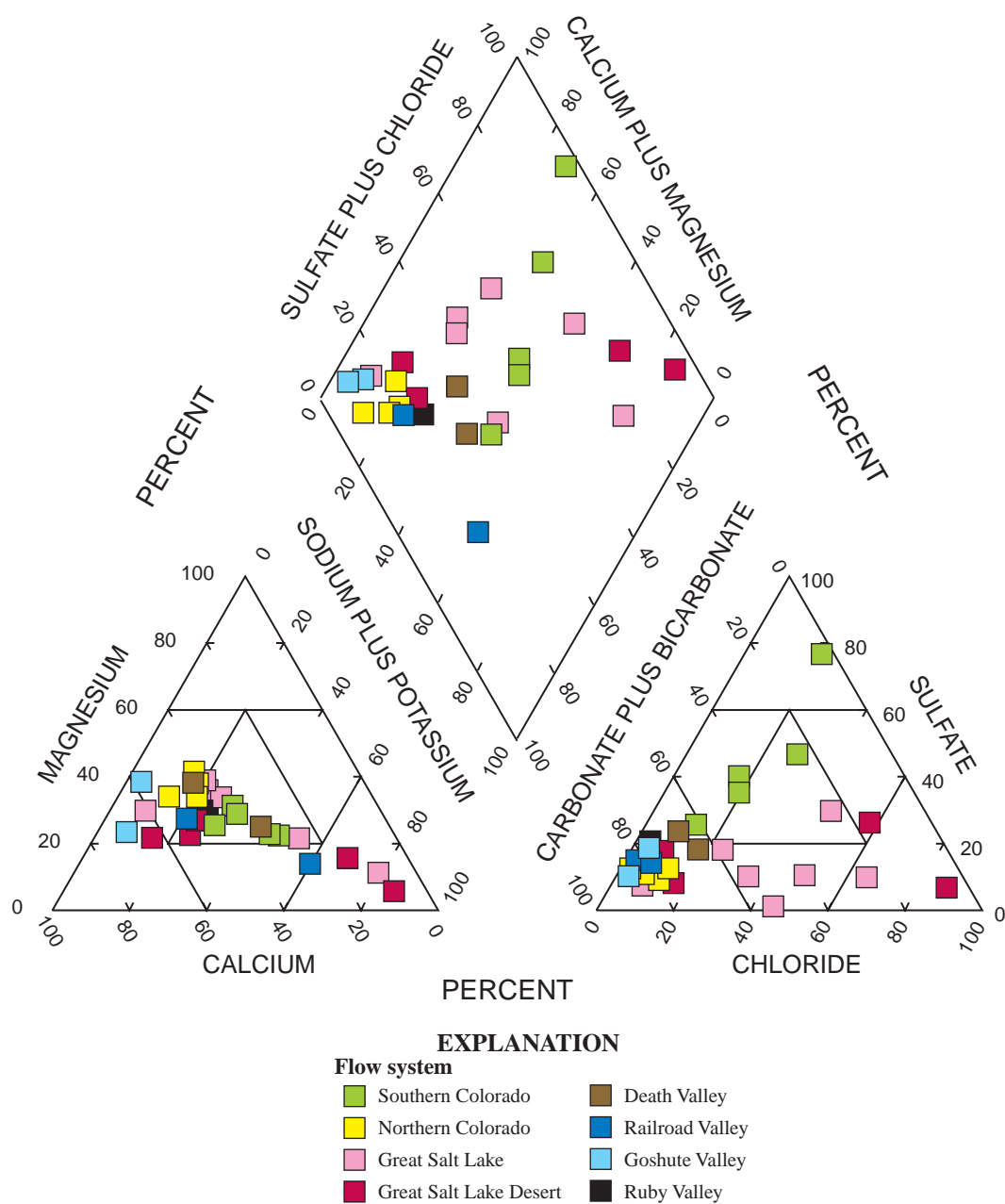


Figure 6. Major-ion composition of water sampled from the carbonate-rock aquifer.

Carbofuran is an insecticide used in parts of the Great Basin to control grasshoppers. One or more of these compounds were found in water from only 4 of the 30 sites sampled with one site containing 4 compounds and the other 3 sites containing a single compound. CIAT was detected in water from two wells, whereas, the other pesticides were detected in one sample each.

The 85 VOCs analyzed as part of this study are listed in the appendix. Eight of the 30 sites sampled contained a VOC other than toluene (toluene was not included in this analysis because of likely contamination). Water from one site had a trace concentration of tetrachloroethylene (PCE, used as a solvent) and water from another site had a trace amount of carbon disulfide (a naturally occurring compound). The other 6 sites contained one or more fuel-related compounds in addition to toluene. As was discussed in the Quality Assurance section of this report, the occurrence of fuel-related VOCs in the ground-water samples may be contamination from the atmosphere through the incomplete combustion of fuels or from the pumping equipment rather than from the aquifer. Because of the possibility of sample contamination, the occurrence of VOCs in the water samples collected from the carbonate-rock aquifer as part of this study may be positively biased. The lack of VOC detections in water sampled from most of the sites is evidence that VOCs are not common in the carbonate-rock aquifer.

Effects of Hydrogeologic Factors on Water Quality

Carbonate-rock aquifer water quality varies to some extent based on which flow system, and the location within each flow system, that the water was sampled. Of the 17 flow systems within the carbonate-rock aquifer identified by Harrill and others (1988), 8 were sampled as part of this study. Six of the sampled flow systems have more than one sample site. This allows some comparison within the individual flow systems to examine the effects of hydrogeologic controls on ground-water flow and quality.

The Colorado flow system contains 10 sampled sites and, although the distribution is somewhat weighted towards the southern end of the system, there does appear to be a pattern to the water quality. Figure 7 shows a Piper plot of the water quality from sites sampled in the Colorado flow system. Ground-water flow within the system generally is from north to south with the major discharge area at the Muddy River springs area. The Muddy River springs area, which discharges about 36,000 acre-ft/yr, is located near Pederson Spring shown in figure 5. Most of the sites in the upgradient northern and western portions of the flow system have calcium-magnesium-bicarbonate water. The sites in the southern part of the flow system are downgradient from the mountainous recharge areas and grade from calcium-bicarbonate water to calcium-sulfate water with an increase in chloride. Some portions of the

carbonate-rock aquifer in the southeastern Great Basin contain interbedded evaporite deposits resulting in higher concentrations of sulfate, chloride, and sodium ions in the ground water (Dettinger and others, 1995, p. 45). The change in water chemistry between sites MX-5 to CSV-2 to Pederson to Mirant to Blue Point probably is due to dissolution reactions with the aquifer material (possibly gypsum) as the water moves through the flow system and concentrations of sulfate and chloride increase. Other reactions that may be taking place are precipitation of calcite and evaporation along the flow path.

The Great Salt Lake Desert flow system contains five sampled sites distributed across the flow system. Ground-water flow generally is from the higher altitude mountain ranges in eastern Nevada towards the lower altitude Great Salt Lake Desert, a large area that serves as an evapotranspiration sink for the flow system. The water chemistry for the Great Salt Lake Desert flow system, as illustrated in figure 8, shows calcium-bicarbonate type water in wells near the recharge areas of the flow system (Trough, Gandy, and Wilkens Springs) and sodium-chloride type water at the regional discharge points (Fish and Blue Lake Springs). This change in water chemistry in the flow system likely is from the dissolution of salt and other minerals as the water moves to the regional discharge areas.

Water in the Great Salt Lake flow system in the northeastern part of the carbonate-rock province varies in water chemistry from a calcium-bicarbonate type from a well in the recharge area to a sodium-chloride type from a well near irrigated areas and the Great Salt Lake (fig. 6). The other five samples from sites near or in mountainous recharge areas have intermediate proportions of calcium-sodium and bicarbonate-chloride ions that likely are dependent on reactions with the aquifer material and geothermal activity. None of the seven sites sampled in the Great Salt Lake flow system are believed to be located in the discharge part of the flow system and all may belong to separate subsystems.

The Great Basin is an area with considerable geothermal resources due to extensional tectonic processes and contains the largest number of geothermal power plants in the United States (Duffield and Sass, 2003, p. 12). Typically, geothermal heating occurs where ground water circulates deep within elevated geothermal gradients along faults. Geothermal heating also can occur where ground water circulates to depths in excess of 25,000 ft in the carbonate-rock flow systems in the east and southern part of the state (Garside, 1994).

