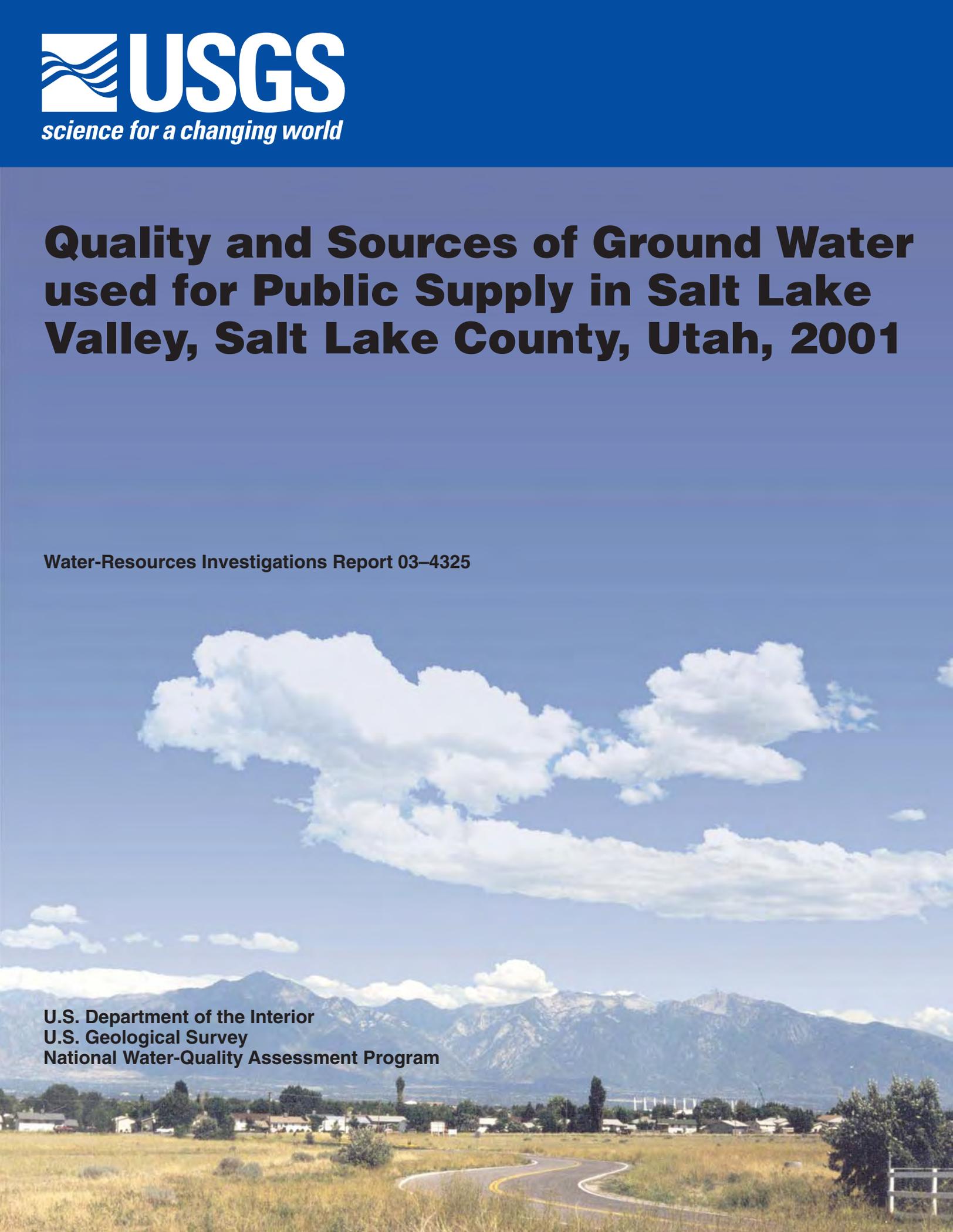


Quality and Sources of Ground Water used for Public Supply in Salt Lake Valley, Salt Lake County, Utah, 2001

Water-Resources Investigations Report 03-4325



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

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By Susan A. Thiros and Andrew H. Manning

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 03-4325

NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Salt Lake City, Utah
2004

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
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FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and 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 of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity *and* quality, even more critical to the long-term sustainability of our communities and ecosystems.

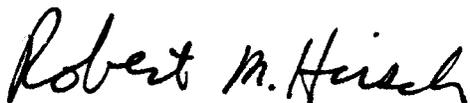
The USGS implemented the National Water-Quality Assessment (NAWQA) program to support national, regional, and local information needs and decisions related to water-quality management and policy (<http://water.usgs.gov/nawqa>). Shaped by and coordinated with ongoing efforts of other Federal, State, and 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. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units (<http://water.usgs.gov/nawqa/nawqamap.html>). Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multi-scale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings (<http://water.usgs.gov/nawqa/natsyn.html>).

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA program 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 program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.



Robert M. Hirsch
Associate Director for Water

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
acre-feet per year (acre-ft/yr)	1,233	cubic meter per year
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day
gallon (gal)	3.785	liter
gallon per minute (gal/min)	3.785	liter per minute
inch (in.)	25.4	millimeter
inch per year (in/yr)	25.4	millimeters per year
mile (mi)	1.609	kilometer
square mile (mi ²)	2.59	square kilometer

Water temperature in degrees Celsius (°C) and degrees Fahrenheit (°F) may be converted by using the following equations:

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

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

Vertical coordinate information is referenced to the North American Vertical Datum of 1929 (NAVD 29). Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Concentration of chemical constituents in water is reported either in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter and micrograms per liter are units expressing the concentration of chemical constituents in solution as weight (grams) of solute per unit volume (liter) of water. A liter of water is assumed to weigh 1 kilogram, except for brines or water at high temperatures because of changes in the density of the water. For concentrations less than 7,000 mg/L or 7,000,000 µg/L, the numerical value is the same as for concentrations in parts per million or parts per billion, respectively.

Specific conductance is reported in microsiemens per centimeter at 25 degrees Celsius (µS/cm). Radon concentration in water is reported as picocuries per liter (pCi/L). Stable-isotope ratios are reported as per mil (‰), which is equivalent to parts per thousand. Tritium concentration in water is reported as tritium units (TU). The ratio of 1 atom of tritium to 10¹⁸ atoms of hydrogen is equal to 1 TU or 3.2 picocuries per liter. Dissolved-gas concentrations are reported in cubic centimeters at standard temperature and pressure per gram of water (cm³STP/g). Chlorofluorocarbons measured in picograms per kilogram (pg/kg) are equivalent to parts per quadrillion.

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ABSTRACT

Ground water supplies about one-third of the water used by the public in Salt Lake Valley, Utah. The occurrence and distribution of natural and anthropogenic compounds in ground water used for public supply in the valley were evaluated. Water samples were collected from 31 public-supply wells in 2001 and analyzed for major ions, trace elements, radon, nutrients, dissolved organic carbon, methylene blue active substances, pesticides, and volatile organic compounds. The samples also were analyzed for the stable isotopes of water (oxygen-18 and deuterium), tritium, chlorofluorocarbons, and dissolved gases to determine recharge sources and ground-water age.

Dissolved-solids concentration ranged from 157 to 1,280 milligrams per liter (mg/L) in water from the 31 public-supply wells. Comparison of dissolved-solids concentration of water sampled from the principal aquifer during 1988-92 and 1998-2002 shows a reduction in the area where water with less than 500 mg/L occurs. Nitrate concentration in water sampled from 12 of the 31 public-supply wells was higher than an estimated background level of 2 mg/L, indicating a possible human influence. At least one pesticide or pesticide degradation product was detected at a concentration much lower than drinking-water standards in water from 13 of the 31 wells sampled. Chloroform was the most frequently detected volatile organic compound (17 of 31 samples). Its widespread occurrence in deeper ground water is likely a result of the recharge of chlorinated public-supply water used to irrigate lawns and gardens in residential areas of Salt Lake Valley.

Environmental tracers were used to determine the sources of recharge to the principal aquifer used for public supply in the valley. Oxygen-18 values and recharge temperatures computed from dissolved noble gases in the ground water were used to differentiate between mountain and valley recharge. Maximum

recharge temperatures in the eastern part of the valley generally are below the range of valley water-table temperatures indicating that mountain-block recharge must constitute a substantial fraction of recharge to the principal aquifer in this area. Together, the recharge temperature and stable-isotope data define two zones with apparently high proportions of valley recharge on the east side of the valley.

The possibility of water samples containing a substantial proportion of water recharged before thermonuclear testing began in the early 1950s (pre-bomb) was evaluated by comparing the initial tritium concentration of each sample (measured tritium plus measured tritiogenic helium-3) to that of local precipitation at the apparent time of recharge. Three interpreted-age categories were determined for water from the sampled wells: (1) dominantly pre-bomb; (2) dominantly modern; and (3) modern or a mixture of pre-bomb and modern. Apparent tritium/helium-3 ages range from 3 years to more than 50 years. Water generally becomes older with distance from the mountain front, with the oldest water present in the discharge area.

The presence of anthropogenic compounds at concentrations above reporting levels and elevated nitrate concentrations (affected wells) in the principal aquifer is well correlated with the distribution of interpreted-age categories. All of the wells (10 of 10) with dominantly modern water are affected. Seventy percent (7 of 10) of the wells with dominantly modern or a mixture of modern and pre-bomb waters are affected. Only 1 of the 11 wells with dominantly pre-bomb water is affected. Anthropogenic compounds were not detected in water with an apparent age of more than 50 years, except for water from one well. All of the samples that consisted mostly of modern water contained at least one anthropogenic compound.

INTRODUCTION

Ground water, primarily from deeper unconsolidated basin-fill deposits known as the principal aquifer, accounts for about one-third of the water used for public supply in Salt Lake Valley, Utah. The quality of water from much of the principal aquifer is generally suitable for drinking. However, withdrawals are regulated and limited by the Utah Division of Water Rights because the resource is over allocated and could be adversely affected by large water-level declines and water-quality degradation. Leakage from the shallow aquifer to the deeper principal aquifer in the valley is possible where a downward gradient exists and confining layers are thin and (or) discontinuous. Compounds resulting from human activities such as volatile organic compounds and pesticides have been frequently detected in shallow ground water sampled in residential areas where the gradient is downward to the principal aquifer (Thiros, 2003). Recharge from the mountains is considerably less likely to contain man-made chemicals and elevated dissolved-solids concentrations than is recharge that occurs in the valley. Continued population growth in the valley will result in an increasing demand for water of suitable quality for drinking and the potential for changes in ground-water flow directions and gradients.

Existing information on the occurrence and distribution of naturally occurring and man-made compounds in water from the principal aquifer is primarily from samples collected from public-supply wells by numerous well owners to comply with mandates of the Safe Drinking Water Act. A water-quality data set constructed by using consistent methods of sampling and analysis is needed to provide a baseline with which to compare data collected in the future. Additional information is also needed on when and where the water currently used for public supply was recharged in order to evaluate how susceptible the water quality is to change.

The chemical composition of ground water used for public supply in the valley was studied during 2001-02 as part of the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) program. The objectives of the NAWQA program are to describe the current water-quality conditions and trends in rivers, streams, and ground water and to understand the natural and human factors that affect the conditions

and trends in water quality throughout the Nation. The Great Salt Lake Basins study unit is 1 of more than 50 study areas selected to meet these objectives.

Purpose and Scope

The purpose of this report is to evaluate the occurrence and distribution of natural and anthropogenic compounds in ground water used for public supply in Salt Lake Valley and to determine the general sources of recharge to the principal aquifer. Water samples were collected from 31 public-supply wells in 2001 and analyzed for field parameters, major ions, trace elements, radon, nutrients, dissolved organic carbon (DOC), methylene blue active substances (MBAS), pesticides, and volatile organic compounds (VOCs). The samples also were analyzed for the stable isotopes of water (oxygen-18 and deuterium), tritium, chlorofluorocarbons, and dissolved gases to determine recharge sources and ground-water age.

Data from the 31 public-supply wells are augmented with data from other studies and sources in order to improve spatial resolution and enable a more comprehensive interpretation of the data. These additional data include (1) concentrations of dissolved solids, arsenic, radon, nitrate, atrazine and its degradation products, chloroform, and oxygen-18 in the principal aquifer from wells sampled for the NAWQA program during 1998-2000; (2) concentrations of dissolved solids and arsenic in the principal aquifer during 1998-2002 obtained from the Utah Division of Drinking Water; (3) concentrations of dissolved solids in the principal aquifer in the southwestern part of the valley (where there are few public-supply wells) during 1998-2002 from Kennecott Utah Copper Corporation; (4) oxygen-18 data from Thiros (1995) collected during 1990-91 and from NAWQA samples collected during 1998-2000; and (5) dissolved-gas and tritium data for water samples collected primarily during 2000 from public-supply wells on the east side of Salt Lake Valley (Manning, 2002).

Description of Study Area

Salt Lake Valley is an urban area bounded by the Wasatch Range, Oquirrh Mountains, Traverse Mountains, and Great Salt Lake (fig. 1). It is near the

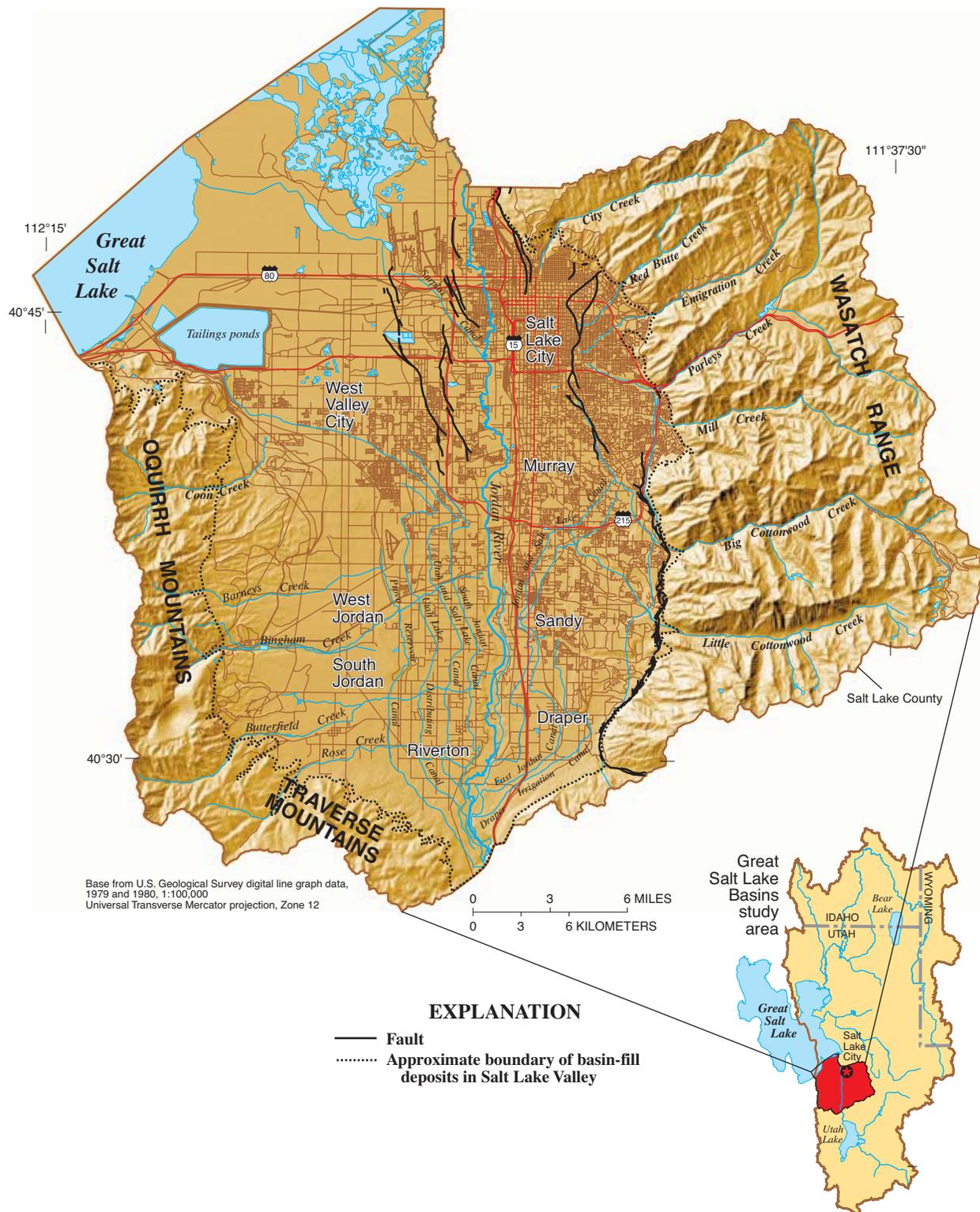


Figure 1. Map showing location and geographic features of Salt Lake Valley, Utah.

transition between the Basin and Range and Rocky Mountain Physiographic Provinces (Fenneman, 1931). The valley is about 28 mi long and 18 mi wide (about 500 mi²) and generally corresponds to the populated part of Salt Lake County, which contains the Salt Lake City metropolitan area. The population of Salt Lake County in 2000 was about 898,000 (U.S. Census Bureau, 2002) and is growing rapidly. The population almost doubled between 1963 and 1994, corresponding to a large increase in land developed for residential and commercial use. Population in Salt Lake County is projected to be about 1,029,000 in 2010 and 1,233,000 in 2020 (Wasatch Front Regional Council, 2000), which will increase water demand for public supply. Because the natural boundaries of the valley restrict expansion of residential areas beyond the extent of agricultural land, population growth will occur mainly through increased population density.

The climate in Salt Lake Valley is semiarid, with a 1961-90 average annual precipitation of about 10 to 20 in. (Daly and Taylor, 1998). Lawns and gardens in the valley require irrigation to supplement precipitation during the growing season. Precipitation in the mountains is about 50 in/yr. Mountain streams draining the Wasatch Range discharge into the Jordan River, which flows north along the axis of the valley, is diverted into canals, and eventually discharges into Great Salt Lake.