Temperature of ground-water samples ranged from 12.2°C to 53.3°C with a median value of 26.0°C. Most of these temperatures exceed the annual mean air temperature for most valleys and likely are heated by deep circulation of ground water through the thick carbonate-rock sequence. Generally, water temperatures less than 20°C were measured at sites in recharge areas within the Eureka heat flow low region (Garside, 1994) in the northeast portion of Nevada. This area is recognized as an area where regional recharge of cool ground water enters the deeper carbonate-rock aquifer (Plume

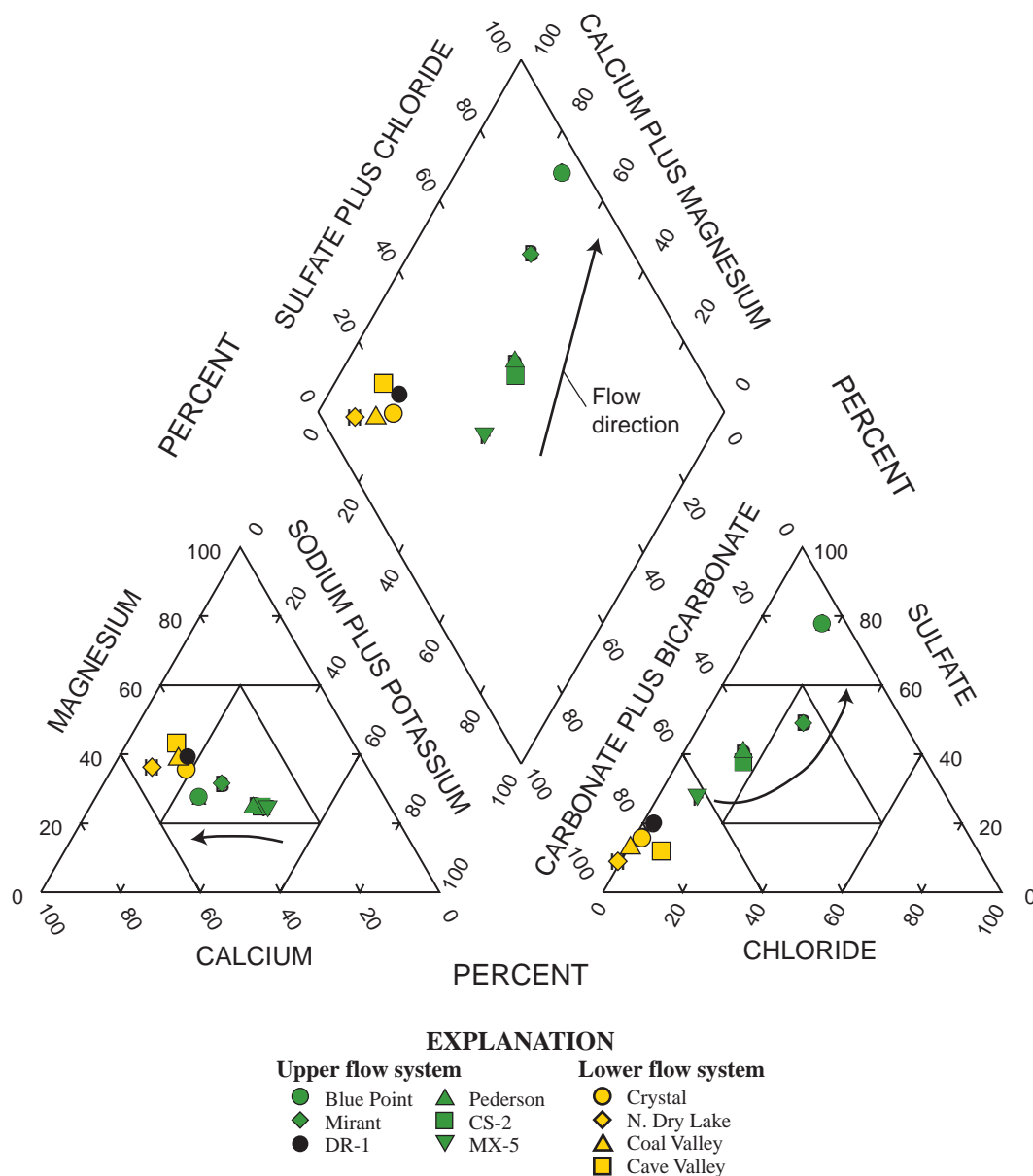


Figure 7. Major-ion composition of water sampled from the Colorado flow system

and Carlton, 1988). Temperatures greater than 20°C were measured at sites in discharge areas of the regional flow system or near faults.

Deeply circulated ground water that obtains elevated temperatures generally has higher concentrations of dissolved solids because the solubility of many minerals in the aquifer, such as chloride and silica, is increased with temperature. Arsenic, boron, and lithium concentrations in geothermal water also increase due to leaching of the host rock. A poor correlation exists between water temperature and the concentration of these constituents in water sampled as part of this study (fig. 9) indicating that geothermal heating is not the main cause for

increases in concentrations of these elements, but that heating during the deep circulation of water may have some minor effects on concentration. Calculations of low (<250°C) reservoir temperatures using chemical solubility equations developed by Fournier (1981) and Kharaka and Mariner (1989) for geothermal systems indicate that maximum reservoir temperatures could not have been greater than 140°C and probably were less. These low reservoir temperatures indicate that deep circulation along relatively normal geothermal gradients is more important than heating in a geothermal reservoir. This is consistent with the evaluation made by Garside (1994) who

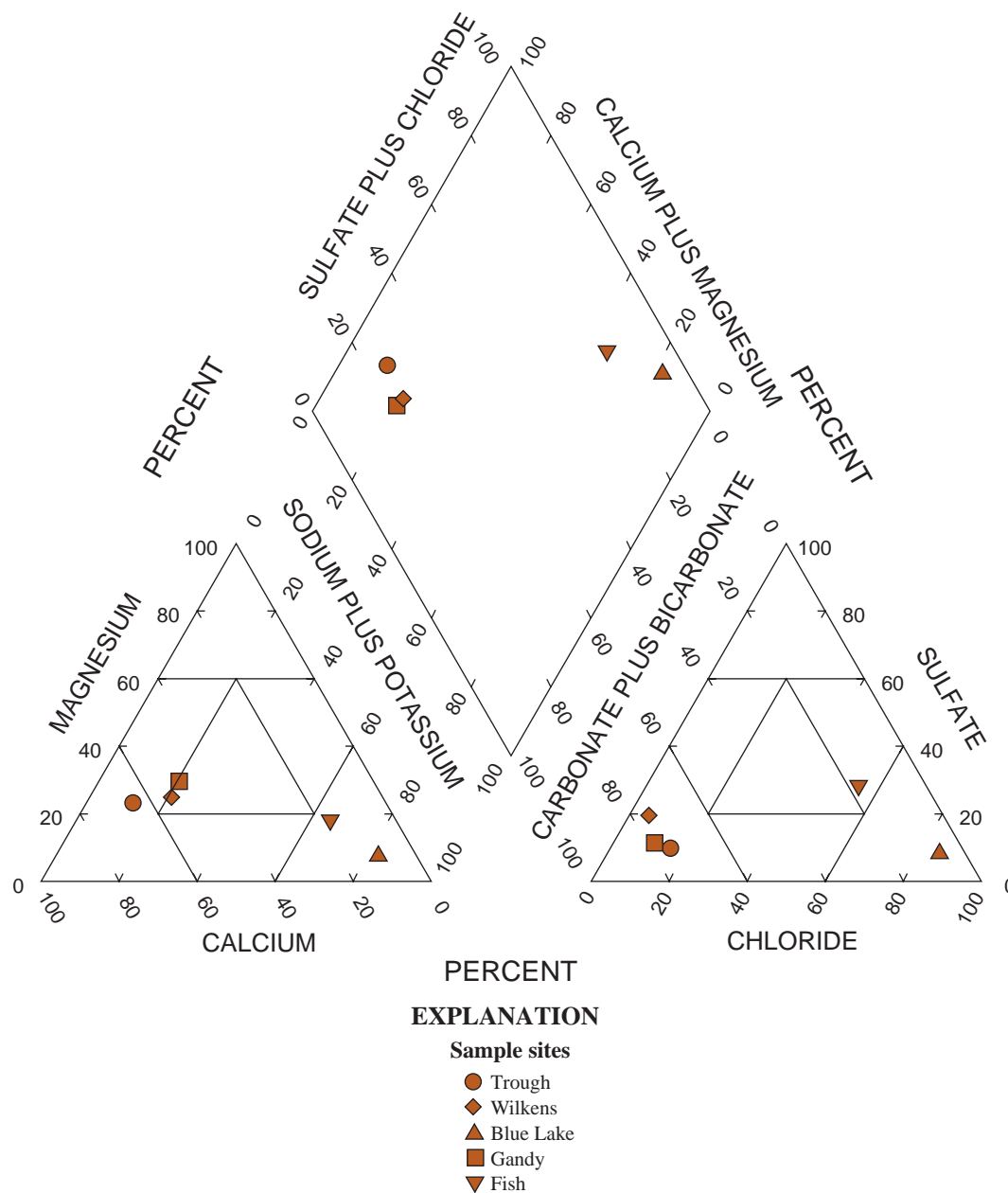


Figure 8. Major-ion composition of water sampled from the Great Salt Lake Desert flow system

suggested that the low- to moderate-temperature geothermal resources in east-central and southern Nevada are related to regional deep circulation of ground water in the fractured carbonate-rock aquifer, and not to high geothermal gradients. Garside (1994) also concluded that maximum reservoir temperatures were less than 100°C in these areas.

Arsenic values for water from the 30 sampled sites range from 0.7 to 45.7 µg/L, with a median value of 9.6 µg/L. The MCL for arsenic is 10 µg/L (U.S. Environmental Protection Agency, 2002b). Factors affecting arsenic concentration in the carbonate-rock aquifer, in addition to geothermal heating, are its natural occurrence in the aquifer material and time of travel

along the flow path. Arsenic concentrations in water sampled from the 10 sites in the Colorado flow system range from 1.8 to 45.7 µg/L (fig. 10) and 8 of the 10 samples exceeded the MCL. Generally, lower arsenic concentrations are in the northern part of the flow system closer to the recharge areas, although recharge does occur all along the flow system. Ground-water flow generally is towards the south and arsenic concentrations tend to increase in that flow direction.

Arsenic concentrations in other flow systems are relatively low, generally less than 10 µg/L. The exception is the one well sampled in the Humboldt flow system that reported an arsenic concentration of 20.3 µg/L.

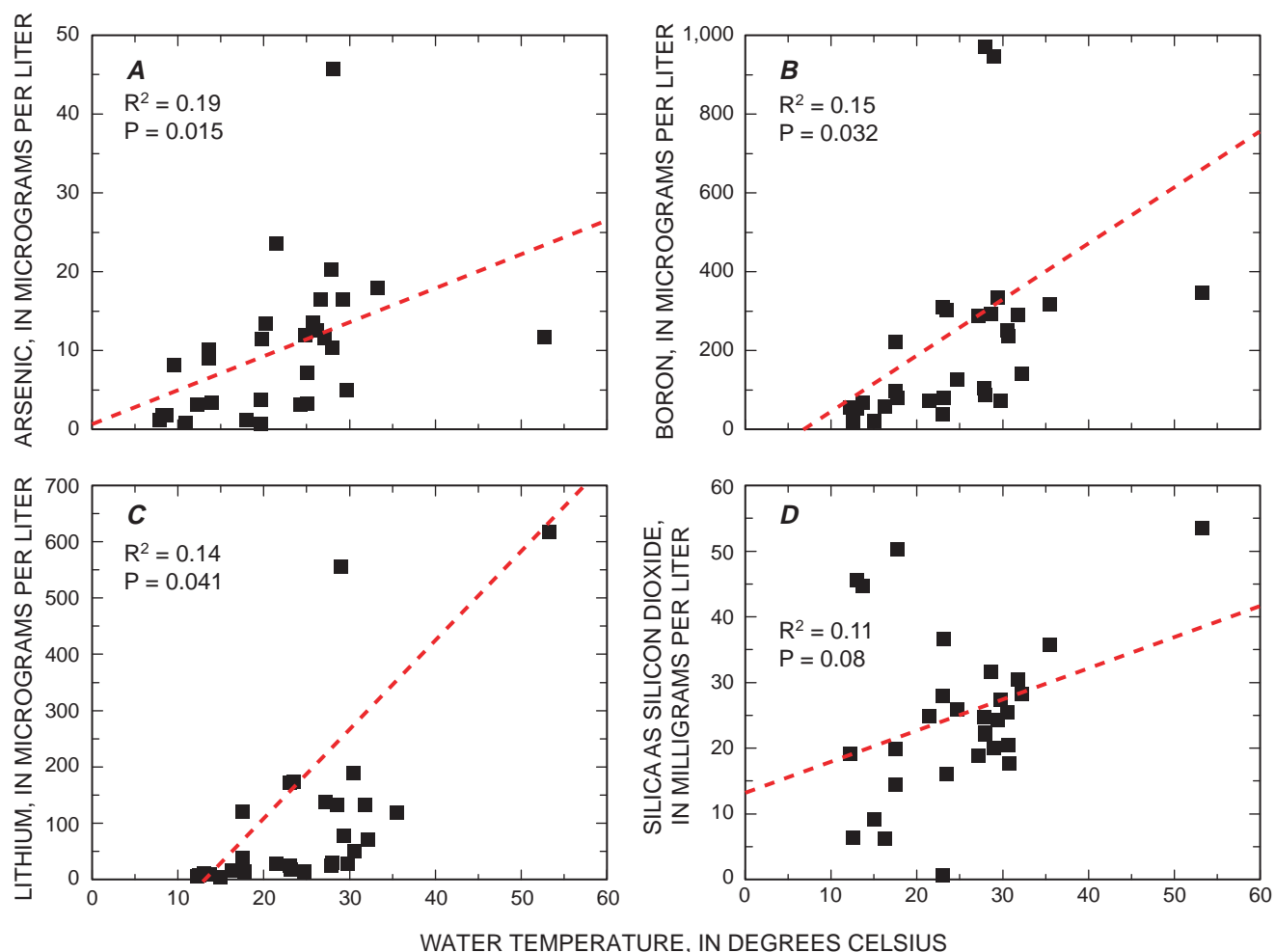


Figure 9. Relation of water temperature to A, arsenic, B, boron, C, lithium, and D, silica concentrations in water sampled from the carbonate-rock aquifer.

The ratio of chloride to bromide ions in water can be used to determine sources of chloride in the water. The chloride/bromide (Cl/Br) ratios for meteoric water generally are between 80 and 160 on the basis of chloride and bromide concentrations in shallow ground water recharged from precipitation (Davis and others, 1998). Ninety rain samples collected from the Yucca Mountain area near the Death Valley flow system had a mean Cl/Br ratio of 74 (Fabryka-Martin and others, 1998). Most of the ground water sampled from sites located in the recharge areas is within this range indicating that the water originated as precipitation that has undergone only evaporation or transpiration (fig. 11). Water from the Great Salt Lake flow system is an exception, with Cl/Br ratios ranging from 720 to 1,420, despite site locations near mountainous recharge areas.

Meteoric water that has undergone evaporation becomes concentrated in chloride and bromide (the Cl/Br ratio does not change) as the chloride concentration increases. The water sampled from Trough Spring had a relatively small Cl/Br ratio coupled with a relatively large chloride concentration (fig. 11) for ground water in a recharge area. This indicates that water

from Trough Spring has undergone some evaporation. The relatively large Cl/Br ratio in water from the recharge areas in the Great Salt Lake flow system (Saddleback well) along with a relatively small chloride concentration (fig. 11) likely results from the site's proximity to the Great Salt Lake and the potential for airborne salts that end up in ground-water recharge to the aquifer.

Water that has a Cl/Br ratio that is much larger than that of meteoric water probably represents water that became enriched in chloride relative to bromide as it flowed through evaporite deposits after recharging the ground-water system. Cl/Br ratios indicative of halite dissolution generally are in the range of 1,000 to 10,000 (Davis and others, 1998). Water from several sites in the discharge areas of the Colorado and Great Salt Lake Desert flow systems have large Cl/Br ratios coupled with large chloride concentrations (fig. 11).

The stable isotopes of water, ^2H and ^{18}O were used to help determine where water was recharged, mixtures of different sources of recharge water, and to identify water that has undergone evaporation. Isotopic ratios are expressed as $\delta^{18}\text{O}$

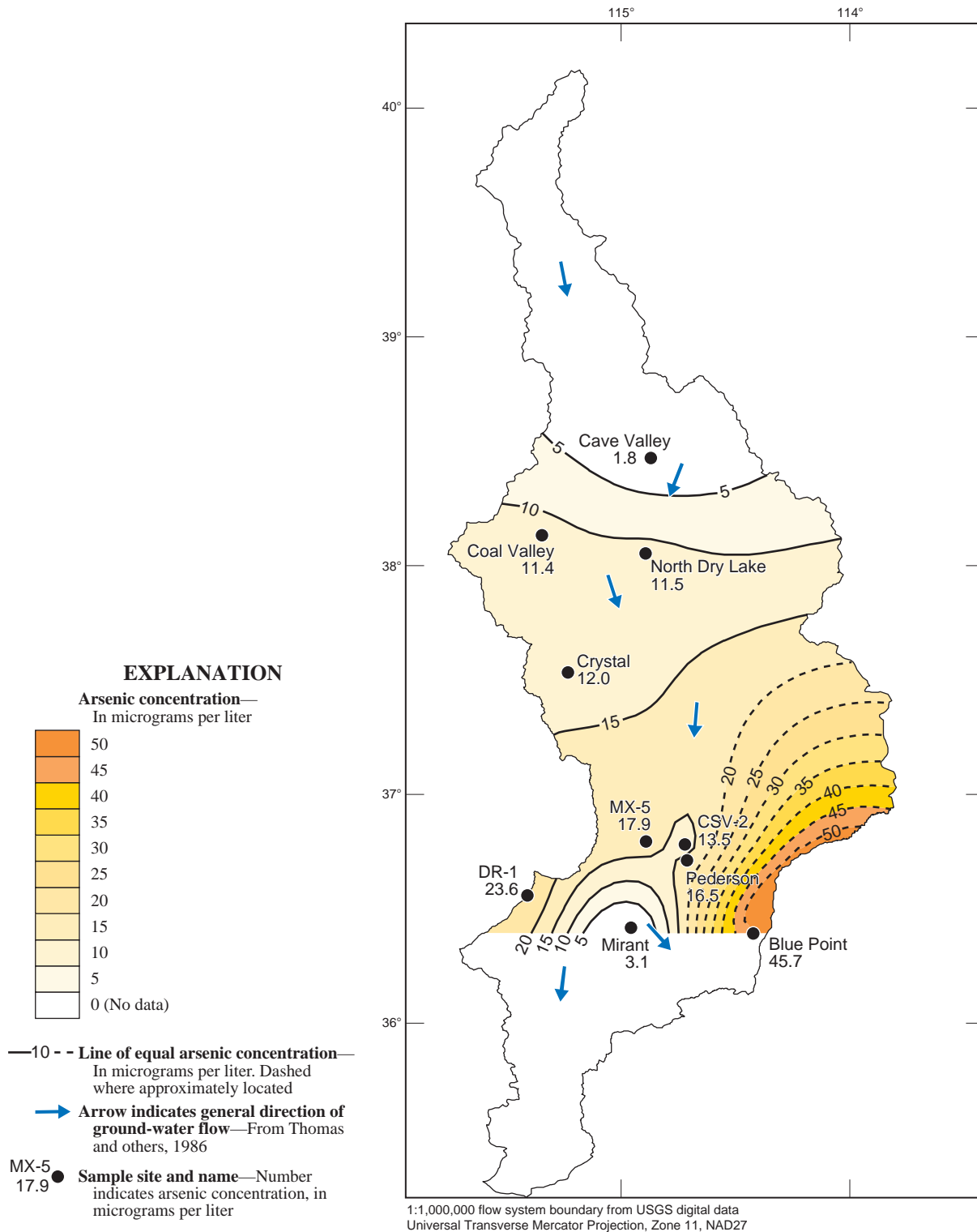


Figure 10. Arsenic concentrations in water sampled from the Colorado flow system (figure 5).