Land and Water Use

Urban areas within the valley more than doubled from 1960 (89 mi²) to 1994 (198 mi²) (Utah Department of Natural Resources, Division of Water Resources, 1999). Land use in urban areas of the valley in 1994 was about 63 percent residential, 6 percent commercial, 14 percent industrial, and 17 percent other (includes open spaces, idle spaces, transportation, and utilities) (Utah Department of Natural Resources, Division of Water Resources, 1995). Much of the industrial land use in Salt Lake Valley is near the Jordan River (fig. 2). Historically, the urban area was centered in the northeastern part of the valley in a recharge area. Many of the recently developed residential/commercial areas are along the mountain front bounding the east side of the valley and are also replacing agricultural areas on the west side (fig. 2).

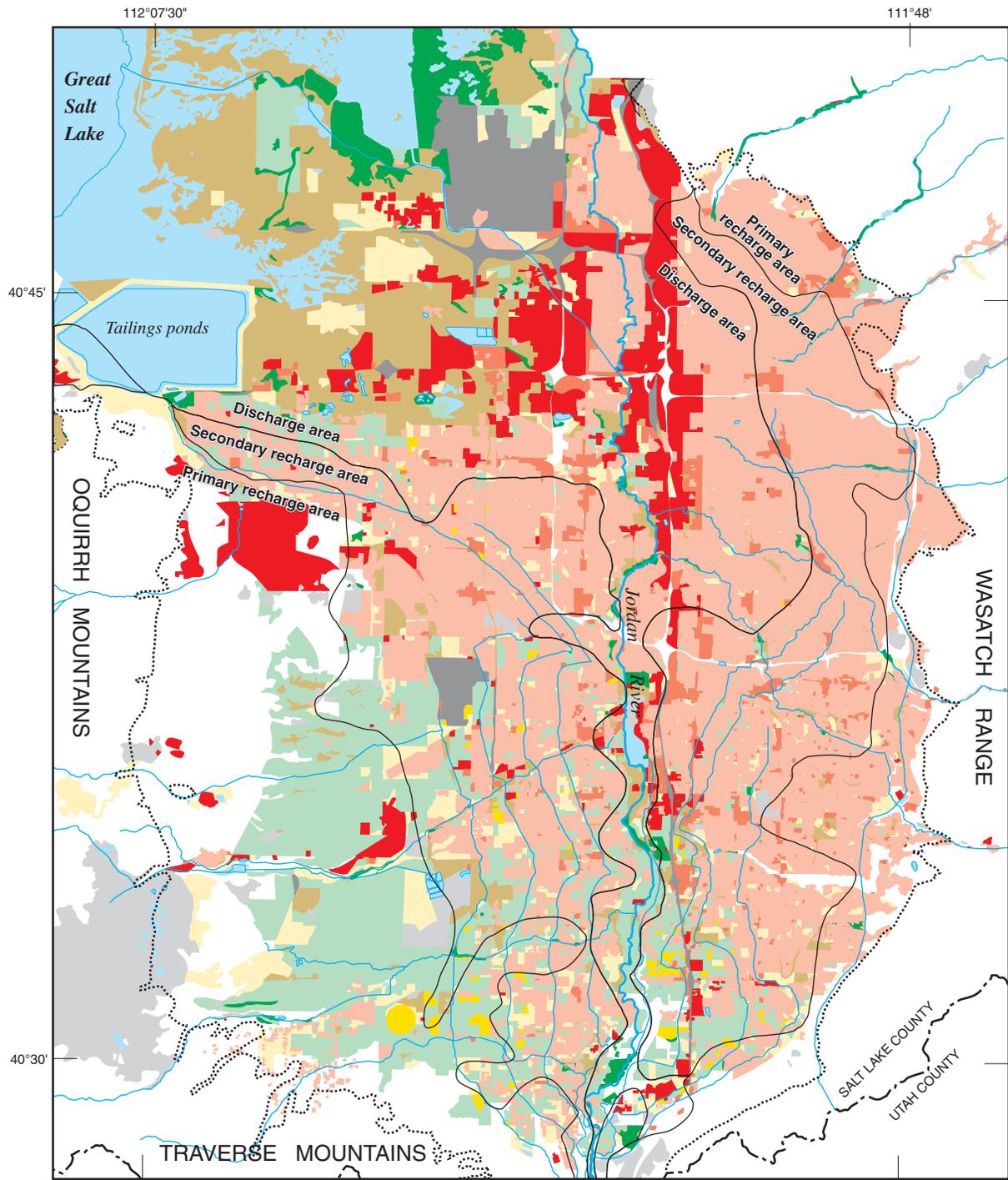
Surface water from streams draining the Wasatch Range provided about 70 percent of the water used for public supply in Salt Lake Valley in 2000. This water is chlorinated and distributed across the valley. Demand

for water peaks during July through August, when lawns and gardens require more water because of the summer heat. Water systems that receive surface water also use wells during the summer to meet the increased demand. Water systems without surface-water sources rely on water from wells throughout the year. Ground-water withdrawal in 2000 from wells in the valley was about 28 percent of the public supply. Springs and tunnels in the Wasatch Range provided a minor amount (about 2 percent) of the valley's public supply.

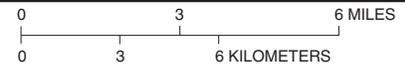
An average of about 79,000 acre-ft/yr was withdrawn from 161 public-supply wells in the valley during 1996-99 (Utah Division of Water Rights, written commun., 2001). The average well withdrawal for this period is shown in figure 3. Most of the ground-water withdrawal occurs on the east side of the valley because of higher yields and lower dissolved-solids concentrations. In some areas, water is blended with water from other sources to improve its quality.

Ground-Water Hydrology

Salt Lake Valley contains basin-fill deposits derived from the surrounding mountains that are deposited mainly in alluvial fans, stream channels, deltas, and lacustrine features associated with Lake Bonneville and other paleolakes. Lake Bonneville covered much of northern Utah about 15,000 years ago. Tertiary-age deposits are semiconsolidated to consolidated and consist mainly of alluvial-fan deposits interbedded with volcanic ash and tuffs. These deposits crop out along the western and southern margins of the valley and are overlain by generally unconsolidated sediments of Quaternary age that are considerably more permeable. The saturated Quaternary deposits range from less than 200 ft thick along the margins of the valley to more than 1,000 ft thick in the northern part of the valley (Hely and others, 1971). Nearly all the wells in the valley are screened in the Quaternary deposits. Lake-deposited clay layers occur throughout the valley, except near the mountain fronts where coarser-grained deposits exist.

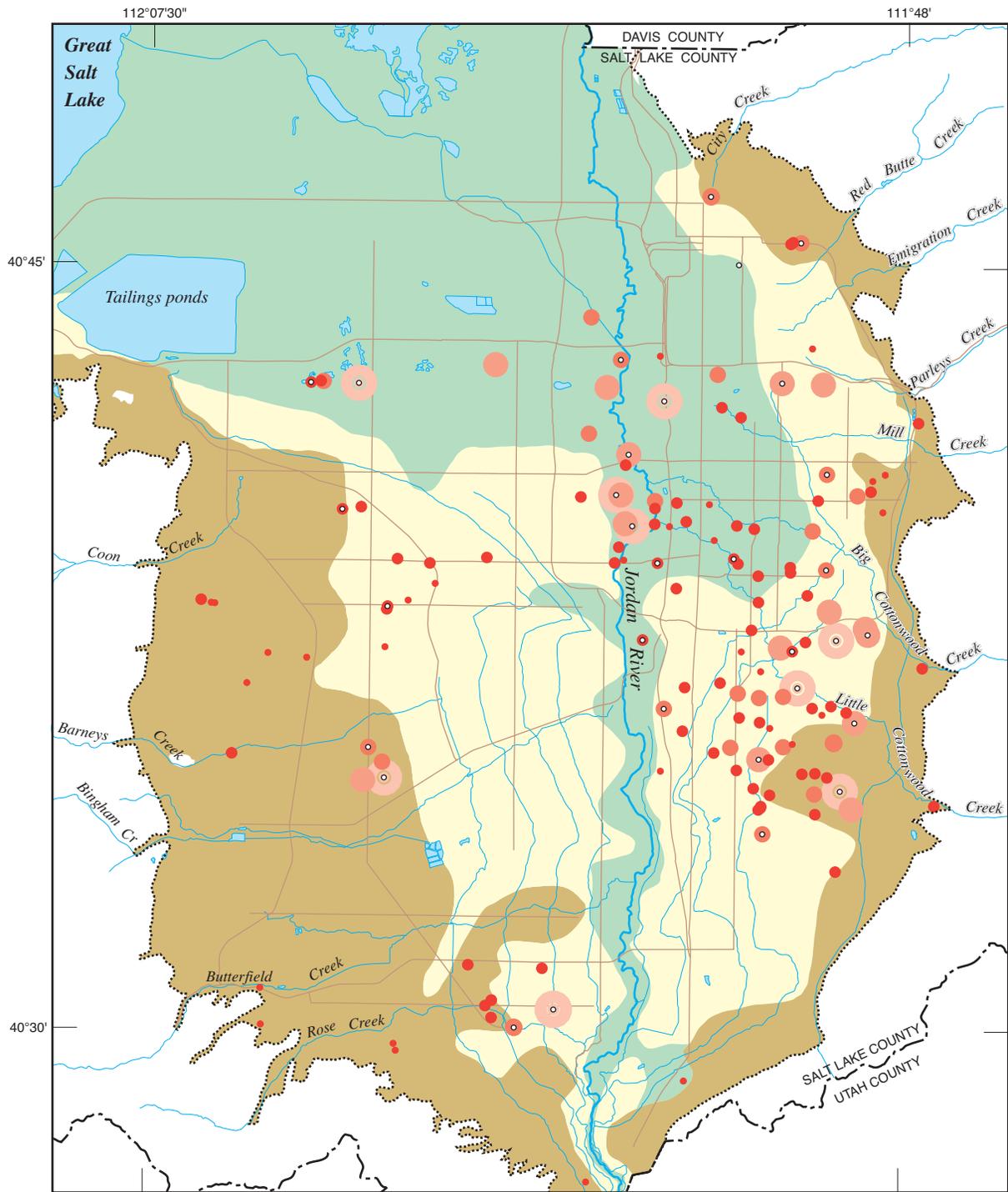


Base from U.S. Geological Survey digital line graph data, 1:100,000, 1979 and 1980
 Universal Transverse Mercator projection, Zone 12



EXPLANATION	
 Residential	 Water
 Commercial	 Riparian
 Industrial	 Agriculture
 Transportation/utilities	 Corn
 Open or idle	 Unknown
 Excavated	 Approximate boundary of basin-fill deposits in Salt Lake Valley

Figure 2. Map showing Land use in Salt Lake Valley, Utah, 1994.



Base from U.S. Geological Survey digital line graph data, 1979 and 1980, 1:100,000
 Universal Transverse Mercator projection, Zone 12

EXPLANATION

- | | |
|---|--|
| <ul style="list-style-type: none"> Discharge area Primary recharge area Secondary recharge area Approximate boundary of basin-fill deposits in Salt Lake Valley Public-supply well sampled as part of this study | <p>Withdrawals from public-supply wells, in acre-feet per year</p> <ul style="list-style-type: none"> 2 – 100 100 – 500 500 – 1,000 1,000 – 1,500 1,500 – 2,480 |
|---|--|

0 3 6 MILES
 0 3 6 KILOMETERS

Figure 3. Map showing Average ground-water withdrawals from public-supply wells in Salt Lake Valley, Utah, 1996-99.

A generalized model of the saturated basin-fill deposits in Salt Lake Valley consists of a relatively deep unconfined aquifer near the mountain fronts that becomes confined toward the center of the valley by layers of fine-grained deposits (fig. 4). Collectively, the deeper aquifers are known as the principal aquifer. Where the principal aquifer is confined, it is overlain by a shallow unconfined aquifer. The primary recharge area for the principal aquifer includes the mountains surrounding the valley and the part of the valley near the mountain fronts where there are no substantial layers of fine-grained deposits to impede the downward movement of water. The secondary recharge area is where downward movement of water from the shallow aquifer to the deeper confined aquifer is possible because a downward gradient exists and confining layers are thin, and (or) discontinuous. In the discharge area an upward gradient exists from the deeper confined aquifer to the overlying shallow aquifer. The recharge and discharge areas in Salt Lake Valley (fig. 5) were mapped by Anderson and others (1994, p. 6) on the basis of lithologic and water-level data.

Depending on the continuity of the confining layers, the shallow ground water overlying these layers may be either localized in extent (perched) or laterally continuous forming an aquifer. The shallow aquifer is susceptible to contamination from activities related to land use because of its proximity to land surface. Water quality in the confined part of the principal aquifer can be degraded by secondary recharge of contaminated water from the shallow aquifer. The unconfined part of the principal aquifer also is vulnerable because of a lack of confining layers that can impede the downward movement of contaminated ground water. The principal aquifer in Salt Lake Valley has been divided into areas where the susceptibility of ground water to contamination is similar on the basis of differences in geology, the rate of ground-water movement, and the direction of vertical hydraulic gradients (Waddell and others, 1987a).

Recharge to and discharge from the principal aquifer in the valley has been estimated in previous studies by Hely and others (1971), Waddell and others (1987b), and Lambert (1995) (table 1). Mountain-front recharge is thought to comprise about 50 percent of recharge to the principal aquifer and includes subsurface inflow from the adjacent mountains (mountain-block recharge) and seepage from streams near the mountain front. Infiltration of unconsumed irrigation water from fields, lawns, and gardens; infiltration of

precipitation on the valley floor; and seepage from canals are the other major sources of recharge. Model simulations of the ground-water flow system were used to better understand the distribution of these recharge components in the valley (Waddell and others, 1987b; Lambert, 1995). Seepage through the shallow aquifer to the Jordan River and other streams and to evapotranspiration are large components of discharge from the principal aquifer. Total withdrawals from wells for all uses is about one-third of the total estimated discharge from the system and affects the amount of ground water available to other forms of discharge.

Acknowledgments

The USGS thanks the well owners who allowed USGS personnel access to their wells for sampling. The assistance of Alan Rigby and Kip Solomon at the University of Utah Department of Geology and Geophysics, Tritium and Noble Gases Laboratory also is appreciated.

STUDY DESIGN AND METHODS

Site Selection

This study consisted of sampling 15 public-supply wells completed in the principal aquifer in Salt Lake Valley that withdraw the most water and therefore supply the most people. An average annual withdrawal based on 1996-99 data (Utah Division of Water Rights, written commun., 2001) was used to rank the public-supply wells. Withdrawal from wells within 0.62 mi (1 kilometer) of each other was totaled for ranking purposes and one well was chosen from the group to be sampled. Water from the 15 public-supply wells and associated nearby wells accounts for 46 percent of the water from wells used for public supply in the valley. An additional 16 public-supply wells were selected to provide a better spatial distribution across the valley. A minimum spacing of 0.62 mi was required between wells. The 31 sampled public-supply wells completed in the principal aquifer are shown in figures 3 and 5 and described in table 2.