and $\delta^2\text{H}$ and are reported in parts per thousand (per mil) deviation from a reference standard called Vienna Standard Mean Ocean Water (VSMOW). Water with more negative per mil values has less ^2H and ^{18}O relative to ^1H and ^{16}O , respectively, and is “lighter” than water with less negative per mil values (“heavier” $\delta^2\text{H}$ or $\delta^{18}\text{O}$ values). The relation between $\delta^2\text{H}$ and $\delta^{18}\text{O}$ in precipitation generally is expressed by the equation: $\delta^2\text{H} = 8 \delta^{18}\text{O} + 10$, known as the global meteoric water line (MWL; Craig, 1961). In general, precipitation falling on the Great Basin becomes progressively lighter in $\delta^2\text{H}$ and $\delta^{18}\text{O}$ from the southwest to the northeast (Friedman and others, 2002a).

Friedman and others (2002b) used stable isotopes to show that precipitation in the Great Basin near Winnemucca, Nevada, comes from one of three different air-mass trajec-

tories that originated offshore of the United States from the northwest, over the Sierra Nevada, and from the tropical southwest. A fourth air-mass trajectory originating over land to the east of Winnemucca was derived from precipitation associated with thunderstorms from cumulonimbus clouds. Each air-mass trajectory has a relatively distinct isotopic signature that contributes to the ground-water composition within the carbonate-rock aquifer.

Water samples from 28 of the 30 sites were analyzed for stable isotopes (table 2). Values of $\delta^2\text{H}$ and $\delta^{18}\text{O}$ for most of the carbonate-rock aquifer samples plot to the right of the MWL, indicating the water has undergone a small amount of evaporation prior to recharging the aquifer (fig. 12). This probably occurs as the water is recharged, but evaporation could occur as the ground water is being discharged at springs. Two

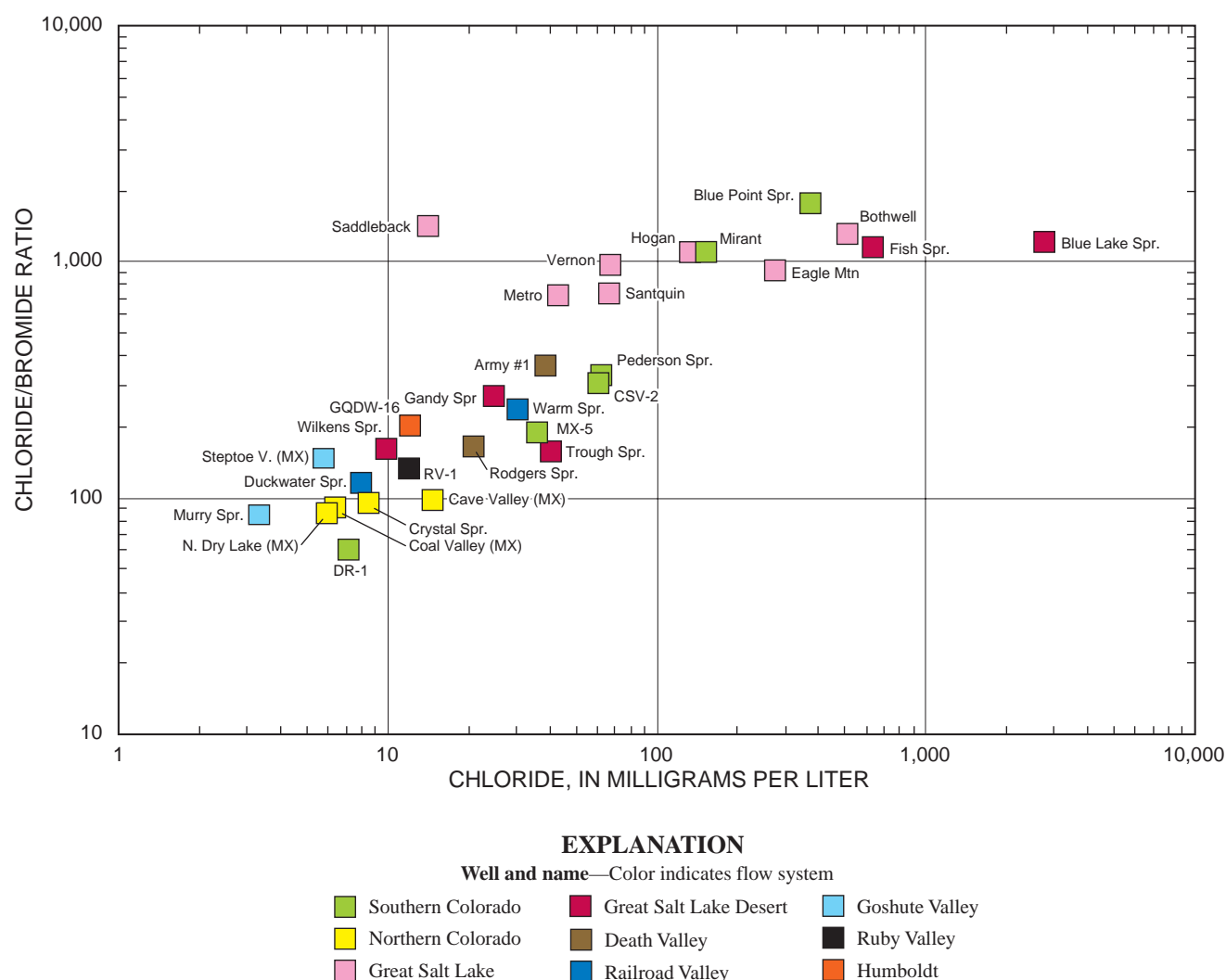


Figure 11. Ratio of chloride to bromide compared to chloride concentration for water sampled from the carbonate-rock aquifer.

of the samples that plot far to the right of the MWL are from the Trough and Bothwell sites. Figure 5 shows that the Bothwell site is located near a large evapotranspiration area, but the Trough site is not.

Smith and others (2002) showed that ground-water samples with $\delta^2\text{H}$ values that are more than 10 per mil lighter (more negative) than local recharge values could have been derived from Pleistocene recharge events. However, ground water sampled from the Great Salt Lake Desert flow system is isotopically lighter than that of the Colorado flow system because of higher recharge altitudes and corresponding present day colder temperatures. Water sampled from an orifice at the Blue Lake springs area, a regional discharge point for the Great Salt Lake Desert flow system located on the border of Nevada and Utah, is isotopically lighter than other samples collected from the flow system. Water-budget calculations indicate that water discharging at this location is derived from precipitation occurring on mountain ranges to the west in Nevada (Gates and Kruer, 1981, p. 18; Nichols, 2000, p. C34) and not derived from Pleistocene recharge events. The isotopic ratio for water from a spring at the Fish Springs area, another regional discharge point in the Great Salt Lake Desert flow system, is much heavier than Blue Lake springs and probably represents water from a warmer recharge area.

Values of $\delta^2\text{H}$ and $\delta^{18}\text{O}$ are considered to be conservative and can be used as tracers to determine different water sources. On a linear plot of $\delta^2\text{H}$ and $\delta^{18}\text{O}$, the isotopic ratio of mixtures with different proportions of two water sources lie on a straight line between the $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values of the sources. This is because of the additive relation between the isotopic ratios of the mixing and evolutionary waters. Isotopic ratios for water from the northern part of the Colorado flow system are clustered in a group with $\delta^2\text{H}$ values between -110 and -105 per mil, whereas values for water from the southern part of the flow system are spread out over a larger range from about -100 to -90 per mil. Thomas and others (1997, p. C36) determined from many more $\delta^2\text{H}$ values for water collected from the Colorado flow system that water discharging from the Muddy River springs area is represented by the water from several areas not necessarily adjacent to the spring. These data were collected from shallow alluvial wells and local springs as well as deeper wells. This means that flow system dynamics are very complex and not a lot of inference about sample source waters can be derived from the limited sampling done for this study.