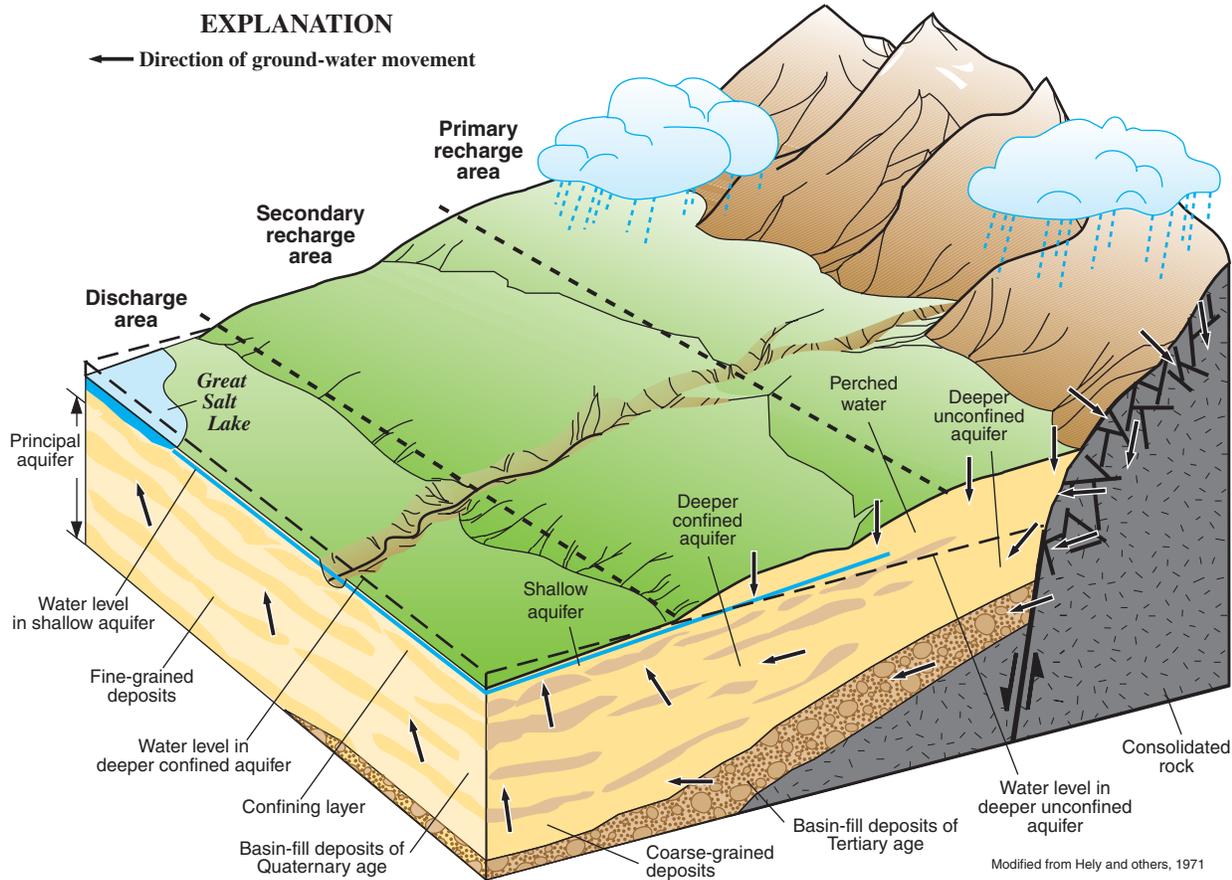
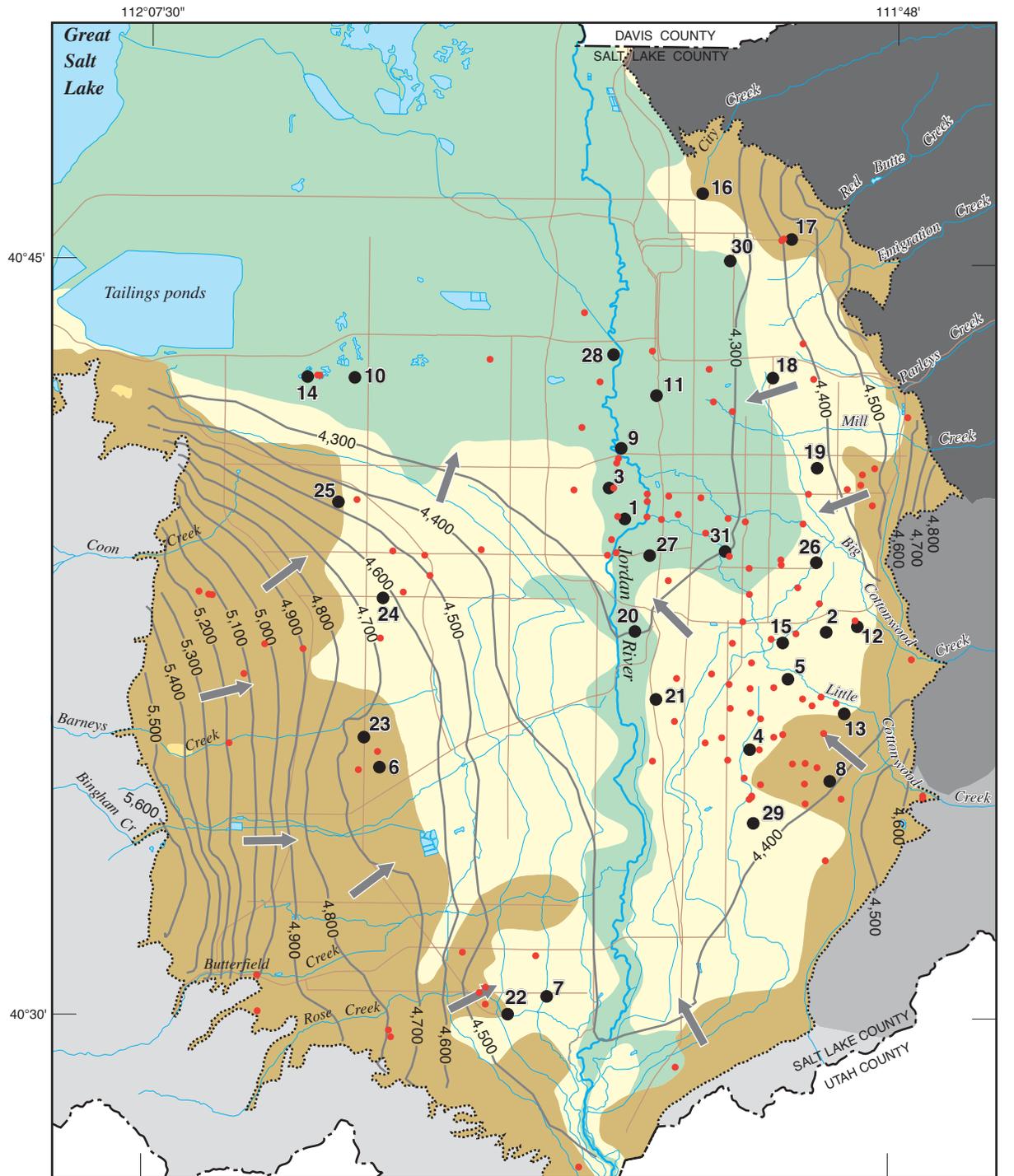


Figure 4. Generalized block diagram showing the basin-fill deposits and ground-water flow system in Salt Lake Valley, Utah.

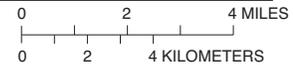
The 31 sampled public-supply wells ranged from 130 to 1,212 ft deep with a median depth of 500 ft. The top of the open intervals in the wells varied from 90 to 650 ft below land surface and typically included more than one open interval. For this report, Salt Lake Valley is divided into an east and west side with the area around the Jordan River included on the east side because of probable ground-water origin. Twenty-three of the wells sampled are on the east side and eight are on the west side of the valley. Because the ground-water system is not the same on the east and west sides of the valley, the primary and secondary recharge areas and the discharge area were distinguished between east and west sides.

Sample Collection

Ground-water samples were collected during May and June 2001 to analyze for major ions, alkalinity, radon, nutrients, DOC, MBAS, oxygen-18, deuterium, selected nutrients, trace elements, pesticides, and VOCs and were processed according to protocols in Koterba and others (1995). Most of the public-supply wells had been pumping during the summer and each well was purged of at least three to five casing volumes of water prior to sampling. Water temperature, pH, specific conductance, dissolved oxygen, turbidity, and discharge were monitored periodically during the purge cycle. Ground-water samples were collected after measurements of these parameters had stabilized.



Base from U.S. Geological Survey digital line graph data, 1979 and 1980, 1:100,000 Universal Transverse Mercator projection, Zone 12



- EXPLANATION**
- Dominantly clastic sedimentary rocks and carbonates
 - Dominantly quartzite with interbedded shales
 - Granitic intrusive rocks
 - Dominantly carbonates and volcanic rocks
 - Discharge area
 - Primary recharge area
 - Secondary recharge area
 - Approximate boundary of basin-fill deposits in Salt Lake Valley
 - ← Approximate direction of horizontal ground-water flow
 - 4,500- Potentiometric contour—Shows altitude of model-computed potentiometric surface for the principal aquifer in 1991 (from Lambert, 1995, fig. 25). Contour interval is 100 feet. Datum is sea level
 - 22 Public-supply well sampled as part of this study—Number is well identifier
 - Public-supply well not sampled as part of this study

Figure 5. Map showing location of ground-water recharge and discharge areas and 31 sampled public-supply wells, and approximate direction of horizontal ground-water flow in Salt Lake Valley, Utah, 2001.

Table 1. Ground-water budget for Salt Lake Valley, Utah, as reported in previous studies

[Reported in acre-feet per year]

	Estimated for 1964-68 (Hely and others, 1971, table 21)	Specified or computed in Waddell and others (1987b, tables 1 and 3) numerical model steady-state simulation	Specified or computed in Lambert (1995, table 5) numerical model steady-state simulation
Recharge from			
Consolidated rock	135,000	154,000	142,000
Irrigated fields, lawns, and gardens	98,000	76,000	57,000
Precipitation	60,000	70,000	67,000
Canals	48,000	24,000	30,000
Streams and channel fill	21,500	17,500	16,000
Underflow at Jordan Narrows	2,500	2,500	2,500
Seepage from tailings ponds near Magna	2,400	0	0
Reinjection from air conditioning	2,000	2,000	¹ 0
Reservoirs and evaporation ponds	0	0	1,900
Jordan River and tributaries	0	0	1,000
Total (rounded)	369,000	346,000	317,000
Discharge to			
Jordan River and tributaries	170,000	146,000	137,000
Wells	107,000	102,000	105,000
Evapotranspiration	60,000	54,000	36,000
Springs	21,000	21,000	19,000
Drains	5,000	5,000	10,000
Great Salt Lake	4,000	7,200	1,300
Canals	0	10,000	9,200
Total (rounded)	367,000	² 345,000	317,000

¹ Amounts reinjected were subtracted from amounts pumped for same wells.

² Previously reported in Waddell and others (1987b, table 3) as 346,000.

Ground-water samples from the 31 public-supply wells also were analyzed for chlorofluorocarbons (CFCs). Analyzed CFCs include CFC-11 (trichlorofluoromethane or CFC1₃), CFC-12 (dichlorodifluoromethane or CF₂Cl₂), and CFC-113 (trichlorotrifluoroethane or C₂F₃Cl₃). To avoid contact with air, water was directed from the well's discharge line through copper tubing to a valve system that allowed for filling and flushing of a borosilicate ampoule. Headspace above the sample was filled with CFC-free ultrapure nitrogen gas before the ampoule was fused closed. Five ampoules were filled at each sampled well in case of breakage or leakage.

As part of this study, dissolved-gas samples from 24 of the 31 public-supply wells were collected by using clamped copper tubes, a standard sampling tech-

nique described by Stute and Schlosser (2000). Samples were collected while the well was operating. Copper tubing (5/8-in. diameter) was plumbed directly to a tap in the well discharge line, and flow through the tubing was regulated with a downstream valve. The well pump provided substantial backpressure in the tubing, preventing gas loss. After several minutes of purging, the sample was isolated in the copper tubing by using pinch-off clamps.

Dissolved-gas samples from 50 public-supply wells on the east side of Salt Lake Valley were collected in the summer of 2000 as part of a previous study by Manning (2002) and included samples from the 7 public-supply wells not sampled for dissolved gases in this study and 5 wells that were sampled as part of both studies. This data set was included to

Table 2. Description of 31 public-supply wells completed in Salt Lake Valley, Utah, 2001

[—, no data]

Well identifier (fig. 5)	Area of valley and classification of ground-water recharge and discharge areas (fig. 5)	Normal pumping period	1996-99 average withdrawal for public supply near sampled well (acre-feet per year)	Well depth	Top of openings	Bottom of openings	(feet below land surface)			
							Surface seal installed	Sand or gravel pack	Static water level	Pumping water level
1	east - discharge	year	3,889	678	280	656	0-120	no	40	180
2	east - secondary recharge	year	3,703	544	265	533	—	no	185	200
3	east - discharge	summer	2,868	935	650	872	0-120	120-935	54	217
4	east - secondary recharge	year	2,593	650	395	648	—	—	279	326
5	east - secondary recharge	summer ¹	2,403	861	440	851	0-380	380-877	135	285
6	west - primary recharge	summer	2,208	590	380	590	surface casing	yes	184	113
7	west - secondary recharge	summer	2,005	500	290	480	0-100	—	212	347
8	east - primary recharge	summer ¹	1,920	950	610	950	0-220	220-960	499	590
9	east - discharge	summer	1,799	965	395	945	0-112	112-980	5	178
10	west - discharge	summer	1,684	250	90	232	0-65	65-250	artesian	32
11	east - discharge	summer	1,609	1,000	418	994	0-405	405-1,004	artesian	70
12	east - secondary recharge	summer	1,470	453	256	451	no	no	290	304
13	east - secondary recharge	summer ¹	1,466	700	275	680	—	—	312	378
14	west - discharge	summer	1,459	177	96	173	0-36	36-106	artesian	80
15	east - secondary recharge	summer	1,440	506	154	495	—	—	136	154
16	east - primary recharge	summer	838	464	162	420	—	—	144	—
17	east - primary recharge	summer	1,265	510	266	470	—	—	194	280
18	east - secondary recharge	summer	1,288	502	160	490	0-113	no	31	96
19	east - secondary recharge	summer	907	657	295	650	surface casing	no	116	130
20	east - discharge	summer	333	386	240	380	0-123	no	13	130
21	east - secondary recharge	summer	606	701	200	545	0-120	no	73	109
22	west - secondary recharge	year	939	410	220	390	0-160	160-410	122	224
23	west - primary recharge	summer	635	610	330	603	0-200	200-620	199	265
24	west - secondary recharge	year	304	900	360	890	0-120	120-900	174	—
25	west - primary recharge	summer	393	1,212	635	1,202	0-145	145-1,212	426	541
26	east - secondary recharge	summer	531	590	295	532	0-100	100-549	69	335
27	east - discharge	summer	254	468	125	460	—	—	51	109
28	east - discharge	year	832	840	145	340	0-100	100-840	artesian	175
29	east - secondary recharge	summer	543	515	205	498	0-100	no	199	259
30	east - discharge	year	5	130	130	130	no	no	-11	—
31	east - discharge	summer	631	496	100	156	surface casing	no	16	63

¹ Well also is used to inject surface water into the principal aquifer.

better understand the sources of recharge to the principal aquifer on the east side of Salt Lake Valley. Samples were collected by using passive diffusion samplers similar to those used in Sanford and others (1996). These in-situ sampling devices consist of a length of copper tubing (3/16-in. diameter) sealed at one end and connected to a sealed length of silicone tubing at the other. Samplers are placed in the water and left for an adequate period to allow dissolved gases to equilibrate with the sampler headspace by diffusion through the silicone tubing. Samplers are then removed from the water and the copper tubing is

immediately sealed, either with a valve or by crimping (cold weld). Samples were collected while the wells were pumping, and most wells had been pumping for at least 48 hours prior to sampling. Samplers were placed within a flow-through cell plumbed directly into the wellhead. The well pump provided significant pressure in the flow-through cell, preventing gas loss. Flow rates through the cell were maintained at about 1 gal/min throughout the 24-hour (minimum) equilibration period. Diffusion samplers were then removed and sealed immediately by crimping.

Sample Analysis

The USGS National Water-Quality Laboratory (NWQL) in Denver, Colorado, analyzed the water samples for major ions, radon, DOC, MBAS, selected nutrients, trace elements, pesticides, and VOCs. Analytical methods used for major ions and trace elements were primarily 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 for by using ultraviolet-promoted persulfate oxidation and infrared spectrometry (Brenton and Arnett, 1993), and radon was analyzed for by 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), for 65 pesticides by using high-performance liquid chromatography/mass spectrometry (HPLC) (Furlong and others, 2001), and for 85 VOCs by using purge and trap capillary column gas chromatography/mass spectrometry (Conner and others, 1998). MBAS analysis was used to determine the concentration of anionic sulfate and sulfonate-based surfactants in unfiltered samples as described by Burkhardt and others (1995). Alkalinity was determined on-site by incremental titration of filtered sample water with sulfuric acid.

Analyses of the stable isotopes of water (deuterium and oxygen-18) were done at the USGS Stable Isotope Laboratory in Reston, Virginia. The deuterium 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 and delta oxygen-18 values are 2 and 0.2 per mil, respectively. CFCs were analyzed for at the USGS CFC Laboratory in Reston, Virginia, by using purge and trap gas chromatography (Busenberg and Plummer, 1992). The detection limit for CFCs is about 0.3 pg/kg of water, which is equivalent to 0.3 parts per quadrillion (Plummer and Friedman, 1999).

The water samples were analyzed for tritium and dissolved gases by the University of Utah Department of Geology and Geophysics, Tritium and Noble Gases Laboratory in Salt Lake City, Utah. Tritium concentrations were determined by helium ingrowth (Bayer and

others, 1989). This method involves degassing the sampled water and isolating it under a vacuum in a special container. The degassed sample is stored from 1 month to 1 year and then the concentration of helium-3 (^3He), the radioactive decay product of tritium, is measured by using a magnetic sector-field mass spectrometer. The USGS Isotope Tracers Project Laboratory in Menlo Park, California, analyzed 13 samples for tritium to compare concentrations collected for different studies and laboratories. Tritium concentration in these samples was determined by using electrolytic enrichment and liquid scintillation (Thatcher and others, 1977) with a minimum-reporting limit of about 0.3 TU.

The dissolved gases nitrogen, neon, argon, and krypton were measured by using a quadrupole mass spectrometer. Helium-3 and 4 (^4He) analyses were done by using a magnetic sector-field mass spectrometer. Dissolved gases were extracted initially from samples collected in clamped copper tubes by using the procedure detailed in Bayer and others (1989) (this step was not required for the diffusion samplers). Gases were inlet directly into a high vacuum purification system that includes a titanium/zirconium sponge for reactive gases. Non-reactive gases were cryogenically separated. Nitrogen was measured dynamically by using a leak valve and the remaining gases were measured statically.

Constituents that are not detected in a water sample are reported as less than the minimum reporting level (MRL). The MRL is defined by the NWQL (Timme, 1995) as the smallest measured concentration of a constituent that may be reliably measured by using a given analytical method. VOCs that are not detected in a water sample are reported as less than the laboratory reporting level (LRL). The LRL for each VOC represents the minimum concentration that can be identified, measured, and reported with 99 percent confidence (Childress and others, 1999). The MRL or LRL for each constituent or compound indicates relative analytical precision and detection sensitivity, but some concentrations are reported as less than the reporting level if the identification criteria for the method were met. Concentrations for detections less than the MRLs or LRLs are designated as estimated values. Overall, the MRLs for pesticides and LRLs for VOCs analyzed for by the NAWQA program are lower than those of analyses done for regulatory purposes.

Quality Assurance

A quality-assurance program was used in the field (Koterba and others, 1995) and in the laboratory to evaluate the bias and variability of the analytical results and to ensure data reliability. Quality-control samples collected as part of sampling the 31 wells are listed in table 3. Analytical results for the quality-assurance samples are listed in tables A-1 to A-9 (appendix).