Tritium (^3H) is a radioactive isotope of hydrogen with a half-life of 12.43 years and is also naturally produced in the upper atmosphere. It occurs in precipitation, bound in water

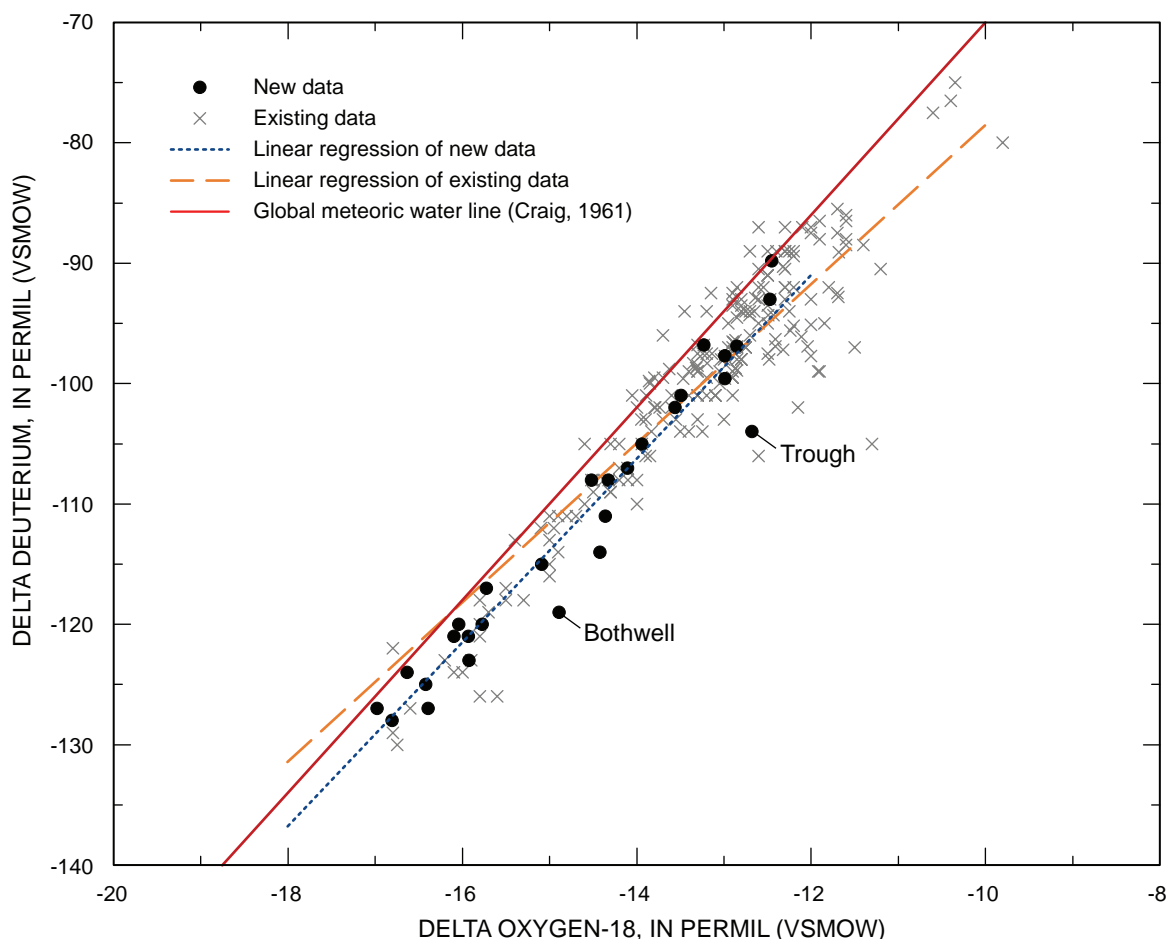


Figure 12. Relation between delta deuterium and delta oxygen-18 for water sampled from the carbonate-rock aquifer.

Table 2. Isotope data, estimated ages, and potential indicators of land-use effects for water sampled from the carbonate-rock aquifer system

[Flow system: DV, Death Valley; COLS, south part of Colorado; COLN, north part of Colorado; RR, Railroad Valley; GV, Goshute Valley; RUBY, Ruby Valley; HUM, Humboldt; GSL, Great Salt Lake; GSLLD, Great Salt Lake Desert. $\delta^2\text{H}$, delta deuterium value; $\delta^{18}\text{O}$, delta oxygen-18 value; Estimated age from ¹Thomas and others (1997) and ²Gates and Kruer (1981); modern, most of water was recharged during or after the 1950s; pre-bomb, most of water was recharged before the 1950s; mixture, mixture of modern and pre-bomb water; —, not applicable; >, greater than; <, less than; e, estimated]

Sampled site name	Flow system	$\delta^2\text{H}$ (per mil)	$\delta^{18}\text{O}$ (per mil)	Tritium (pCi/L)	Tritium error (pCi/L)	Estimated age	Area of flow system	Nitrate (mg/L)	Organic carbon (mg/L)	Dis-solved oxygen (mg/L)	Total coliform colonies (per 100 mL)	E coli colonies (per 100 mL)	Pesticides detected	Surrounding land use
Army Well #1	DV	-101	-13.49	—	—	—	intermediate	0.31	<0.3	2.5	<1	<1	—	rangeland
Blue Lake	GSLD	-123	-15.92	0.1	0.58	pre-bomb	discharge	0.41	<0.3	4.4	<1	0	Carbofuran	rangeland
Blue Point	COLS	-93	-12.47	—	—	—	discharge	0.21	<0.3	1.5	<1	<1	—	rangeland
Bothwell	GSL	-119	-14.89	20.5	1.3	modern	recharge	3.38	<0.3	3.5	<1	0	CIAT	agricultural
Cave Valley	COLN	-105	-13.94	-0.3	0.58	pre-bomb	recharge	1.38	0.4	1.2	<1	<1	—	rangeland
Coal Valley	COLN	-108	-14.52	—	—	—	recharge	0.64	0.2 e	2.0	<1	<1	—	rangeland
Crystal	COLN	-108	-14.32	—	—	'8,500 years	intermediate	0.26	0.2 e	1.1	<1	<1	—	wetland
CSV-2	COLS	-97.7	-12.99	—	—	—	discharge	0.48	1.4	3.0	<1	<1	—	rangeland
DR-1	COLS	-89.8	-12.45	—	—	—	recharge	0.09	0.3 e	1.7	<1	<1	Tebuthiuron	barren land
Duckwater	RR	-121	-15.93	—	—	—	recharge	<0.06	0.5	1.3	65	8 e	—	rangeland
Eagle Mountain	GSL	-125	-16.42	1.5	0.06	pre-bomb	recharge	0.09	<0.3	1.0	<1	0	—	rangeland
Fish	GSLD	-111	-14.36	—	—	'29,000 years	discharge	0.16	<0.3	5.0	<1	0	—	rangeland
Gandy	GSLD	-120	-15.77	16.4	1.1	modern	recharge	0.73	<0.3	6.3	8 e	8	—	rangeland
GQDW-16	HUM	—	—	—	—	—	recharge	0.05	0.2 e	0.2	<1	<1	—	barren land
Hogan	GSL	-128	-16.81	0.03	0.03	pre-bomb	recharge	0.48	<0.3	5.5	<1	0	—	rangeland
Metro	GSL	-127	-16.98	0.5	0.03	pre-bomb	recharge	<0.06	0.4	2.7	<1	0	—	rangeland
Mirant	COLS	-96.8	-13.23	—	—	—	discharge	0.10	<0.3	1.9	<1	<1	—	rangeland
Murry	GV	-117	-15.72	3.0	0.58	mixture	recharge	0.66	0.5	6.0	3 e	<1	—	forest land
MX-5	COLS	-99.6	-12.99	—	—	—	discharge	0.29	0.2 e	2.0	<1	<1	—	rangeland
North Dry Lake	COLN	-107	-14.11	—	—	—	recharge	0.05 e	0.5	0.2	<1	<1	—	rangeland
Pederson	COLS	-96.9	-12.85	—	—	'6,100 years	discharge	0.41	4.6	2.5	160	<1	—	rangeland
Rodgers	DV	-102	-13.56	—	—	'>4,000 years	intermediate	<0.3	0.4	1.8	<1	<1	—	rangeland
RV-1	RUBY	-127	-16.39	—	—	—	recharge	0.74	0.8	2.7	<1	<1	—	rangeland
Saddleback	GSL	-124	-16.63	25.9	1.28	modern	recharge	0.71	0.4	8.0	<1	0	—	rangeland
Santaquin	GSL	-121	-16.10	1.0	0.58	mixture	recharge	1.09	0.2 e	4.8	<1	0	Atrazine, CIAT, Prometon, Terbacil	barren land
Steptoe Valley	GV	-115	-15.09	15.6	1.0	modern	recharge	0.85	1.0	5.9	<1	<1	—	forest land
Trough	GSLD	-104	-12.68	—	—	—	recharge	2.85	0.6	6.3	82 e	7 e	—	rangeland
Vernon	GSL	-120	-16.04	0	0.58	pre-bomb	recharge	0.07	<0.3	2.6	<1	0	—	agricultural
Warm	RR	-114	-14.42	—	—	—	recharge	<0.06	1.1	0.6	<1	<1	—	barren land
Wilkins	GSLD	—	—	—	—	—	recharge	0.72	0.3 e	3.0	80 e	2 e	—	rangeland

molecules at concentrations of about 6–8 tritium units (TU; 1 TU = 3.2 pCi/L). Above ground thermonuclear testing, beginning in 1952 and continuing through the 1960s, introduced large amounts of tritium to the atmosphere, causing concentrations in precipitation to peak in the early 1960s at more than 1,000 TU throughout the northern hemisphere. Tritium concentrations in water recharged to the aquifer prior to thermonuclear testing (pre-bomb), assuming no mixing with other sources of younger water, would have decayed to less than 0.5 TU by 2002. Water recharged during and after the bomb-testing period is called modern water. Water with small amounts of tritium (but greater than 0.5 TU) and contaminants originating at the land surface were considered a mixture of pre-bomb and modern water (table 2).