Field-blank samples were collected to evaluate contamination introduced during sample collection, processing, shipment, and analysis. Blank water assumed to have less than the MRL or LRL for the analyzed constituents and compounds was pumped through the tubing and other sampling equipment with a peristaltic pump. Relatively small volumes of blank water flowed through the sampling equipment prior to collection of a field-blank sample, whereas a much larger amount of ground water flowed through the system prior to collection of a ground-water sample. This additional rinsing likely reduces the concentration of contaminants that may remain in the equipment after cleaning compared to the rinse provided prior to collection of a field-blank sample.

The trace elements thallium and zinc were detected in one field-blank sample each (table A-2 in appendix) at concentrations in the range of those detected in the ground-water samples; therefore, the ground-water data may be biased. Antimony, copper, lead, and lithium also were detected in one or more blank samples but at concentrations less than those detected in the ground-water samples.

DOC, nitrate plus nitrite, and nitrite were detected in water from one field-blank sample at very low concentrations (table A-3 in appendix). Because DOC was not detected in the source-solution blank samples, it likely results from insufficient rinsing (1 to 3 gal) to remove residual cleaning agents from the sampling equipment. Additional rinsing with ground water during the purging cycle of sampling (generally more than 20 gal) likely reduces DOC, nitrate, and nitrite concentrations in the environmental samples to below those determined for the field blanks. Therefore, concentrations measured for these constituents are assumed to be uncontaminated.

None of the 103 pesticides and pesticide breakdown products analyzed for in the field-blank samples were detected. Caffeine, a compound included in the sample analysis for pesticides, was detected in one of the field-blank samples (table A-4 in appendix). It also was detected in water sampled from two public-supply wells at concentrations similar to that estimated in the field blank; therefore, caffeine was not included in the pesticide data analysis. Bromacil and metolachlor were detected in one ground-water sample each. Estimated concentrations for these compounds were so small relative to the MRLs that they were not included in the data analysis. Carbofuran was analyzed for by using both the GCMS and HPLC methods. Although detected with the GCMS method at a low concentration in one environmental sample, it was not detected with the HPLC method that has a lower MRL; therefore, carbofuran was not included in the data analysis.

The VOC dichloromethane was detected in the equipment-blank sample and in one field-blank sample (table A-5 in appendix) at concentrations in the range of those estimated for two ground-water samples.

Table 3. Quality-control sampling for 31 public-supply wells in Salt Lake Valley, Utah, 2001

[DOC, Dissolved organic carbon; MBAS, methylene blue active substances; VOCs, volatile organic compounds; GCMS, gas chromatography/mass spectrometry; HPLC, high-performance liquid chromatography]

Type of sample	Number of samples	Constituents or compounds analyzed for
Equipment blank	1	Major ions, nutrients, DOC, MBAS, trace elements, pesticides, VOCs
Field blank	3	Major ions, nutrients, DOC, MBAS, trace elements, pesticides, VOCs
Source-solution blank	4	DOC, VOCs
Trip blank	1	VOCs
Replicate	3	Major ions, nutrients, DOC, MBAS, trace elements, radon, pesticides, VOCs
Field spike	3	VOCs, pesticides analyzed by GCMS method
Laboratory spike	3	Pesticides analyzed by HPLC method

Other VOCs that have similar uses also were detected in the two ground-water samples, but not in the blank samples. The dichloromethane detected in these samples therefore is assumed not to be introduced during sampling and was used in the VOC data analysis. Toluene was detected in most of the blank samples (equipment, field, and source-solution) (table A-5 in appendix) and environmental samples at similar concentrations and is possibly the result of sample vial contamination. Toluene detections were not used in the VOC data analysis. Benzene was detected in a source-solution blank sample and in a ground-water sample at similar trace concentrations. This compound could be introduced into the source-solution sample when the blank water was poured into the sample vial. The atmosphere can receive benzene from the incomplete combustion of gasoline used to power the generator or nearby vehicles. The benzene detected in the ground-water sample may be from the atmosphere rather than the aquifer and caution should be used when interpreting these data.

Trichloroethylene was detected in the trip-blank sample and in two ground-water samples at similar concentrations. Tetrachloroethylene was detected with trichloroethylene in the ground-water samples. Both compounds have similar uses and trichloroethylene can be formed from the degradation of tetrachloroethylene. Therefore the occurrence of trichloroethylene in the two ground-water samples is probably not the result of contamination and the data were used in the VOC data analysis.

Sequential replicate ground-water samples were collected from three wells to determine the concentration variability for major ions, nutrients, DOC, MBAS, trace elements, and radon (tables A-1, A-2, and A-3 in appendix). Concentrations for most constituents in the sample pairs generally were within 10 percent. Nickel concentration in water from one replicate sample was more than five times greater than was measured in the original sample and may be related to contamination.

Surrogate pesticide compounds and VOCs were added in known concentrations to all of the ground-water and blank-water samples at the laboratory and percent recovery was determined for each surrogate (tables A-6 and A-7 in appendix). These surrogate compounds are similar chemically to other compounds that were analyzed and provide information on sample-matrix effects and analyte recovery. Recovery of the surrogates from most of the samples was within 25 percent of the amount added to the water.

Spike solutions containing known concentrations of target VOCs and pesticide compounds were added to three sets of replicate ground-water samples (tables A-8 and A-9 in appendix) to determine analyte recovery in the sample matrix and to evaluate the effectiveness of the analytical methods for selected analytes. Recovery of most target compounds was within 25 percent of the amount present in the unspiked sample plus the amount added in the spike solution. A low mean recovery generally means that the compound may not have been detected in ground water if present at low concentrations or that detected concentrations may be biased low. A high mean recovery generally means that detection is real, but the concentration may be biased high. Recovery of the atrazine degradation products deethyl-atrazine and 2-hydroxyatrazine was less than (55 percent mean recovery) and greater than (118 percent mean recovery), respectively, the amount added to the three matrix-spiked samples. Degradation from one form to another may have occurred in the sample during the time between collection and analysis.

GROUND-WATER QUALITY

Water-quality data collected from the 31 public-supply wells sampled in Salt Lake Valley consist of field parameters, major ions, trace elements, nutrients, DOC, MBAS, pesticides, and VOCs. Summary statistics for field parameters, major ions, trace elements, nutrients, DOC, and MBAS are listed in table 4; detected pesticides are in table 5; and detected VOCs are in table 6. The analytical results are listed in tables 13 to 18 at the back of the report. A more detailed discussion is presented in the following sections. Water-quality data for the principal aquifer collected for the NAWQA program from wells other than the 31 public-supply wells sampled during this study are shown in the following figures. Water-quality data for these wells also are available on the Internet at <http://water-data.usgs.gov/ut/nwis/qwdata>.

Concentrations of water-quality constituents and compounds are compared to drinking-water standards set by the U.S. Environmental Protection Agency (USEPA) for 2002 (U.S. Environmental Protection Agency, 2002). The maximum contaminant level (MCL) is the maximum concentration of a contaminant permissible in a public-water system. MCLs are based on a level at which no known or anticipated adverse

Table 4. Summary of physical properties and concentration of major ions, trace elements, and nutrients in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001

[USEPA, U.S. Environmental Protection Agency; —, not applicable or no standard; °C, degrees Celsius; µS/cm, microsiemens per centimeter; SDWR, secondary drinking-water regulations; mg/L, milligrams per liter; E, estimated; MCL, maximum contaminant level; <, less than; µg/L, micrograms per liter; HAL, lifetime health-advisory level; pCi/L, picocuries per liter]

Property or constituent, and reporting unit	Number of detections	Minimum reporting level	Minimum	Maximum	Median	USEPA drinking-water standard or health advisory ¹
Physical properties						
Well depth (feet)	31	—	130	1,212	590	—
Pumping water level (feet)	28	—	32	590	190	—
Water temperature (°C)	31	—	9.5	30.5	14.5	—
Specific conductance (µS/cm at 25 °C)	31	—	250	2,030	880	—
pH (standard units)	31	—	7.0	8.0	7.4	6.5—8.5 (SDWR)
Alkalinity (mg/L as CaCO ₃)	31	—	84	302	174	—
Oxygen, dissolved (mg/L)	31	—	.3	9.9	5.7	—
Turbidity (Nephelometric turbidity units)	31	—	.1	.5	.1	—
Major ions (mg/L, except as indicated)						
Bicarbonate (as HCO ₃)	31	—	103	369	198	—
Bromide, dissolved	31	.01	.01	.30	.09	—
Calcium, dissolved	31	.01	25.9	172	63.5	—
Chloride, dissolved	31	.1	8.6	308	77.2	250 (SDWR)
Fluoride, dissolved	31	.2	E 0.1	.8	.3	4 (MCL); 2 (SDWR)
Iron, dissolved (µg/L)	7	10	<10	320	<10	300 (SDWR)
Magnesium, dissolved	31	.008	7.28	55.3	24.8	—
Manganese, dissolved (µg/L)	6	3.0	E 1.8	160	<3.0	50 (SDWR)
Potassium, dissolved	31	.09	1.42	34.7	2.97	—
Silica, dissolved	31	.1	9.9	105	17.6	—
Sodium, dissolved	31	.1	8.0	330	41.4	—
Sulfate, dissolved	31	.1	11.1	285	75.5	250 (SDWR)
Dissolved solids, sum of constituents	31	—	146	1,240	504	500 (SDWR)
Dissolved solids, residue at 180 °C	31	10	157	1,280	496	500 (SDWR)
Trace elements (µg/L, except as indicated)						
Aluminum, dissolved	7	1	<1	8	<1	50-200 (SDWR)
Antimony, dissolved	28	.05	E .03	.17	.10	6 (MCL)
Arsenic, dissolved	31	.2	.4	17.9	1.1	10 (MCL)
Barium, dissolved	31	1.0	19.6	774	77.7	2,000 (MCL)
Beryllium, dissolved	0	.06	<.06	<.06	<.06	4 (MCL)
Boron, dissolved	31	7	11	284	57	600 (HAL)
Cadmium, dissolved	20	.04	E .02	.20	.04	5 (MCL)
Chromium, dissolved	25	.8	E .4	4.6	<.8	² 100 (MCL)
Cobalt, dissolved	31	.02	.03	.27	.10	—
Copper, dissolved	31	.2	.4	6.3	1.6	1,000 (SDWR)
Lead, dissolved	29	.08	<.08	2.70	.46	—
Lithium, dissolved	31	.3	1.2	143	14.7	—
Molybdenum, dissolved	31	.2	.4	8.6	2.0	40 (HAL)
Nickel, dissolved	14	.06	E .04	3.02	<.06	100 (HAL)

Table 4. Summary of physical properties and concentration of major ions, trace elements, and nutrients in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001—Continued

Property or constituent, and reporting unit	Number of detections	Minimum reporting level	Minimum	Maximum	Median	USEPA drinking-water standard or health advisory ¹
Trace elements (µg/L, except as indicated)—Continued						
Radon-222, total (pCi/L)	31	26	251	1,980	702	300 (MCL)
Selenium, dissolved	28	.3	E .2	3.2	.9	50 (MCL)
Silver, dissolved	0	1.0	<1.0	<1.0	<1.0	100 (SDWR and HAL)
Strontium, dissolved	31	.08	179	1,730	631	4,000 (HAL)
Thallium, dissolved	14	.04	E .02	.17	<.04	2 (MCL); .5 (HAL)
Uranium, dissolved	31	.02	.04	15.1	3.10	30 (MCL)
Vanadium, dissolved	31	.2	.4	19.2	1.7	—
Zinc, dissolved	31	1	1	35	5	5,000 (SWDR); 2,000 (HAL)
Nutrients (mg/L)						
Ammonia, dissolved as N	5	.040	<.040	2.24	<.040	30 (HAL)
Ammonia plus organic nitrogen, dissolved as N	7	.10	E .06	2.5	<.10	—
Carbon, organic, dissolved as C	14	.30	<.15	1.2	<.30	—
Methylene blue active substances, total	2	.02	<.02	.02	<.02	—
Nitrite, dissolved as N	12	.006	E.003	.01	<.006	1 (MCL)
Nitrate plus nitrite, dissolved as N	31	.050	E.026	5.99	1.33	10 (MCL)
Phosphorus, dissolved as P	31	.006	E.004	.132	.013	—
Orthophosphorus, dissolved as P	19	.020	E.009	.105	.030	—

¹ U.S. Environmental Protection Agency (2002).

² MCL is for total chromium.

Table 5. Detection frequency and concentration of pesticides detected in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001

[Concentrations reported in micrograms per liter; E, estimated value; —, not applicable or no applicable standard; Maximum contaminant level is the U.S. Environmental Protection Agency established drinking-water standard (U.S. Environmental Protection Agency, 2002). Lifetime health advisory level is defined as the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects for a lifetime of exposure (U.S. Environmental Protection Agency, 2002)]

Pesticide	Trade name(s)	Predominant uses	Number of detections	Minimum reporting level	Maximum concentration	Minimum detected concentration	Maximum contaminant level	Lifetime health advisory level
Atrazine	AAtrex	Restricted use herbicide	7	0.007	0.034	E 0 .002	¹ 3	3
Deethylatrazine	DEA, Desethylatrazine	Degradation product of atrazine	10	.006	E .065	E .002	—	—
Deethyldeisopropylatrazine	—	Degradation product of atrazine	1	.01	E .01	—	—	—
Imazethapyr	Pursuit	Herbicide	2	.017	E .014	E .006	—	—

¹ Maximum contaminant level is under review.

Table 6. Detection frequency and concentration of volatile organic compounds detected in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001

[Concentration reported in micrograms per liter; E, estimated value; —, not applicable or no applicable standard; M, presence of compound verified but not quantified; Maximum contaminant level is the U.S. Environmental Protection Agency established drinking-water standard (U.S. Environmental Protection Agency, 2002); Lifetime health advisory level is defined as the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects for a lifetime of exposure (U.S. Environmental Protection Agency, 2002)]

Volatile organic compound	Alternative name or abbreviation	Predominant uses	Number of detections	Laboratory reporting level	Maximum concentration	Minimum detected concentration	Maximum contaminant level	Lifetime health advisory level
Bromodichloromethane	Dichlorobromomethane	Chlorination byproduct	11	0.05	5.4	E 0.02	¹ 80	—
Chloroform	Trichloromethane	Solvent, chlorination byproduct	17	.02	19.7	E .01	¹ 80	—
cis-1,2-Dichloroethylene	cis-1,2-Dichloroethene	Solvent, refrigerant	1	.04	E .03	—	70	70
Dibromochloromethane	Chlorodibromomethane	Chlorination byproduct	2	.2	1	0.4	¹ 80	—
Dichloromethane	Methylene chloride	Solvent, metal degreaser	2	.2	M	M	5	—
Tetrachloroethylene	Tetrachloroethene, PCE	Solvent	3	.1	1	M	5	—
Tetrachloromethane	Carbon tetrachloride	Solvent, metal degreaser	2	.06	E .04	E .02	5	—
1,1,1-Trichloroethane	Methyl chloroform, TCA	Solvent	6	.03	E .05	E .01	200	200
Trichloroethylene	Trichloroethene, TCE	Solvent	2	.04	E .02	E .01	5	—
Trichlorofluoromethane	Freon 11, CFC-11	Refrigerant, aerosol propellant	2	.09	.12	E .02	—	2,000
1,1,2-Trichlorotrifluoroethane	CFC-113	Refrigerant, aerosol propellant	3	.06	.28	E .04	—	—

¹The maximum contaminant level for total trihalomethanes is 80 micrograms per liter.

effects on human health occur and which allows an adequate margin of safety, but also considers the cost and feasibility of meeting the standard. The lifetime health advisory level (HAL) is the concentration of a chemical in drinking water at or below which is not expected to cause any adverse noncarcinogenic effects during a lifetime of exposure (U.S. Environmental Protection Agency, 2002). It is based on health effects information and is provided as technical guidance for regulatory and management officials.

The water samples analyzed for this study were collected near the wellhead before treatment or distribution, and represent source water. Water used for public supply is required to meet drinking-water standards before distribution to users. Finished water supplied to the public may have undergone treatment or dilution to meet these standards.

Physical Properties

Physical properties measured in the field during sampling of water from the public-supply wells included temperature, specific conductance, pH, alka-

linity, dissolved oxygen, and turbidity (table 4 and table 13). The median water temperature was 14.5°C and ranged from a median value of 16°C for water from wells in the central discharge area near the Jordan River to 12°C for water from wells in the southeastern part of the valley near the mountain front. The deepest well sampled as part of this study (well 25 is 1,212 ft deep) also had the warmest water (30.5°C).

Specific conductance ranged from 250 to 2,030 µS/cm with a median value of 880 µS/cm. Generally, water from the northeastern and western part of the valley had a higher specific-conductance value than water from the central or southeastern part. Specific conductance for water from the 31 wells ranged from 51 to 71 percent of the dissolved-solids concentration determined for residue remaining after evaporation of the sample at 180°C (mean and median value of 61 percent). The median pH value was 7.4; pH ranged from 7.0 to 8.0, within the range established for secondary drinking-water regulations (6.5 to 8.5) (U.S. Environmental Protection Agency, 2002). Alkalinity varied from 84 to 302 mg/L with a median value of 174 mg/L.

Dissolved-oxygen concentrations ranged from 0.3 to 9.9 mg/L with a median value of 5.7 mg/L. The oxidation-reduction (redox) state of water can affect what constituents are present and at what concentrations. Dissolved-oxygen concentrations greater than an arbitrary level of 2.0 mg/L and no detectable concentrations of nitrite, ammonia, iron, or manganese generally indicate oxidizing conditions. Anomalously high dissolved-oxygen concentrations can result from aeration of ground water during pumping. Reducing conditions are indicated by relatively low concentrations of dissolved oxygen and nitrate and the presence of nitrite, ammonia, iron, or manganese. Reducing conditions occur at five of the public-supply wells sampled on the basis of dissolved oxygen concentrations less than 2.0 mg/L. Four of the five wells are in the ground-water discharge area for the principal aquifer near the Jordan River. Low dissolved-oxygen concentrations are accompanied by the lowest nitrate concentrations and the highest ammonia, iron, and manganese concentrations in water sampled during the study (wells 9, 11, and 28). Water from well 1, which also is in this area, has slightly more dissolved oxygen (2.6 mg/L), possibly indicating mixing with oxygenated water. Water from wells 24 and 25, relatively deep wells on the west side of the valley, had a dissolved-oxygen concentration of 2.3 and 0.9 mg/L, respectively.

The highest dissolved-oxygen concentrations in ground water sampled for this study were measured in wells in or near the primary recharge area. Direct recharge of oxygenated water to the principal aquifer and the abundance of coarse-grained deposits that allow faster ground-water movement facilitate oxidizing conditions in the primary recharge areas of the valley.

Major Ions

Chemical composition of ground water largely depends on the type of rocks and associated minerals that it has contacted and how long the water has been in contact with the aquifer material. The most mineralized ground water sampled as part of this study was from the northwestern part of the valley where the dominant ions were sodium and chloride (fig. 6). The least mineralized water was from wells in the southeastern part where the nearby rock types are more resistant to weathering. Water from the southeastern part of the valley is predominantly a calcium-bicarbonate type. Water from the northeastern part of the valley contains

more sulfate, likely from contact with Triassic-age shale and mudstone in the mountain block and in the basin-fill deposits in and near the area.

The distribution of dissolved-solids concentration (residue at 180°C) in water from the 31 wells ranged from 157 to 1,280 mg/L with a median concentration of 496 mg/L. The 15 public-supply wells that pumped the most water in the valley had the same range of dissolved-solids concentration, but the median concentration was 370 mg/L. Water from 8 wells on the west side of the valley had a median concentration of 844 mg/L compared to 357 mg/L for water from 16 wells on the east side and 370 mg/L for water from 7 wells in the center of the valley near the Jordan River. Water pumped from wells on the west side of the valley generally is blended with water from other areas to reduce dissolved-solids concentrations.

Dissolved-solids concentration in ground water from the principal aquifer during 1988-92 (Thiros, 1995) is shown in figure 7. This map was revised with data from the Utah Division of Drinking Water (written commun., 2002), Kennecott Utah Copper Corporation (written commun., 2002), and from this study to show the distribution of dissolved-solids concentration in water from the principal aquifer during 1998-2002 (fig. 8). Most of the public-supply wells on the east side of the valley pump water with a dissolved-solids concentration of less than 500 mg/L, whereas only a few wells on the west side receive water with a dissolved-solids concentration of less than 500 mg/L. Water in the southeastern part of the aquifer generally contains less dissolved solids than the rest of the aquifer. Previous studies (Hely and others, 1971; Waddell and others, 1987b; Lambert, 1995) indicate that recharge from the mountain block in this area moves rapidly through the coarse-grained deposits near the mountain front and has less time to react with the more resistant aquifer material.

Comparison of water sampled during 1988-92 and 1998-2002 shows a reduction in the area with a dissolved-solids concentration of less than 500 mg/L (figs. 7 and 8). Ground water with a dissolved-solids concentration of less than 500 mg/L in an area extending to the northwest, past the Jordan River, receded back to the southeast likely because of pumping in the area and in upgradient areas to the southeast. Dissolved-solids concentration has increased in water from some wells located in the ground-water discharge area of the valley where the gradient has been upward between the

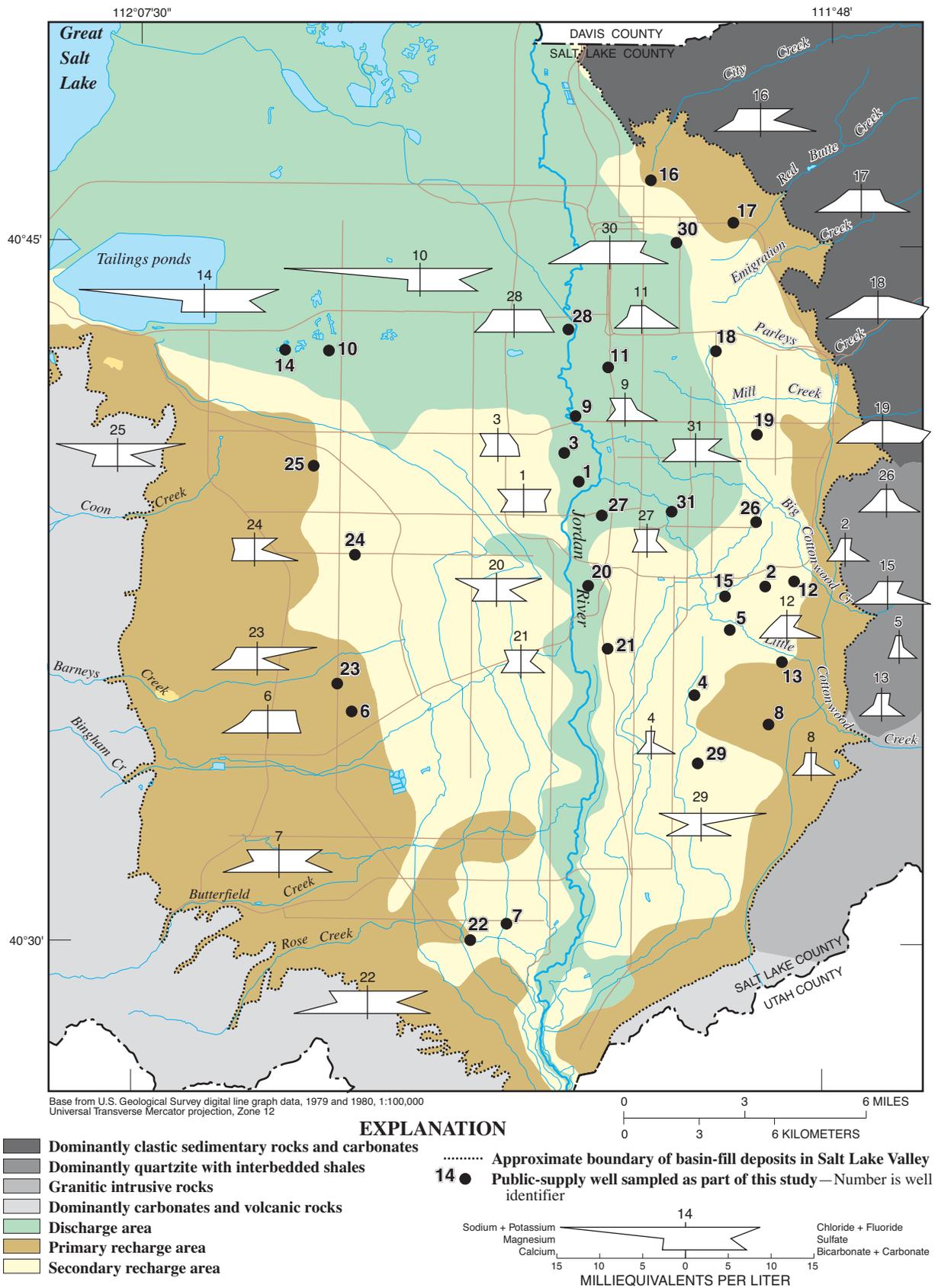
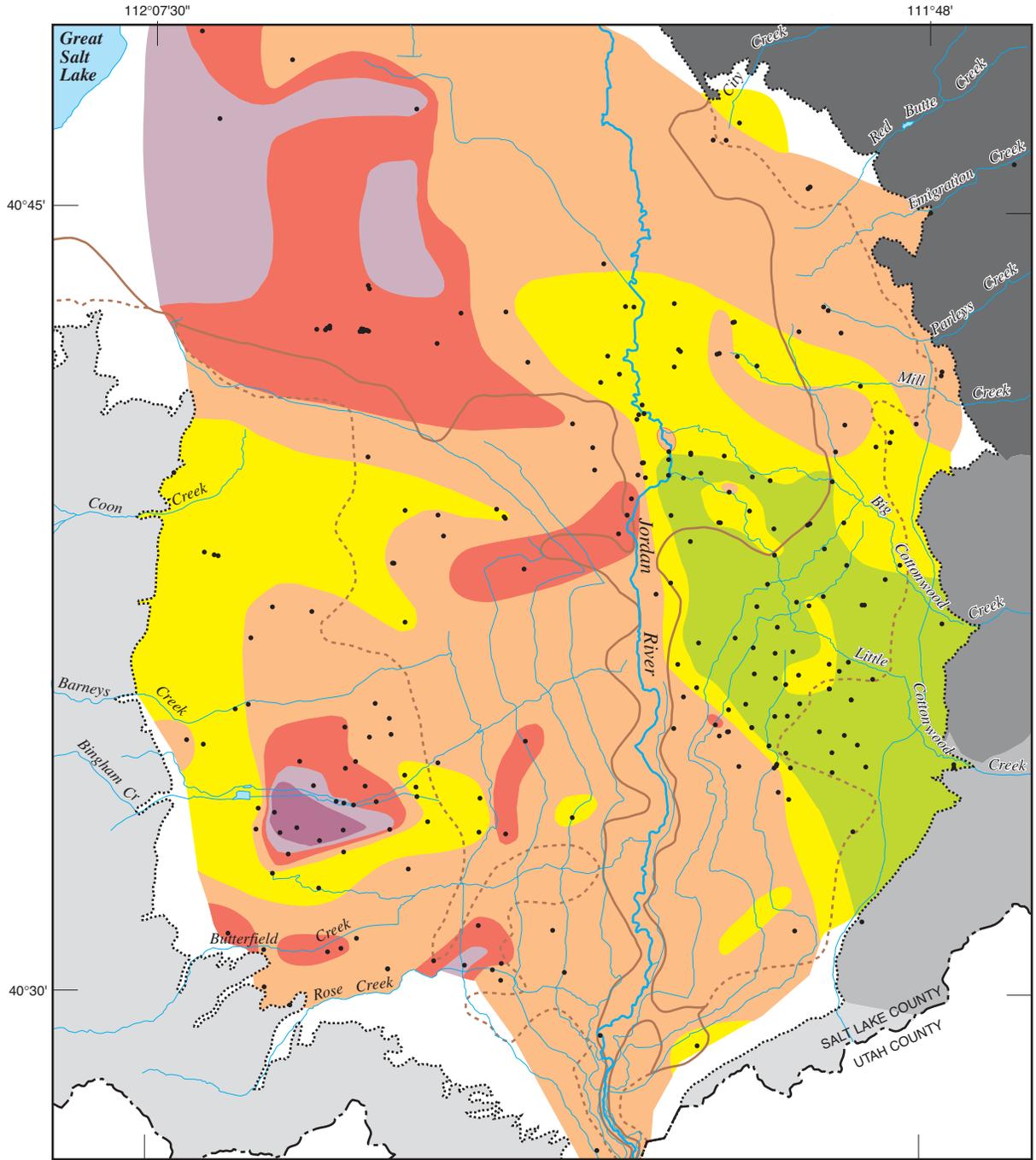


Figure 6. Map showing Major-ion composition of water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001.



Base from U.S. Geological Survey digital line graph data, 1979 and 1980, 1:100,000 Universal Transverse Mercator projection, Zone 12

EXPLANATION

- | | | | | | |
|--|--|---|---|---|---|
| Dissolved-solids concentration, in milligrams per liter, 1988-92 (Thiros, 1995) | | | | | |
| Less than 250 | 250 to 500 | 500 to 1,000 | 1,000 to 2,000 | 2,000 to 5,000 | Greater than 5,000 |
| Dominantly clastic sedimentary rocks and carbonates | Boundary between secondary recharge area and discharge area | | Boundary between primary and secondary recharge areas | | |
| Dominantly quartzite with interbedded shales | • Well used to determine the distribution of dissolved-solids concentration in water from the principal aquifer, 1988-92 (Thiros, 1995) | | | | |
| Granitic intrusive rocks | | | | | |
| Dominantly carbonates and volcanic rocks | | | | | |
| Approximate boundary of basin-fill deposits in Salt Lake Valley | | | | | |

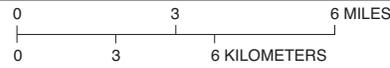
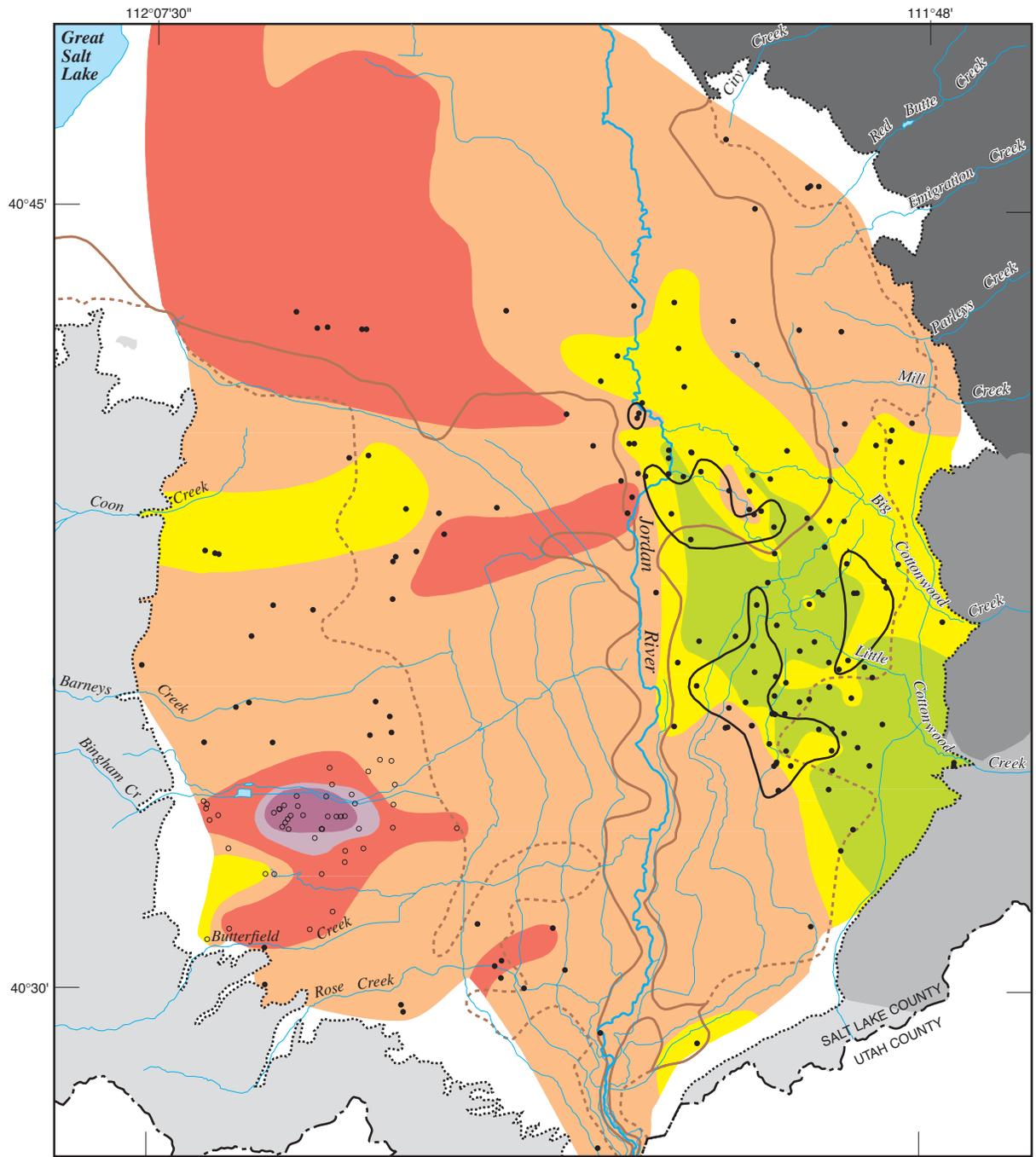


Figure 7. Map showing Dissolved-solids concentration in water sampled from the principal aquifer in Salt Lake Valley, Utah, 1988-92.



Base from U.S. Geological Survey digital line graph data, 1:100,000, 1979 and 1980
 Universal Transverse Mercator projection, Zone 12

EXPLANATION

- | | |
|---|---|
| Dissolved-solids concentration, in milligrams per liter, 1998–2002 | |
| Less than 250 | 250 to 500 |
| 500 to 1,000 | 1,000 to 2,000 |
| 2,000 to 5,000 | Greater than 5,000 |
| Dominantly clastic sedimentary rocks and carbonates | Boundary between secondary recharge area and discharge area |
| Dominantly quartzite with interbedded shales | Boundary between primary and secondary recharge areas |
| Granitic intrusive rocks | Public-supply well used to determine the distribution of dissolved-solids concentration in water from the principal aquifer during 1998–2002 |
| Dominantly carbonates and volcanic rocks | Well greater than 300 feet deep with dissolved-solids concentration data for 1998–2002 from Kennecott Utah Copper Corporation (written commun., 2002) |
| Boundary of area where the dissolved-solids concentration in water from more than one well increased 20 percent or more during 1988–2002 | |
| Approximate boundary of basin-fill deposits in Salt Lake Valley | |

0 3 3 6 MILES
 0 3 6 KILOMETERS

Figure 8. Map showing Dissolved-solids concentration in water sampled from the principal aquifer in Salt Lake Valley, Utah, 1998-2002.

principal aquifer and land surface. Ground-water withdrawals for public supply may have caused the water-level gradient to reverse, allowing more mineralized water to move from the shallow aquifer to the principal aquifer. The shallow aquifer in the area is recharged from the principal aquifer and from surface-water sources such as the Jordan River. The possibility of water movement from the shallow aquifer to the principal aquifer is discussed in more detail in the "Sources of Ground-Water Recharge" section of this report.

Fewer wells are available on the west side of the valley that are completed in the principal aquifer. Water from some west-side wells increased in dissolved-solids concentration from 1988-92 to 1998-2002, resulting in a reduction in the extent of less-than-500-mg/L water on the west side of Salt Lake Valley.