Tritium was analyzed for in 12 of the 30 water samples (table 2), mostly from sites in or near recharge areas, to determine if there is any modern component in the ground water. Although water in the carbonate-rock aquifer is interpreted to be several thousand years old near the regional discharge points, the presence of tritium in samples collected in and near recharge areas can provide an indication of water movement from the land surface since the 1950s. Tritium concentrations were greater than 15 pCi/L in 4 of the 12 water samples indicating that at least a component of the water from these sites was recharged after 1952. The sites with appreciable tritium are in or near local recharge areas so water may reach the aquifer through fractures or through poorly sealed well casings.

Thomas and others (1997) used geochemical and isotopic data to determine ground-water flow paths and flow velocities in the major carbonate-rock flow systems in southern Nevada. The average age of water determined from carbon-14 analysis by Thomas and others (1997, p. C57) for water discharging from the Ash Meadows springs area (includes Rodgers Spring; fig. 5) is more than 4,000 years old and the average age of water discharging at the Muddy River springs area (includes Pederson Spring; fig. 5) is about 6,100 years old. The Ash Meadows and Muddy River springs are considered to be primary discharge points for the Death Valley and Colorado flow systems, respectively. An average adjusted carbon-14 age for Crystal Spring (fig. 5) and Ash Spring in the middle part of the Colorado flow system was calculated to be 8,500 years before present (Thomas and others, 1997, p. C57). Ground water discharging from the Fish Springs (fig. 5) complex in western Utah was thought to be recharged about 9,000 to 14,000 years ago on the basis of carbon-14 analyses (Gates and Krueger, 1981).

Although estimated ground-water ages based on isotopic data are not available for all of the sample sites, a correlation exists between water that is thousands of years old in the discharge areas and the presence of measurable tritium in water from many sites in or near recharge areas. Additional data, such as carbon-14 analyses, are needed to date the water samples that have less than 0.5 TU tritium units but are near recharge areas.

Effects of Environmental Factors on Water Quality

Figure 13 shows the land-use pattern overlying the carbonate-rock aquifer in the eastern Great Basin. The primary land use is rangeland accounting for about 63 percent of the total land use. The next two largest land-use categories are forest at about 23 percent and barren land at about 6 percent of the total land use. These three categories account for about 92 percent of the total land use in the carbonate-rock province. Urban and commercial activities account for less than 1 percent of the land-use activities in the study area.

The types of land use (or cover) around each sampled site was determined within a 0.25 mi radius to see if any relations between land use and water quality were present. Of the 30 sites, 22 (73 percent) lie within the rangeland classification; 3 sites (10 percent) lie within the barren land classification; and the remaining 5 sites fell within other land-use classifications that are listed in table 2. Land-use patterns at the sampling sites are very similar to the overall land-use pattern in the carbonate-rock aquifer region as a whole.

Anthropogenic (human related) compounds, such as VOCs, pesticides, and elevated levels of nitrate, can occur at the land surface in urban, industrial, and agricultural areas. The majority of the land use in the carbonate-rock aquifer area (rangeland and forest) typically would not contribute these anthropogenic compounds to water in the aquifer. Most of the chemical analyses, especially for VOCs and nutrients, indicate little if any effect of overlying land-use on ground-water quality. The water quality in recharge areas where human activities are more intense may be affected by urban and/or agricultural land uses as evidenced by pesticide detections. The Santaquin site (Great Salt Lake flow system) is located in a gravel pit surrounded by orchards and had four herbicides detected in its water sample (table 2). The Bothwell site, located near an agricultural area, also had an herbicide degradate detected in its water sample, the highest nitrate concentration (3.38 mg/L) of samples collected for this study, and water that has undergone evaporation on the basis of stable-isotope data. Carbofuran was detected in water sampled from the Blue Lake site (table 2) despite its being a regional discharge point for the Great Salt Lake Desert flow system. This insecticide is used to control grasshoppers on public rangeland and some local recharge may have occurred near the spring and application of this pesticide may have occurred in the spring area.

Another indicator of activities occurring at the land surface affecting ground-water quality is the occurrence of certain types of bacteria in the water. Coliform bacteria are commonly found in the environment and are associated with vegetation, soil, and animals. Because bacteria tend to die off quickly once hospitable environments are removed, the presence of bacteria tends to indicate recent recharge. Total coliform bacteria were detected in water sampled from 6 of the 30 sites (table 2). All of the sites with measurable total coliform bacteria were springs located in recharge areas, with the exception of Pederson Spring, which is part of the major discharge area

for the Colorado flow system. Water from Pederson Spring also contained the largest concentration of DOC (4.6 mg/L), which may be indicative of decomposing organic matter in the spring area. *Escherichia coli* (E. coli) are a type of coliform bacteria whose presence indicates recent fecal contamination from warm-blooded animals. E. coli bacteria were detected in water sampled from 4 of the 6 sites where total coliform bacteria were detected. Water sampled from Trough Spring contained coliform bacteria, had an elevated nitrate concentration (2.85 mg/L) relative to other ground-water samples collected from the carbonate-rock aquifer, and had undergone evaporation on the basis of stable-isotope data. Although this site is in a mixed rangeland area and does not have any age data available, it likely has received at least part of its water recently from nearby areas where livestock are present.

The proximity of the carbonate-rock aquifer at these sites to the land surface and the potential for local recharge to occur through the fractured rock likely results in the occurrence of these and other land-surface related contaminants in the ground water. Water from sites sampled near outcrops of carbonate-rock aquifer likely has a much shorter residence time resulting in a potential for detection of anthropogenic or land-surface related compounds. Sites located in discharge areas of the flow systems, or that are completed at a great depth below the land surface, generally show no effects of land-use activities on water quality. Flow times within the carbonate-rock aquifer, away from recharge areas, are on the order of hundreds to thousands of years, so any contaminants introduced at the land surface probably have not reached the sampled sites. Anthropogenic compounds may also be introduced at the well as a result of poor well construction or completion.

Future changes in land-use may affect ground-water quality. Although population density within the carbonate-rock province is low, the potential for increased urban use exists with two of the fastest growing metropolitan areas in the west (Las Vegas and Salt Lake City) located within or near the province's borders. For State fiscal year (July 1 to June 30) 2001 to 2002, assessed value of rural land in Nevada decreased 0.93 percent, whereas assessed value of urban land increased 8.31 percent. The implication is that rural land is being converted to urban land use. As more rural land becomes converted to urban and industrial uses, the current water quality of the carbonate-rock aquifer may change. If large-scale withdrawals from the carbonate-rock aquifer occur in the future, some monitoring of water quality would be useful to determine if changes are occurring.

Historical Changes in Water Quality

Although several of the sites sampled as part of this study have some historical water-quality data available, it is generally not possible to determine if water quality has changed over a span of time longer than a few decades. One site, however, that had 13 water-quality analyses spanning 1962 to 2003 is Army Well #1 located at the southern edge of the NTS

(fig. 5). The well has been used for many years as a production well for the NTS. Table 3 lists selected constituents measured in water sampled from Army Well #1 including major ions, temperature, dissolved solids, and stable isotopes, but not all sample dates have all constituents. The data indicate that most all of the constituents measured are fairly consistent over the 41 years of record. This site is located between recharge and discharge areas in the Death Valley flow system and therefore, should not be expected to have undergone changes in water quality during this timeframe.

More water-quality monitoring is needed at sites located in recharge areas, sites in areas with changing land uses, and sites where ground-water withdrawals are expected to increase in the future to determine the susceptibility of the carbonate-rock aquifer to these factors. Additional age dating of ground water would help guide the selection of sites where monitoring is needed.

Summary

The carbonate-rock aquifer of the Great Basin is named for the thick sequence of Paleozoic limestone and dolomite with lesser amounts of shale, sandstone, and quartzite. It lies primarily in the eastern half of the Great Basin and includes areas of eastern Nevada and western Utah as well as the Death Valley area of California and small parts of Arizona and Idaho. The carbonate-rock aquifer is contained within the Basin and Range principal aquifers, one of 16 principal aquifers selected for study by the USGS NAWQA Program.

Recharge to a carbonate-rock aquifer occurs mostly in the surrounding mountain ranges originating primarily as snow melt at high altitudes. Water recharging the carbonate rocks in the mountains may travel through or beneath several basins and ranges before reaching a discharge area.

Water samples from 30 sites (20 in Nevada and 10 in Utah) were collected in the summer of 2003 and analyzed for major anions and cations, nutrients, trace elements, dissolved organic carbon, volatile organic compounds, pesticides, radon, and limited microbiology. Water samples from selected sites also were analyzed for the isotopes, oxygen-18, deuterium, and tritium to determine recharge sources and the occurrence of water recharged since the early 1950s.