Areas encompassing more than one well where the dissolved-solids concentration in water increased 20 percent or more from 1988-92 to 1998-2002 also are shown in figure 8. Three distinct areas on the east side of the valley have undergone an increase in dissolved-solids concentration: (1) west of the mouth of Big Cottonwood Canyon near the mountain front in the primary recharge area; (2) in part of the secondary recharge area near Sandy; and (3) in part of the discharge area near Murray. Ground-water withdrawals from wells may have caused the vertical or lateral gradients to change, which could allow water with a higher dissolved-solids concentration to reach the wells in these areas.

Trace Elements

Concentrations of the trace elements molybdenum, nickel, selenium, antimony, chromium, uranium, and barium, analyzed for in water from the public-supply wells, were less than the MCLs or HALs (table 4). Silver and beryllium were analyzed for, but not detected (table 15). Arsenic and radon were detected in water from some wells at concentrations that exceeded established or proposed MCLs.

Dissolved arsenic concentrations ranged from 0.4 to 17.9 $\mu\text{g/L}$ (table 15) with a median of 1.1 $\mu\text{g/L}$ in water from the 31 public-supply wells sampled as part of this study. Concentrations in water from five wells, four of which are on the west side of the valley,

exceeded the drinking water MCL of 10 $\mu\text{g/L}$ issued by the USEPA on January 22, 2001 (U.S. Environmental Protection Agency, 2001).

Data for wells accessed from the Utah Division of Drinking Water and other NAWQA studies were used to augment the data collected as part of this study and to show the distribution of arsenic in the principal aquifer in the valley (fig. 9). Water from wells in much of the western part of the valley generally had higher arsenic concentrations than other areas. This may be related to more arsenic-bearing minerals in the fine-grained deposits in this area coupled with less recharge available to transport arsenic through the system.

Dissolved-uranium concentration in water from the public-supply wells ranged from 0.04 to 15.1 $\mu\text{g/L}$ with a median value of 3.10 $\mu\text{g/L}$. The MCL for uranium of 30 $\mu\text{g/L}$ (U.S. Environmental Protection Agency, 2002) was not exceeded. Uranium is soluble under oxidizing conditions and because of its long half life (4.5×10^9 years) can be present in ground water farther from its source areas than can radon, which has a much shorter half life. Uranium is concentrated in the sediment in reducing environments as a result of mineral precipitation. The low uranium concentration in water from wells 9 and 28 in the discharge area (0.04 and 0.08 $\mu\text{g/L}$, respectively) is related to reducing conditions. The relatively high uranium concentration in water from well 29 (15.1 $\mu\text{g/L}$) may result from its proximity to intrusive rocks in the Wasatch Range coupled with oxidizing conditions.

Radon occurs naturally as a gas that is soluble in ground water and is released through radioactive decay from rocks containing uranium. It is the direct result of decay of radium-226, a decay product of uranium-238. Greater amounts of radon occur in areas with uranium-rich sources such as granite, some metamorphic rocks, and basin-fill deposits weathered from these rocks. Because of a short half-life of 3.8 days, radon generally is detected near its source. The amount of radon in water is reported in terms of activity where 1 pCi/L is about equal to the decay of two atoms of radon per minute in a liter of water. Radon moves more easily through highly permeable material, such as sand, gravel, and fractures, and readily degasses from water exposed to air. Breathing radon in indoor air is the second leading cause of lung cancer and is a greater health concern than drinking water that contains radon (U.S. Environmental Protection Agency, 1999). The USEPA's proposed MCL for radon in drinking water is

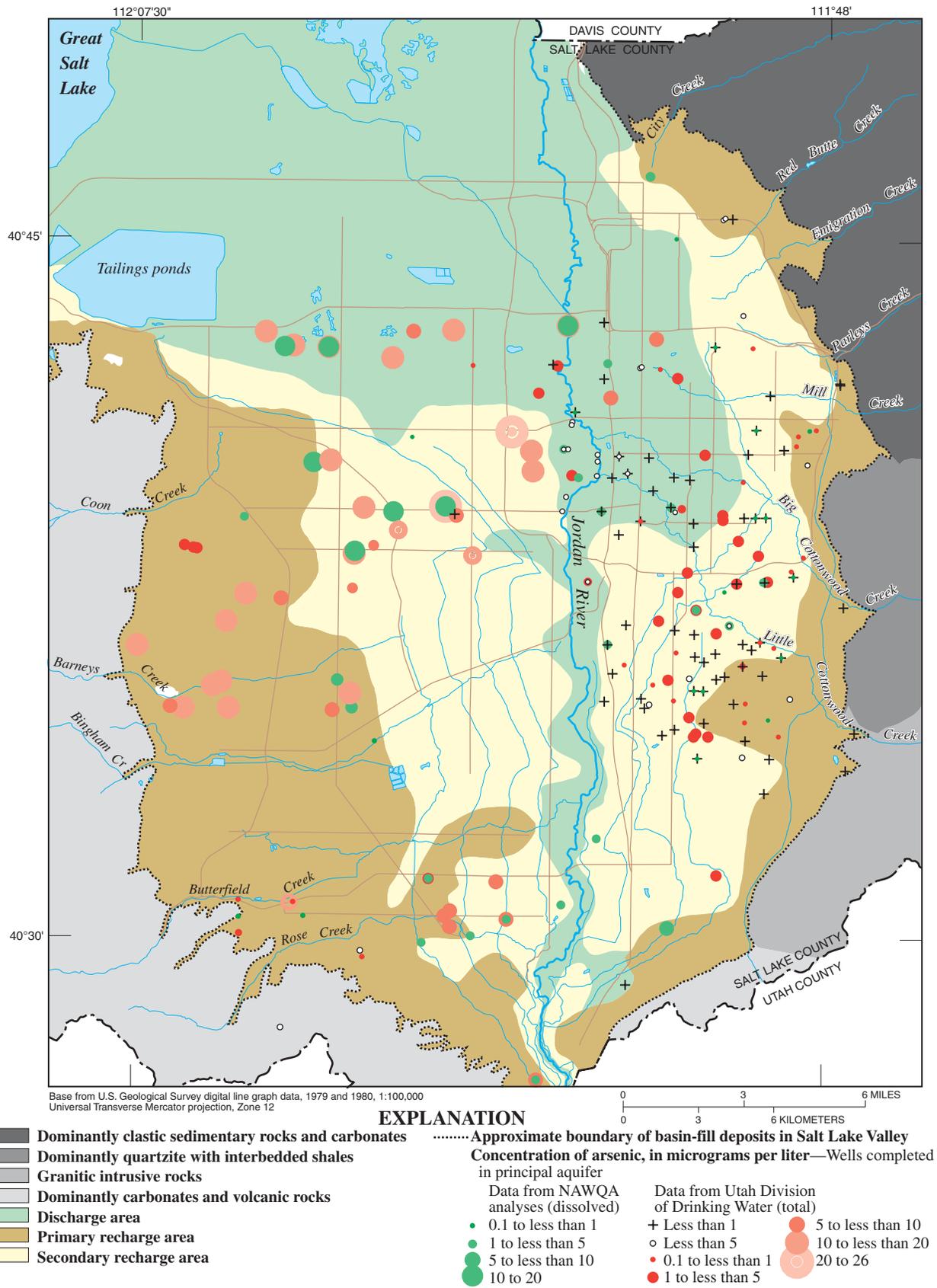


Figure 9. Map showing Arsenic concentration in water sampled from the principal aquifer in Salt Lake Valley, Utah.

300 pCi/L (U.S. Environmental Protection Agency, 2002). The USEPA proposed rule for radon allows States and community-water systems to use an alternative standard of 4,000 pCi/L if they implement a program to address radon risks in indoor air.

Radon concentration in water from the 31 wells ranged from 251 to 1,980 pCi/L (fig. 10 and table 15), with a median value of 702 pCi/L. Water from wells in the discharge area near the Jordan River had the lowest radon concentrations because of distance from uranium-bearing rocks. The highest concentration was in water from well 13 near the mountain front south of Little Cottonwood Canyon where the mountain block is composed of quartzite and quartz monzonite.

Nutrient Constituents and Dissolved Organic Carbon

Although the nutrients nitrogen and phosphorus can occur naturally in ground water, elevated concentrations in ground water generally are thought to be caused by human activities. Some of the potential sources of nutrients in ground water include fertilizers applied to lawns and gardens and leaking or improperly functioning septic systems and sewer pipes. Nitrogen compounds such as ammonia and ammonium fertilizers naturally transform into nitrate, which is relatively stable in oxygenated subsurface environments and is readily transported in water. Nitrite is unstable in oxygenated water and is seldom present in measurable concentrations under oxidizing conditions. In this report, nitrate is reported as the sum of nitrite and nitrate as nitrogen. Nationally, background nitrate concentrations in ground water from areas not associated with agricultural practices commonly are less than 2 to 3 mg/L as nitrogen (Halberg and Keeney, 1993, p. 316), and concentrations greater than 2 mg/L may indicate effects of human activities (U.S. Geological Survey, 1999, p. 34). The national background concentration of nitrate was estimated on the basis of samples collected from undeveloped areas that are considered to be minimally affected by agriculture, urbanization, and associated land uses.

Nitrate concentration in water sampled from 12 of the 31 public-supply wells (39 percent) was higher than the estimated background level of 2 mg/L, indicating a likely human influence. Concentrations ranged from less than 0.026 to 5.99 mg/L (fig. 11 and table 16), less than the MCL of 10 mg/L (U.S. Environmen-

tal Protection Agency, 2002). The median nitrate concentration for water from public-supply wells on the east side of the valley was 1.21 mg/L compared to 3.12 mg/L on the west side.

Concentrations of nitrite, ammonia, ammonia plus organic nitrogen, phosphorus, and orthophosphorus in water from the public-supply wells were low, two to three orders of magnitude less than MCLs or HALs, where applicable. Ammonia concentrations greater than 0.1 mg/L were measured in water from three wells, all of which were under reducing conditions. Water from one well (well 28) had a phosphorus concentration greater than 0.1 mg/L (0.132 mg/L).

The presence of MBAS (methylene blue active substances) can be used as an indicator of contamination from wastewater because these substances generally are contained in soaps and detergents. MBAS concentrations in water samples from the public-supply wells were less than the reporting limit, except in water from two wells with concentrations of about 0.02 mg/L (wells 8 and 23) (table 16). The low MBAS concentrations coupled with nitrate concentrations above estimated background levels indicate that water from leaking sewer lines may possibly reach parts of the principal aquifer in the area of these wells.

DOC (dissolved organic carbon) can affect ground-water quality because it is involved in oxidation/reduction reactions with chemical constituents of the aquifer material and ground water. The median DOC concentration in water from the public-supply wells was less than 0.30 mg/L and ranged from less than 0.15 to 1.2 mg/L (tables 4 and 16).

Pesticides

Much lower analytical reporting levels were used in this study than are typically used in routine pesticide monitoring of public-water supplies. Therefore, higher rates of detection were obtained than would have been possible with less sensitive analytical methods. The MRL for atrazine is 0.007 µg/L, about two orders of magnitude lower than that used on water from drinking-water wells for the USEPA's National Pesticide Survey done during 1988-90 (Barbash and others, 1999, p. 8).

Four of the 103 pesticides and pesticide degradation products analyzed for (atrazine, deethylatrazine (DEA), deethyldeisopropylatrazine, and imazethapyr) were detected in 1 or more water samples collected as

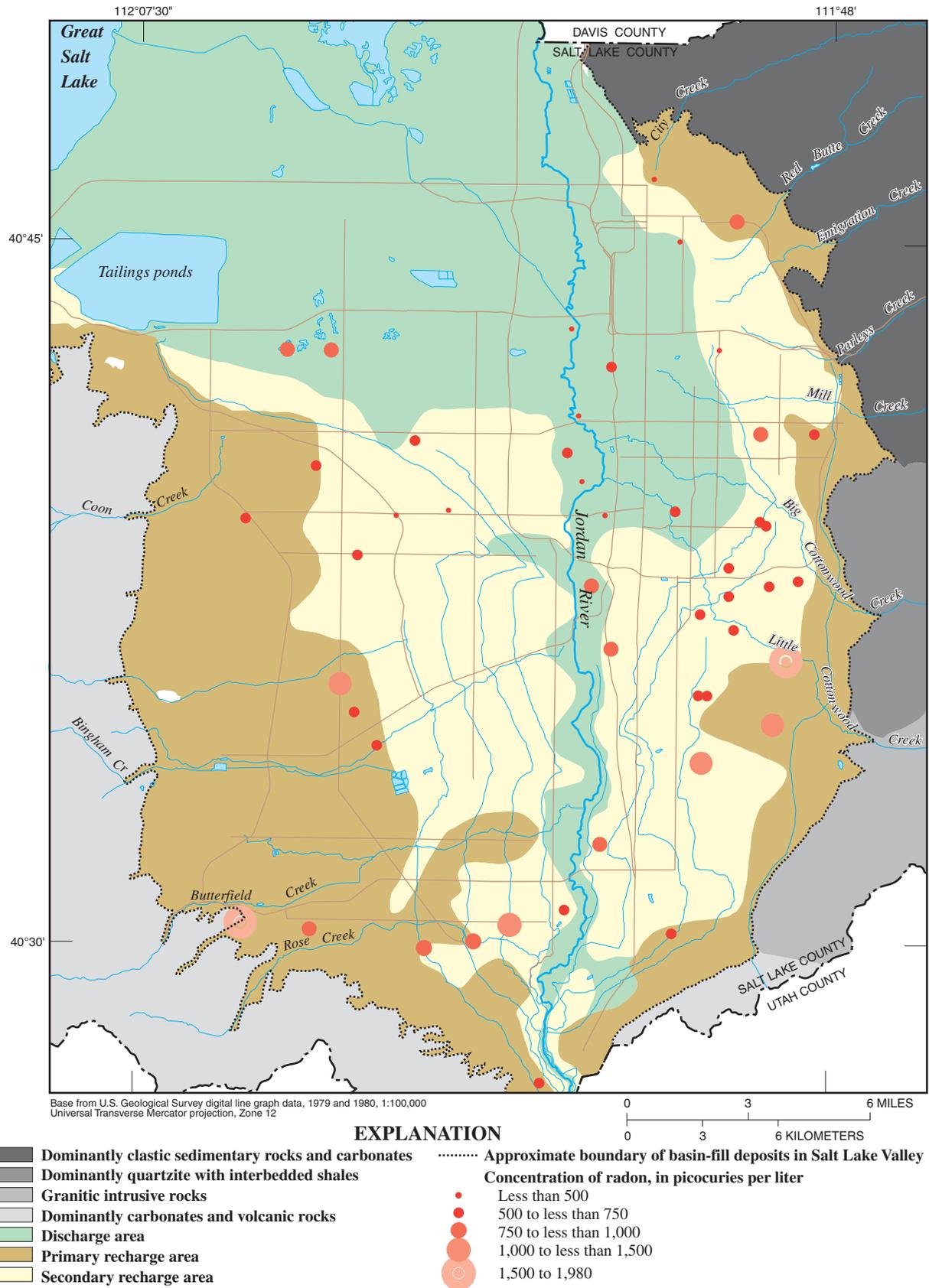


Figure 10. Map showing Radon concentration in water sampled from the principal aquifer in Salt Lake Valley, Utah, 1998-2001.

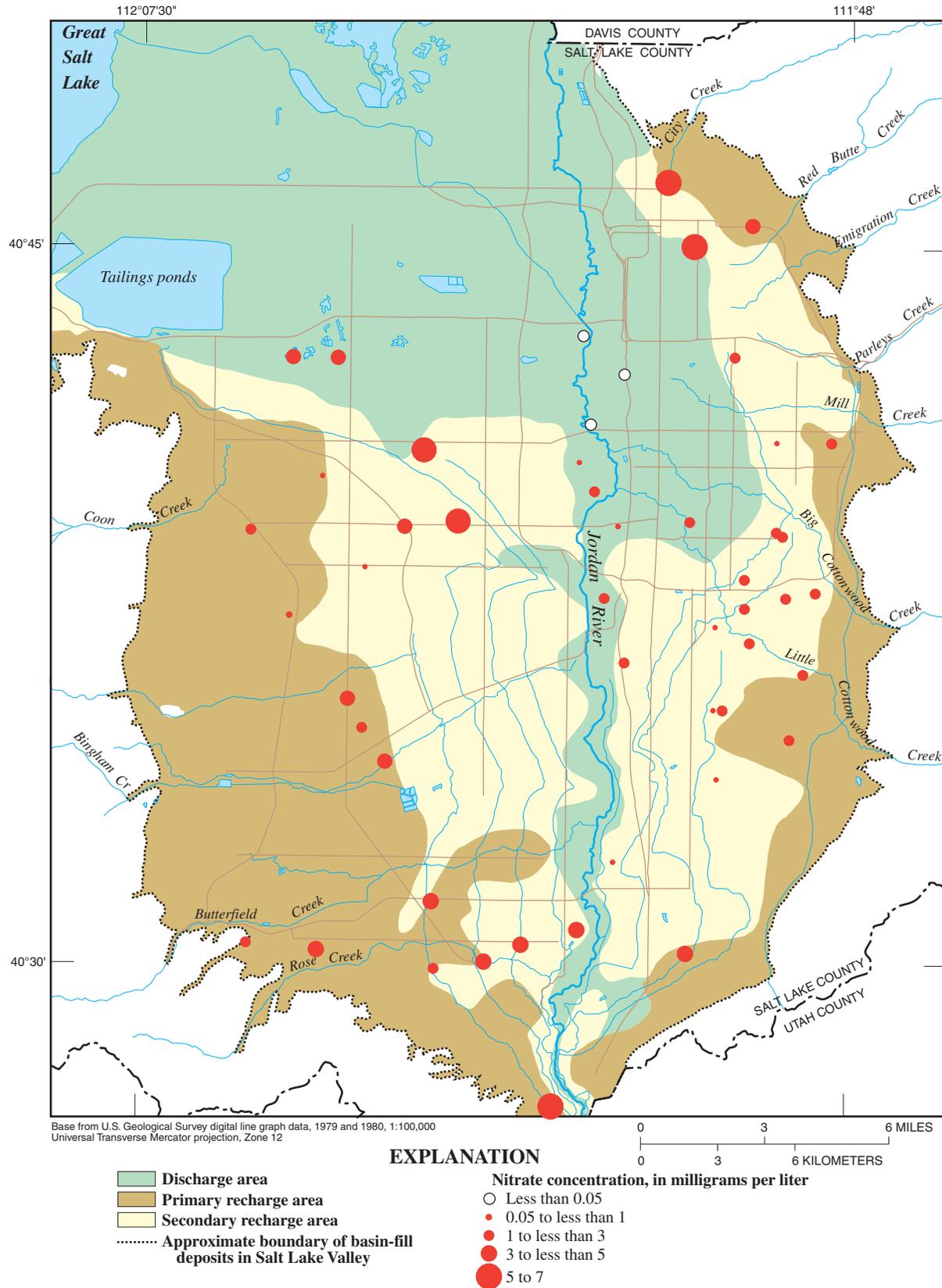


Figure 11. Map showing Nitrate concentration in water sampled from the principal aquifer in Salt Lake Valley, Utah, 1998-2001.

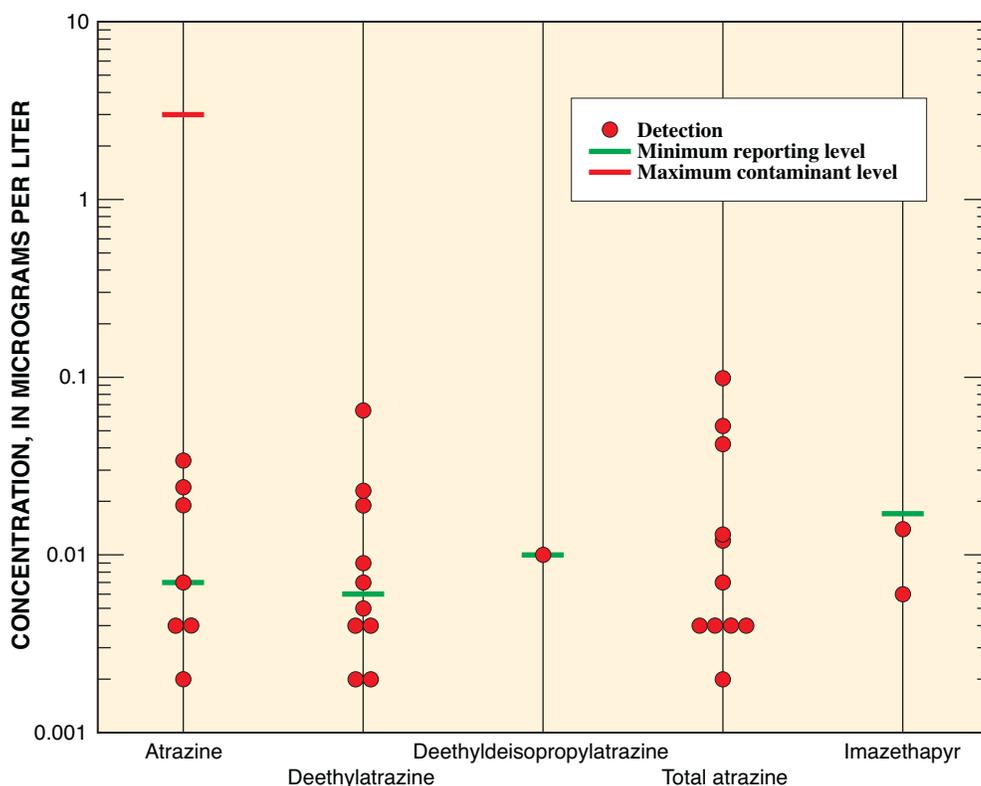


Figure 12. Graph showing Concentration of selected pesticides in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001.

part of this study (table 5, fig. 12). Degradation products of pesticides (metabolites or degradates) are formed through the metabolic breakdown of a parent compound. All of the pesticides analyzed for as part of this study are listed in table 7. At least 1 of the 4 pesticides or pesticide degradation products was detected in water from 13 of the 31 wells sampled (table 17). None of the pesticide concentrations exceeded USEPA drinking-water standards or guidelines (U.S. Environmental Protection Agency, 2002), although atrazine was the only compound detected that has an established standard.

The herbicide atrazine was detected in seven samples. Atrazine is a restricted-use pesticide that is generally used on corn and other row crops in agricultural areas and along roads, railroads, other rights-of-way, utility substations, and industrial lots to control weeds and undesired vegetation. It is not available for household use. Atrazine concentrations detected in

water from the 31 wells sampled ranged from an estimated 0.002 to 0.034 µg/L (fig. 12), all less than the drinking-water MCL of 3 µg/L (U.S. Environmental Protection Agency, 2002). Atrazine was detected in 5 of 8 wells sampled on the west side of the valley and in 2 of 23 wells on the east side. The relatively high detection frequency of atrazine in water samples from the west side of Salt Lake Valley may be the result of its application in agricultural or industrial areas that may also be recharge areas.

The degradation products of atrazine, deethylatrazine and deethyldeisopropylatrazine, were detected in 10 samples and 1 sample, respectively. The total concentration of atrazine and its degradation products in water samples from this study with detections ranged from an estimated 0.002 µg/L to 0.099 µg/L (figs. 12 and 13). The presence of atrazine and its degradation products in ground water is likely the result of widespread use rather than small-scale point sources

Table 7. Pesticides and degradation products analyzed for in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001

[Parameter code is used in U.S. Geological Survey National Water Information System database; minimum reporting level in micrograms per liter; LRL, laboratory reporting level; MRL, minimum reporting level; —, registry number not available]

Compound	Parameter code	Chemical Abstracts Service registry number	Minimum reporting level	Reporting level type	Compound	Parameter code	Chemical Abstracts Service registry number	Minimum reporting level	Reporting level type
Gas Chromatography/Mass Spectrometry analytical method					Gas Chromatography/Mass Spectrometry analytical method—Continued				
2,6-Diethylaniline	82660	579-66-8	0.002	LRL	Triallate	82678	2303-17-5	.002	LRL
Acetochlor	49260	34256-82-1	.004	LRL	Trifluralin	82661	1582-09-8	.009	LRL
Alachlor	46342	15972-60-8	.002	LRL	High-Performance Liquid Chromatography analytical method				
alpha-HCH	34253	319-84-6	.005	LRL	2,4-D	39732	94-75-7	.02	MRL
Atrazine	39632	1912-24-9	.007	LRL	2,4-D methyl ester	50470	1928-38-7	.009	MRL
Azinphos-methyl	82686	86-50-0	.050	LRL	2,4-DB	38746	94-82-6	.02	MRL
Benfluralin	82673	1861-40-1	.010	LRL	2-Hydroxyatrazine	50355	2163-68-0	.008	MRL
Butylate	04028	2008-41-5	.002	MRL	3(4-Chlorophenyl)-1-methyl urea	61692	5352-88-5	.024	MRL
Carbaryl	82680	63-25-2	.041	LRL	3-Hydroxycarbofuran	49308	16655-82-6	.01	MRL
Carbofuran	82674	1563-66-2	.020	LRL	3-Ketocarbofuran	50295	16709-30-1	1.50	MRL
Chlorpyrifos	38933	2921-88-2	.005	LRL	Acifluorfen	49315	50594-66-6	.01	MRL
cis-Permethrin	82687	54774-45-7	.006	LRL	Aldicarb	49312	116-06-3	.04	MRL
Cyanazine	04041	21725-46-2	.018	LRL	Aldicarb sulfone	49313	1646-88-4	.02	MRL
Dacthal	82682	1861-32-1	.003	LRL	Aldicarb sulfoxide	49314	1646-87-3	.01	MRL
Deethylatrazine	04040	6190-65-4	.006	LRL	Atrazine	39632	1912-24-9	.009	MRL
Diazinon	39572	333-41-5	.005	LRL	Bendiocarb	50299	22781-23-3	.025	MRL
Dieldrin	39381	60-57-1	.005	LRL	Benomyl	50300	17804-35-2	.004	MRL
Disulfoton	82677	298-04-4	.021	LRL	Bensulfuron-methyl	61693	83055-99-6	.016	MRL
EPTC	82668	759-94-4	.002	LRL	Bentazon	38711	25057-89-0	.01	MRL
Ethalfuralin	82663	55283-68-6	.009	LRL	Bromacil	04029	314-40-9	.03	MRL
Ethoprophos	82672	13194-48-4	.005	LRL	Bromoxynil	49311	1689-84-5	.02	MRL
Fonofos	04095	944-22-9	.003	LRL	Caffeine	50305	58-08-2	.010	MRL
Lindane	39341	58-89-9	.004	LRL	Carbaryl	49310	63-25-2	.03	MRL
Linuron	82666	330-55-2	.035	LRL	Carbofuran	49309	1563-66-2	.01	MRL
Malathion	39532	121-75-5	.027	LRL	Chloramben methyl ester	61188	7286-84-2	.02	MRL
Metolachlor	39415	51218-45-2	.013	LRL	Chlorimuron-ethyl	50306	90982-32-4	.010	MRL
Metribuzin	82630	21087-64-9	.006	LRL	Chlorothalonil	49306	1897-45-6	.04	MRL
Molinate	82671	2212-67-1	.002	LRL	Clopyralid	49305	1702-17-6	.01	MRL
Napropamide	82684	15299-99-7	.007	LRL	Cycloate	04031	1134-23-2	.01	MRL
p,p'-DDE	34653	72-55-9	.003	LRL	Dacthal monoacid	49304	887-54-7	.01	MRL
Parathion	39542	56-38-2	.007	LRL	Deethylatrazine	04040	6190-65-4	.03	MRL
Parathion-methyl	82667	298-00-0	.006	LRL	Deethyldeisopropylatrazine	04039	3397-62-4	.01	MRL
Pebulate	82669	1114-71-2	.002	LRL	Deisopropylatrazine	04038	1007-28-9	.04	MRL
Pendimethalin	82683	40487-42-1	.010	LRL	Dicamba	38442	1918-00-9	.01	MRL
Phorate	82664	298-02-2	.011	LRL	Dichlorprop	49302	120-36-5	.01	MRL
Prometon	04037	1610-18-0	.015	LRL	Dinoseb	49301	88-85-7	.01	MRL
Propachlor	04024	1918-16-7	.010	LRL	Diphenamid	04033	957-51-7	.03	MRL
Propanil	82679	709-98-8	.011	LRL	Diuron	49300	330-54-1	.01	MRL
Propargite	82685	2312-35-8	.023	LRL	Fenuron	49297	101-42-8	.03	MRL
Propyzamide	82676	23950-58-5	.004	LRL	Flumetsulam	61694	98967-40-9	.011	MRL
Simazine	04035	122-34-9	.011	LRL	Fluometuron	38811	2164-17-2	.03	MRL
Tebuthiuron	82670	34014-18-1	.016	LRL	Imazaquin	50356	81335-37-7	.016	MRL
Terbacil	82665	5902-51-2	.034	LRL	Imazethapyr	50407	81335-77-5	.017	MRL
Terbufos	82675	13071-79-9	.017	LRL					
Thiobencarb	82681	28249-77-6	.005	LRL					

Table 7. Pesticides and degradation products analyzed for in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001—Continued

Compound	Parameter code	Chemical Abstracts Service registry number	Minimum reporting level	Reporting level type
High-Performance Liquid Chromatography analytical method—Continued				
Imidacloprid	61695	138261-41-3	.007	MRL
Linuron	38478	330-55-2	.01	MRL
MCPA	38482	94-74-6	.02	MRL
MCPB	38487	94-81-5	.01	MRL
Metalaxyl	50359	57837-19-1	.020	MRL
Methiocarb	38501	2032-65-7	.01	MRL
Methomyl	49296	16752-77-5	.004	MRL
Methomyl oxime	61696	13749-94-5	.011	MRL
Metsulfuron methyl	61697	74223-64-6	.025	MRL
Neburon	49294	555-37-3	.01	MRL
Nicosulfuron	50364	111991-09-4	.013	MRL
Norflurazon	49293	27314-13-2	.02	MRL
Oryzalin	49292	19044-88-3	.02	MRL
Oxamyl	38866	23135-22-0	.01	MRL
Oxamyl oxime	50410	30558-43-1	.013	MRL
Picloram	49291	—	.02	MRL
Propham	49236	122-42-9	.01	MRL
Propiconazole	50471	60207-90-1	.021	MRL
Propoxur	38538	114-26-1	.01	MRL
Siduron	38548	1982-49-6	.017	MRL
Sulfometuron-methyl	50337	74222-97-2	.009	MRL
Tebuthiuron	82670	34014-18-1	.006	MRL
Terbacil	04032	5902-51-2	.01	MRL
Tribenuron-methyl	61159	101200-48-0	.01	MRL
Triclopyr	49235	55335-06-3	.02	MRL

such as spills, although it probably is transported to the ground-water system by more direct sources of recharge, such as seepage from drainage systems and retention basins. Imazethapyr, an herbicide used to control grasses and broadleaf weeds, was detected at very low concentrations in water sampled from two wells (fig. 12 and table 17).

Volatile Organic Compounds

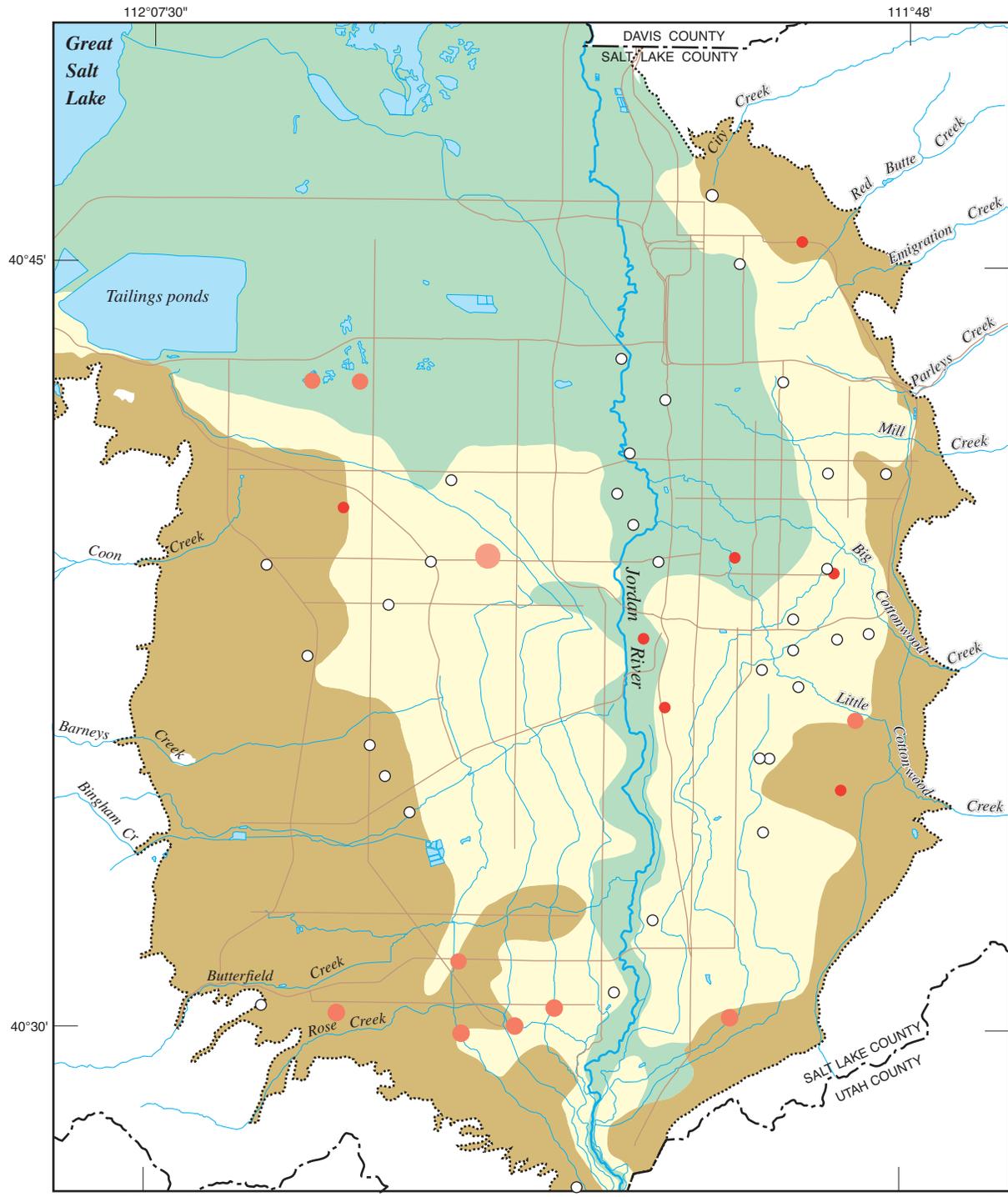
VOCs are carbon-containing chemicals that readily evaporate at normal air temperature and pressure. They are contained in many manufactured products such as gasoline, paints, adhesives, solvents, wood preservatives, dry cleaning agents, pesticides, fertilizers, cosmetics, and refrigerants. Potential sources of

VOCs to ground water are direct industrial and wastewater discharges, infiltration of spills, leaking underground storage tanks, runoff to storm drains, septic systems, leaking sewer lines, and atmospheric deposition of vehicle and industrial emissions. The U.S. Environmental Protection Agency (2002) has established MCLs in drinking water for more than 20 VOCs because of human health concerns.