Primary drinking-water standards were exceeded for several inorganic constituents in water from the carbonate-rock aquifer. The maximum contaminant level was exceeded for concentrations of dissolved antimony (6 µg/L) in one sample, arsenic (10 µg/L) in 11 samples, and thallium (2 µg/L) in one sample. Secondary drinking-water regulations were exceeded for several inorganic constituents in water samples: chloride (250 mg/L) in five samples, fluoride (2 mg/L) in two samples, iron (0.3 mg/L) in four samples, manganese (0.05 mg/L) in one sample, sulfate (250 mg/L) in three samples, and total dissolved solids (500 mg/L) in seven samples. Arsenic values for water from the 30 sampled sites range from 0.7 to

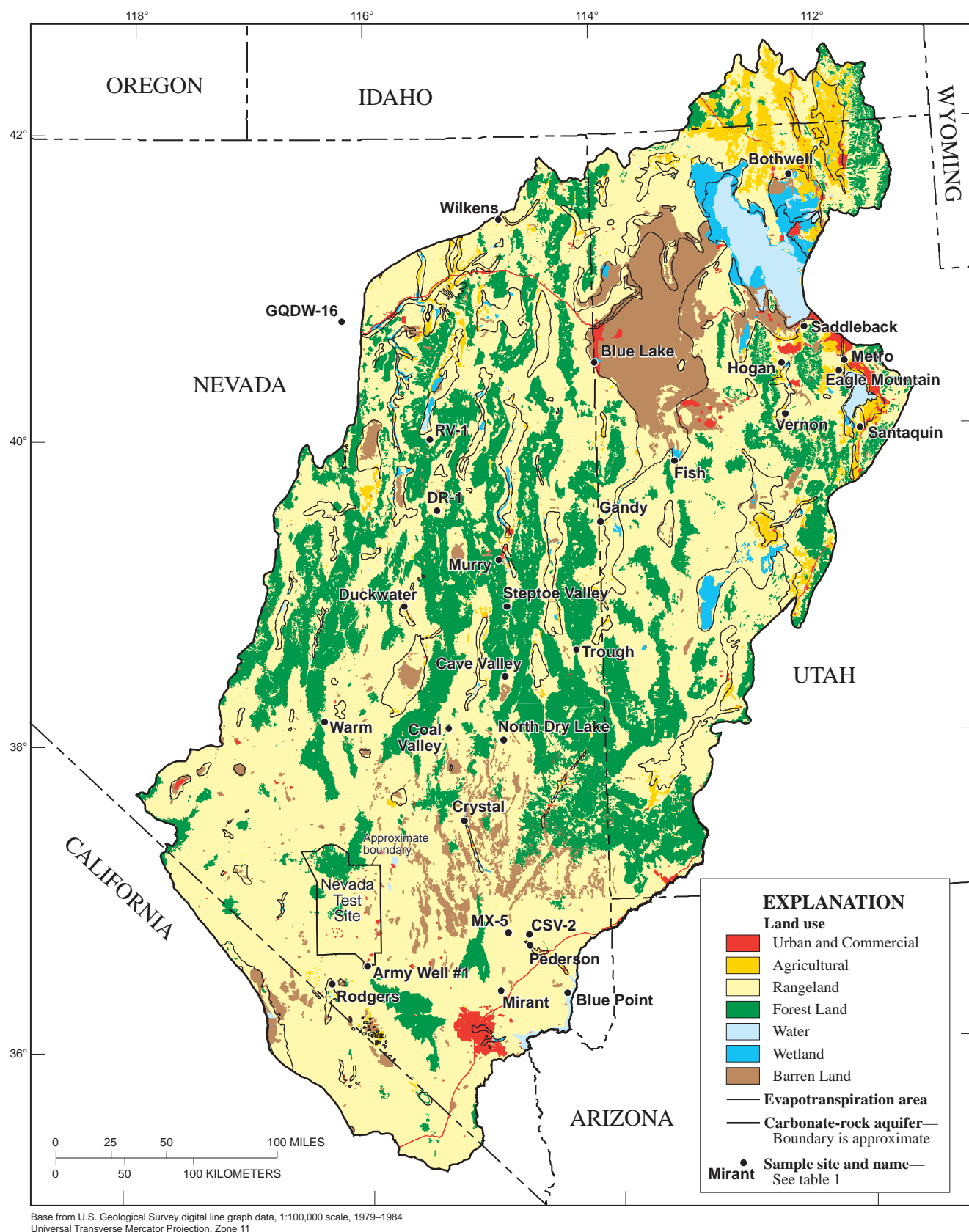


Figure 13. Land-use patterns, evapotranspiration areas, and sample sites, in the carbonate-rock aquifer.

Table 3. Historical water-quality data for selected constituents at Army Well #1

[NA: Not Available]

Sample date	Temp °C	Calcium (Ca) mg/L	Magnesium (Mg) mg/L	Sodium (Na) mg/L	Potassium (K) mg/L	Bicarbonate (HCO ₃) mg/L	Sulfate (SO ₄) mg/L	Chloride (Cl) mg/L	Silica (SiO ₂) mg/L	Dissolved Solids (ROE 180 °C) mg/L	H-2/H-1 ratio per mil	O-18/O-16 ratio per mil
07/10/1962	33.3	47	21	37	5.2	254	53	16	21	330	NA	NA
09/25/1963	31	44	22	34	4.8	258	51	15	18	316	NA	NA
10/20/1964	30	45	21	38	5.2	256	52	16	19	315	NA	NA
11/16/1967	NA	46	22	36	5.4	258	49	15	19	362	NA	NA
04/15/1969	30.5	44	22	36	5.9	258	51	13	20	308	NA	NA
04/22/1969	31	44	22	36	6	258	51	13	20	308	NA	NA
03/01/1970	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	-103	NA
03/18/1971	31	44	22	37	5.2	262	51	15	19	301	NA	NA
04/13/1972	NA	41	21	39	7.7	257	52	16	21	334	NA	NA
12/18/1991	30.5	46	21	41	5.7	251	NA	17	23	NA	-101	-13.55
08/28/1995	NA	42	20	38	5	NA	52	17	19	324	NA	NA
09/18/1996	31	44	21	40	5.6	259	53	20	19	328	-102	-13.43
05/29/2003	30.6	46	21	42	5.2	250	52	39	20	352	-101	-13.49

45.7 µg/L, with a median value of 9.6 µg/L. Factors affecting arsenic concentration in the carbonate-rock aquifer, in addition to geothermal heating, are its natural occurrence in the aquifer material and time of travel along the flow path.

Six different pesticides or metabolites were detected at very small concentrations in the water samples. The lack of volatile organic compound detections in water sampled from most of the sites is evidence that volatile organic compounds are not common in the carbonate-rock aquifer.

Water samples from 28 of the 30 sites were analyzed for stable isotopes. Values of $\delta^2\text{H}$ and $\delta^{18}\text{O}$ for most of the carbonate-rock aquifer samples plot to the right of the MWL, indicating the water has undergone a small amount of evaporation prior to recharging the aquifer. Tritium was analyzed for 12 of the 30 samples, mostly from sites in or near recharge areas, to determine if there is any modern component in the ground water. Tritium concentrations were greater than 15 pCi/L in 4 of the 12 water samples indicating that at least a component of the water from these sites was recharged after 1952.

Most of the chemical analyses, especially for volatile organic compounds and nutrients, indicate little if any effect of overlying land-use on ground-water quality. Water quality in recharge areas for the aquifer where human activities are more intense may be affected by urban and/or agricultural land uses as evidenced by pesticide detections. The proximity of the carbonate-rock aquifer at these sites to the land surface and the potential for local recharge through the fractured rock likely results in the occurrence of these and other land-surface related contaminants in the ground water. Water from sites sampled near outcrops of carbonate-rock aquifer likely has a much shorter residence time resulting in a potential for detection of anthropogenic or land-surface related compounds. Springs located in discharge areas of the flow systems, or wells that are completed at a great depth below the land surface, generally show no effects of land-use activities on water quality. Flow times within the carbonate-rock aquifer, away from recharge areas, are on the order of hundreds to thousands of years, so any contaminants introduced at the land surface probably have not reached the sampled sites.

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Appendix 1. Water-quality constituents analyzed in ground-water samples from wells and springs in the carbonate-rock aquifer, Nevada and Utah

[Parameter code is used in U.S. Geological Survey National Water Information System database: na, not applicable; mg/L, milligrams per liter; µg/L, micrograms per liter, µS/cm, micro siemens per centimeter, °C, degrees centigrade]

Constituent	Parameter code	Number of samples/ number of detections	Laboratory reporting limit (lrl)
FIELD MEASUREMENTS			
Bicarbonate, whole water, mg/L as HCO ₃	00450	30/30	na
Dissolved oxygen, mg/L	00300	30/30	na
pH (standard units)	00400	30/30	na
Specific Conductance, µS/cm	00095	30/30	na
Water temperature (°C)	00010	30/29	na
INORGANICS			
Total dissolved solids (residue at 180 °C)	70300	30/29	10
Major Ions			
Schedule 2750 (sample passed through 0.45-micron filter; lrl in mg/L unless otherwise noted)			
Bromide	71870	30/30	0.02
Calcium	00915	30/30	0.02
Chloride	00940	30/30	0.2
Fluoride	00950	30/30	0.1
Iron	01046	30/25	6 µg/l
Magnesium	00925	30/30	0.008
Manganese	01056	30/26	0.6
Potassium	00935	30/30	0.16
Silica	00955	30/30	0.04
Sodium	00930	30/30	0.2
Sulfate	00945	30/30	0.18
Nutrients Schedule 2755			
(sample passed through 0.45-micron filter; lrl in mg/l)			
Ammonia, as N	00608	30/4	0.04
Ammonia plus organic nitrogen, as N	00623	30/8	0.1
Nitrite, as N	00613	30/3	0.008
Nitrite plus Nitrate, as N	00631	30/26	0.06
Orthophosphate, as P	00671	30/8	0.006
Trace Elements Schedule 2710			
(sample passed through 0.45-micron filter; lrl in µg/L)			
Aluminum	01106	30/14	1.6
Antimony	01095	30/19	0.2
Arsenic	01000	30/30	0.2
Barium	01005	30/30	0.2
Beryllium	01010	30/6	0.06
Boron	01020	30/30	8
Cadmium	01025	30/13	0.04
Chromium	01030	30/12	0.8
Cobalt	01035	30/30	0.014
Copper	01040	30/30	0.4
Lead	01049	30/22	0.08
Lithium	01130	30/30	0.6
Manganese	01056	30/28	0.2
Molybdenum	01060	30/30	0.4
Nickel	01065	30/30	0.06
Selenium	01145	30/27	0.4
Silver	01075	30/3	0.2
Strontium	01080	30/30	0.4
Thallium	01057	30/23	0.04
Uranium	22703	30/30	0.04

Appendix 1. Water-quality constituents analyzed in ground-water samples from wells and springs in the carbonate-rock aquifer, Nevada and Utah—Continued

Constituent	Parameter code	Number of samples/ number of detections	Laboratory reporting limit (lrl)
Vanadium	01085	30/30	0.14
Zinc	01090	30/30	0.6
Radionuclides (whole water sample; lrl in pCi/L unless otherwise noted)			
Radon-222	82203	28/28	25
Tritium	07000	8/5	0.3
H-2/H-1 ratio	82082	28/28	na
O-18/O-16 ratio	82085	28/28	na
ORGANICS			
Dissolved organic carbon (sample passed through 0.45 micron glass fiber filter)	00681	30/20	0.3 mg/L
Pesticides Schedule 2001 (sample passed through a 0.7 micron glass fiber filter); lrl in µg/L			
2,6-Diethylaniline	82660	30/0	0.006
CIAT	04040	30/2	0.006
Acetochlor	49260	30/0	0.006
Alachlor	46342	30/0	0.005
alpha-HCH-d6	34253	30/0	0.005
Atrazine	39632	30/1	0.007
Azinphos-methyl	82686	30/0	0.05
Benfluralin	82673	30/0	0.01
Butylate	04028	30/0	0.004
Carbaryl	82680	30/0	0.041
Carbofuran	82674	30/1	0.02
Chlorpyrifos	38933	30/0	0.005
cis-Permethrin	82687	30/0	0.006
Cyanazine	04041	30/0	0.018
Dacthal	82682	30/0	0.003
Desulfenylfipronil	62170	30/0	0.012
Diazinon	39572	30/0	0.005
Dieldrin	39381	30/0	0.009
Disulfoton	82677	30/0	0.021
EPTC	82668	30/0	0.004
Ethalfuralin	82663	30/0	0.009
Ethoprophos	82672	30/0	0.005
Desulfenylfipronil amide	62169	30/0	0.029
Fipronil sulfide	62167	30/0	0.005
Fipronil sulfone	62168	30/0	0.005
Fipronil	62166	30/0	0.007
Fonofos	04095	30/0	0.003
Lindane	39341	30/0	0.004
Linuron	82666	30/0	0.035
Malathion	39532	30/0	0.027
Methyl parathion	82667	30/0	0.015
Metolachlor	39415	30/0	0.013
Metribuzin	82630	30/0	0.006
Molinate	82671	30/0	0.003
Napropamide	82684	30/0	0.007
p,p'-DDE	34653	30/0	0.003
Parathion	39542	30/0	0.01
Pebulate	82669	30/0	0.004
Pendimethalin	82683	30/0	0.022

Appendix 1. Water-quality constituents analyzed in ground-water samples from wells and springs in the carbonate-rock aquifer, Nevada and Utah—Continued

Constituent	Parameter code	Number of samples/ number of detections	Laboratory reporting limit (lrl)
Phorate	82664	30/0	0.011
Prometon	04037	30/1	0.005
Propyzamide	82676	30/0	0.004
Propachlor	04024	30/0	0.025
Propanil	82679	30/0	0.011
Propargite	82685	30/0	0.023
Simazine	04035	30/0	0.005
Tebuthiuron	82670	30/1	0.016
Terbacil	82665	30/1	0.034
Terbufos	82675	30/0	0.017
Thiobencarb	82681	30/0	0.01
Tri-allate	82678	30/0	0.002
Trifluralin	82661	30/0	0.009
Volatile Organic Compounds Schedule 2020 (whole water sample; lrl in µg/L)			
1,1,1,2-Tetrachloroethane	77562	30/0	0.03
1,1,1-Trichloroethane	34506	30/0	0.03
1,1,2,2-Tetrachloroethane	34516	30/0	0.09
1,1,2-Trichlorotrifluoroethane	77652	30/0	0.06
1,1,2-Trichloroethane	34511	30/0	0.06
1,1-Dichloroethane	34496	30/0	0.04
1,1-Dichloroethylene	34501	30/0	0.04
1,1-Dichloropropene	77168	30/0	0.05
1,2,3,4-Tetramethylbenzene	49999	30/1	0.2
1,2,3,5-Tetramethylbenzene	50000	30/2	0.2
1,2,3-Trichlorobenzene	77613	30/0	0.3
1,2,3-Trichloropropane	77443	30/0	0.16
1,2,3-Trimethylbenzene	77221	30/2	0.1
1,2,4-Trichlorobenzene	34551	30/0	0.1
1,2,4-Trimethylbenzene	77222	30/2	0.06
1,2-Dibromo-3-chloropropane	82625	30/0	0.5
1,2-Dibromoethane	77651	30/0	0.04
1,2-Dichlorobenzene	34536	30/0	0.03
1,2-Dichloroethane	32103	30/0	0.1
1,2-Dichloropropane	34541	30/0	0.03
1,3,5-Trimethylbenzene	77226	30/2	0.04
1,3-Dichlorobenzene	34566	30/0	0.03
1,3-Dichloropropane	77173	30/0	0.1
1,4-Dichlorobenzene	34571	30/0	0.05
2,2-Dichloropropane	77170	30/0	0.05
2-Chlorotoluene	77275	30/0	0.04
o-Ethyl toluene	77220	30/2	0.06
3-Chloropropene	78109	30/0	0.12
4-Chlorotoluene	77277	30/0	0.05
4-Isopropyl-1-methylbenzene	77356	30/2	0.12
Acetone	81552	30/1	7
Acrylonitrile	34215	30/0	1
Benzene	34030	30/3	0.04
Bromobenzene	81555	30/0	0.04
Bromochloromethane	77297	30/0	0.12
Bromodichloromethane	32101	30/1	0.05

Appendix 1. Water-quality constituents analyzed in ground-water samples from wells and springs in the carbonate-rock aquifer, Nevada and Utah—Continued

Constituent	Parameter code	Number of samples/ number of detections	Laboratory reporting limit (lrl)
Bromoethene	50002	30/0	0.1
Bromomethane	34413	30/0	0.3
Carbon disulfide	77041	30/4	0.07
Chlorobenzene	34301	30/0	0.03
Chloroethane	34311	30/0	0.1
Chloromethane	34418	30/0	0.2
cis-1,2-Dichloroethylene	77093	30/0	0.04
cis-1,3-Dichloropropene	34704	30/0	0.09
Dibromochloromethane	32105	30/1	0.2
Dibromomethane	30217	30/0	0.05
Dichlorodifluoromethane	34668	30/0	0.18
Dichloromethane	34423	30/0	0.2
Diethyl ether	81576	30/0	0.2
Diisopropyl ether	81577	30/0	0.1
Ethyl methacrylate	73570	30/0	0.2
methyl ethyl ketone	81595	30/0	5
Ethylbenzene	34371	30/4	0.03
Hexachlorobutadiene	39702	30/0	0.1
Hexachloroethane	34396	30/0	0.2
Iodomethane	77424	30/0	0.35
Isopropyl-acetone	78133	30/1	0.4
Isopropylbenzene	77223	30/3	0.06
Methacrylonitrile	81593	30/1	0.6
Methyl acrylate	49991	30/0	2
Methyl methacrylate	81597	30/0	0.3
tert-Pentyl methyl ether	50005	30/0	0.08
m- + p-Xylene	85795	30/4	0.06
Naphthalene	34696	30/1	0.5
Butylmethylketon	77103	30/0	0.7
n-Butylbenzene	77342	30/0	0.2
n-Propylbenzene	77224	30/3	0.04
o-Xylene	77135	30/3	0.07
sec-Butylbenzene	77350	30/1	0.06
Styrene	77128	30/1	0.04
Ethyl-tert-butyl ether	50004	30/0	0.05
Methyl tertiary-butyl ether (MTBE)	78032	30/0	0.2
t-Butylbenzene	77353	30/0	0.1
Tetrachloroethen	34475	30/1	0.03
Tetrachloromethane	32102	30/0	0.06
Tetrahydrofuran	81607	30/0	2
Toluene	34010	30/14	0.05
trans-1,2-Dichloroethylene	34546	30/0	0.03
trans-1,3-Dichloropropene	34699	30/0	0.09
trans-1,4-Dichloro-2-butene	73547	30/0	0.7
Tribromomethane	32104	30/1	0.1
Trichloroethene	39180	30/0	0.04
Trichlorofluoromethane	34488	30/0	0.09
Trichloromethane	32106	30/1	0.02
Vinyl chloride	39175	30/0	0.1