Eleven of the 85 VOCs analyzed for were detected in one or more of the water samples collected from the 31 public-supply wells (table 6, fig. 14, and table 18). All of the VOCs analyzed for as part of this study are listed in table 8. Detection of many VOCs is the result of improved analytical methods that allow measurement of lower concentrations (Conner and others, 1998). The most frequently detected VOCs were chloroform (54.8 percent), bromodichloromethane (35.5 percent), and 1,1,1-trichloroethane (19.4 percent).

Chloroform and bromodichloromethane are byproducts of chlorinated ground and surface water that has reacted with organic material in the water and aquifer material and are part of a group of VOCs known as trihalomethanes (THMs). These disinfection byproducts are regulated by the USEPA as total THMs with a cumulative MCL of 80 µg/L (U.S. Environmental Protection Agency, 2002, p. 2). The MCL primarily applies to water sampled from distribution lines and at taps after being chlorinated. Widespread occurrence of chloroform and bromodichloromethane in ground water is likely a result of the recharge of chlorinated public-supply water used to irrigate lawns and gardens in residential areas of Salt Lake Valley. Water disinfected for public supply also can enter the ground-water system through leaking water lines, sewer lines, and swimming pools.

Chloroform and bromodichloromethane were detected together in water from 11 wells and neither was detected in water from 14 wells. The median chloroform concentration in water from the 31 public-supply wells was less than 0.02 µg/L, whereas the median concentration in 17 samples with detections was 0.37 µg/L. Total THM (chloroform, bromodichloromethane, and chlorodibromomethane) concentration in samples with detections ranged from an estimated 0.01 µg/L to 26.1 µg/L, less than the MCL. Wells 8 and 13, in and near the primary recharge area on the east side of the valley, had the highest THM concentrations (14.4 and 26.1 µg/L, respectively) because they also



Base from U.S. Geological Survey digital line graph data, 1979 and 1980, 1:100,000
 Universal Transverse Mercator projection, Zone 12

EXPLANATION

- Discharge area
- Primary recharge area
- Secondary recharge area
- Approximate boundary of basin-fill deposits in Salt Lake Valley

- Total concentration of atrazine and its degradation products, in micrograms per liter**
- Not detected
 - 0.002 to less than 0.01
 - 0.01 to less than 0.1
 - 0.1 to 1.0

Figure 13. Map showing Total concentration of atrazine and its degradation products in water sampled from the principal aquifer in Salt Lake Valley, Utah, 1998-2001.

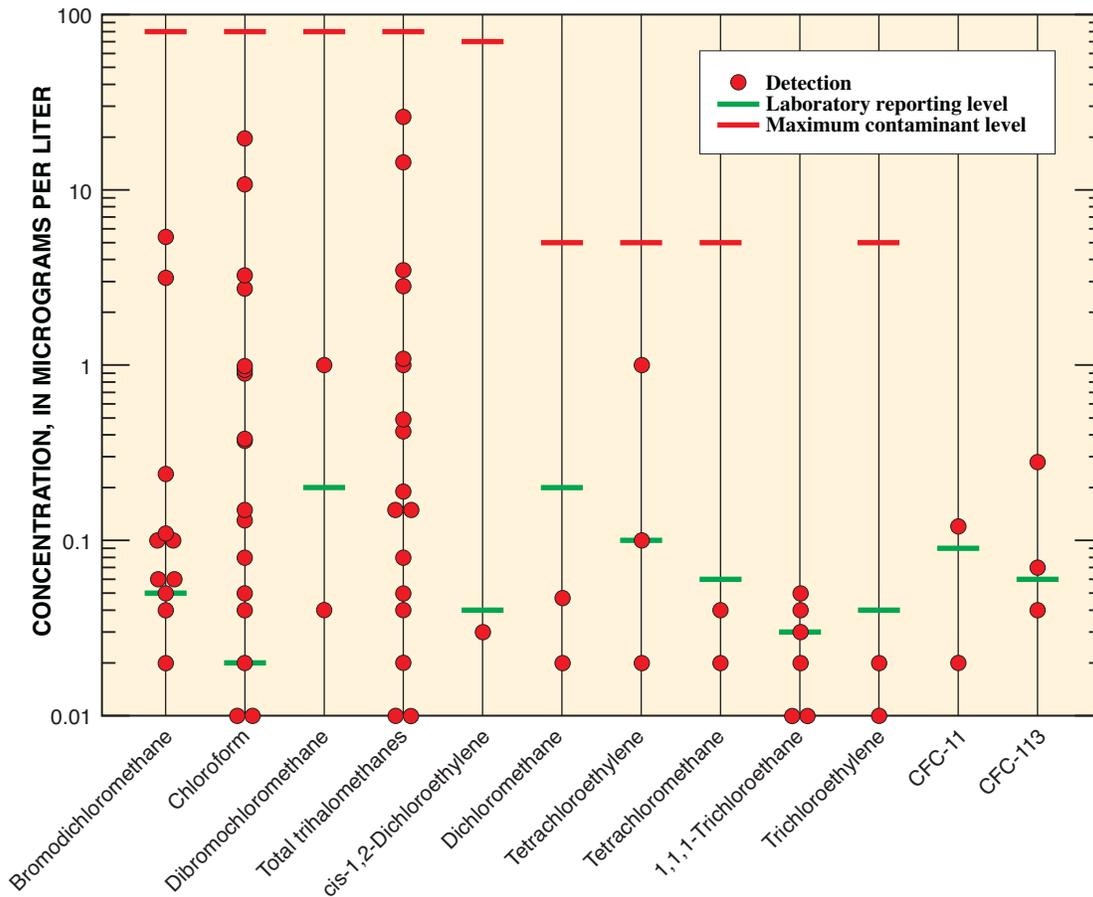


Figure 14. Graph showing Concentration of selected volatile organic compounds in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001.

inject chlorinated surface water into the aquifer during parts of the year. Chloroform concentration in these wells is greater than 10 µg/L (fig. 15). This water is stored in the aquifer and the wells are used to withdraw water during peak water-use periods.

1,1,1-trichloroethane (methyl chloroform, TCA) was detected in water from six wells at estimated concentrations ranging from 0.01 µg/L to 0.05 µg/L. It is generally used as a solvent and has an MCL of 200 µg/L. 1,1,1-trichloroethane was detected with other VOCs in samples from five of the public-supply wells and in shallow ground water in Salt Lake Valley (Thiros, 2003), indicating movement from land surface or the shallow aquifer. It was the only VOC detected in the water sample from well 1 in the discharge area,

where VOCs were not detected in water from other sampled wells. Pumping in the area may have reversed the water-level gradient around the well, allowing shallow ground water to move to the principal aquifer.

Tetrachloroethylene (tetrachloroethene, perchloroethylene (PCE)), primarily used as a dry cleaning agent, was detected in water from three wells with a maximum concentration of 1 µg/L. The MCL for PCE in drinking water is 5 µg/L (U.S. Environmental Protection Agency, 2002). Trichloroethylene (trichloroethene (TCE)), also used as a dry cleaning agent and solvent, was detected in two of the water samples that contained PCE (wells 4 and 17). TCE can be formed from the degradation of PCE by bacteria under reducing conditions.

Table 8. Volatile organic compounds analyzed for in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001

[Parameter code is used in U.S. Geological Survey National Water Information System database; Laboratory reporting level in micrograms per liter; —, registry number not available]

Compound	Parameter code	Chemical Abstracts Service registry number	Laboratory reporting level	Compound	Parameter code	Chemical Abstracts Service registry number	Laboratory reporting level
1,1,1,2-Tetrachloroethane	77562	630-20-6	0.03	Chloroethane	34311	75-00-3	.1
1,1,1-Trichloroethane	34506	71-55-6	.03	Chloroform	32106	67-66-3	.02
1,1,2,2-Tetrachloroethane	34516	79-34-5	.09	Chloromethane	34418	74-87-3	.2
1,1,2-Trichloroethane	34511	79-00-5	.06	Dibromochloromethane	32105	124-48-1	.2
1,1,2-Trichlorotrifluoroethane	77652	76-13-1	.06	Dibromomethane	30217	74-95-3	.05
1,1-Dichloroethane	34496	75-34-3	.04	Dichlorodifluoromethane	34668	75-71-8	.3
1,1-Dichloroethylene	34501	75-35-4	.04	Dichloromethane	34423	75-09-2	.2
1,1-Dichloropropene	77168	563-58-6	.03	Diethyl ether	81576	60-29-7	.2
1,2,3,4-Tetramethylbenzene	49999	488-23-3	.2	Diisopropyl ether	81577	108-20-3	.1
1,2,3,5-Tetramethylbenzene	50000	527-53-7	.2	Ethyl methacrylate	73570	97-63-2	.2
1,2,3-Trichlorobenzene	77613	87-61-6	.3	Ethyl tert-butyl ether	50004	637-92-3	.05
1,2,3-Trichloropropane	77443	96-18-4	.2	Ethylbenzene	34371	100-41-4	.03
1,2,3-Trimethylbenzene	77221	526-73-8	.1	Hexachlorobutadiene	39702	87-68-3	.1
1,2,4-Trichlorobenzene	34551	120-82-1	.2	Hexachloroethane	34396	67-72-1	.2
1,2,4-Trimethylbenzene	77222	95-63-6	.06	Isopropylbenzene	77223	98-82-8	.03
1,2-Dibromo-3-chloropropane	82625	96-12-8	.2	Methyl acrylate	49991	96-33-3	1
1,2-Dibromoethane	77651	106-93-4	.04	Methyl acrylonitrile	81593	126-98-7	.6
1,2-Dichlorobenzene	34536	95-50-1	.03	Methyl iodide	77424	74-88-4	.1
1,2-Dichloroethane	32103	107-06-2	.1	Methyl methacrylate	81597	80-62-6	.3
1,2-Dichloropropane	34541	78-87-5	.03	Naphthalene	34696	91-20-3	.2
1,3,5-Trimethylbenzene	77226	108-67-8	.04	Styrene	77128	100-42-5	.04
1,3-Dichlorobenzene	34566	541-73-1	.03	Tetrachloroethylene	34475	127-18-4	.1
1,3-Dichloropropane	77173	142-28-9	.1	Tetrachloromethane	32102	56-23-5	.06
1,4-Dichlorobenzene	34571	106-46-7	.05	Tetrahydrofuran	81607	109-99-9	2
2,2-Dichloropropane	77170	594-20-7	.05	Toluene	34010	108-88-3	.05
2-Butanone	81595	78-93-3	2	Trichloroethylene	39180	79-01-6	.04
2-Chlorotoluene	77275	95-49-8	.03	Trichlorofluoromethane	34488	75-69-4	.09
2-Hexanone	77103	591-78-6	.7	Vinyl bromide	50002	593-60-2	.1
3-Chloropropene	78109	107-05-1	.1	Vinyl chloride	39175	75-01-4	.1
4-Chlorotoluene	77277	106-43-4	.06	cis-1,2-Dichloroethylene	77093	156-59-2	.04
4-Isopropyl-1-methylbenzene	77356	99-87-6	.07	cis-1,3-Dichloropropene	34704	10061-01-5	.09
4-Methyl-2-pentanone	78133	108-10-1	.4	m- and p-Xylene	85795	—	.06
Acetone	81552	67-64-1	7	n-Propylbenzene	77224	103-65-1	.04
Acrylonitrile	34215	107-13-1	1	o-Ethyl toluene	77220	611-14-3	.06
Benzene	34030	71-43-2	.04	o-Xylene	77135	95-47-6	.04
Bromobenzene	81555	108-86-1	.04	sec-Butylbenzene	77350	135-98-8	.03
Bromochloromethane	77297	74-97-5	.04	tert-Butyl methyl ether	78032	1634-04-4	.2
Bromodichloromethane	32101	75-27-4	.05	tert-Butylbenzene	77353	98-06-6	.06
Bromoform	32104	75-25-2	.06	tert-Pentyl methyl ether	50005	994-05-8	.1
Bromomethane	34413	74-83-9	.3	trans-1,2-Dichloroethylene	34546	156-60-5	.03
Butylbenzene	77342	104-51-8	.2	trans-1,3-Dichloropropene	34699	10061-02-6	.09
Carbon disulfide	77041	75-15-0	.07	trans-1,4-Dichloro-2-butene	73547	110-57-6	.7
Chlorobenzene	34301	108-90-7	.03				

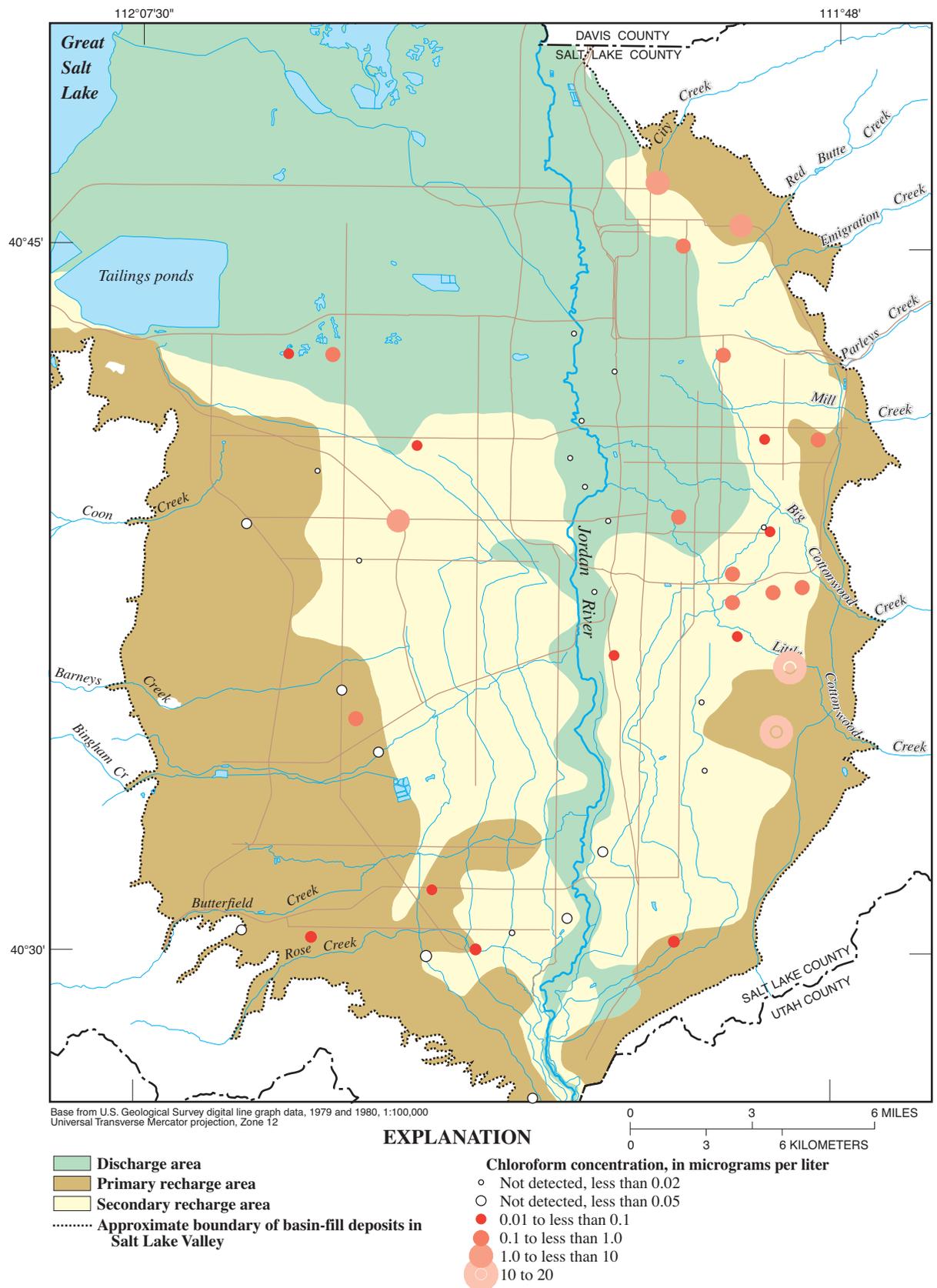


Figure 15. Map showing Chloroform concentration in water sampled from the principal aquifer in Salt Lake Valley, Utah, 1998-2001.

Leaking underground storage tanks commonly are a source of shallow ground-water contamination from the VOCs benzene, toluene, ethylbenzene, and xylene (BTEX). These gasoline-derived compounds were not detected in the water samples from the public-supply wells in Salt Lake Valley, except for a trace amount of benzene in water from well 25. This well is more than 1,200 ft deep, and environmental-tracer data indicate that the water was recharged prior to the 1950s. Therefore, the benzene detected in water from well 25 may be a result of contamination during sampling. Natural attenuation likely removes most of the BTEX compounds before they reach the principal aquifer.

SOURCES OF GROUND-WATER RECHARGE

Environmental tracers were used to determine the sources of recharge to the principal aquifer. The stable isotopes of water (deuterium and oxygen-18) and recharge temperatures computed from dissolved noble gases in the ground water were used to differentiate between water that enters the ground-water system in the valley (valley recharge) and subsurface inflow from the adjacent mountains (mountain-block recharge). Tritium, ^3He , and CFCs were used to identify and date ground water recharged within the past 50 years. The location of wells completed in the principal aquifer where environmental-tracer data has been collected is shown on figure 16.

The majority of the local population resides in Salt Lake Valley, along with most of the local industry. Valley recharge therefore has a higher likelihood of containing man-made chemical compounds that are potentially harmful to human health than does mountain-block recharge. Occurrence of such compounds in the shallow aquifer, which receives valley recharge, at levels exceeding USEPA drinking-water standards is well documented (Thiros, 2003; Seiler and Waddell, 1984). Wells with a larger component of valley recharge should have a greater susceptibility to effects from water containing these compounds (henceforth “susceptibility”) than wells that primarily receive mountain-block recharge.

Production and use of industrial chemicals increased substantially in the latter half of the 20th century. Wells that receive dominantly pre-1950s recharge

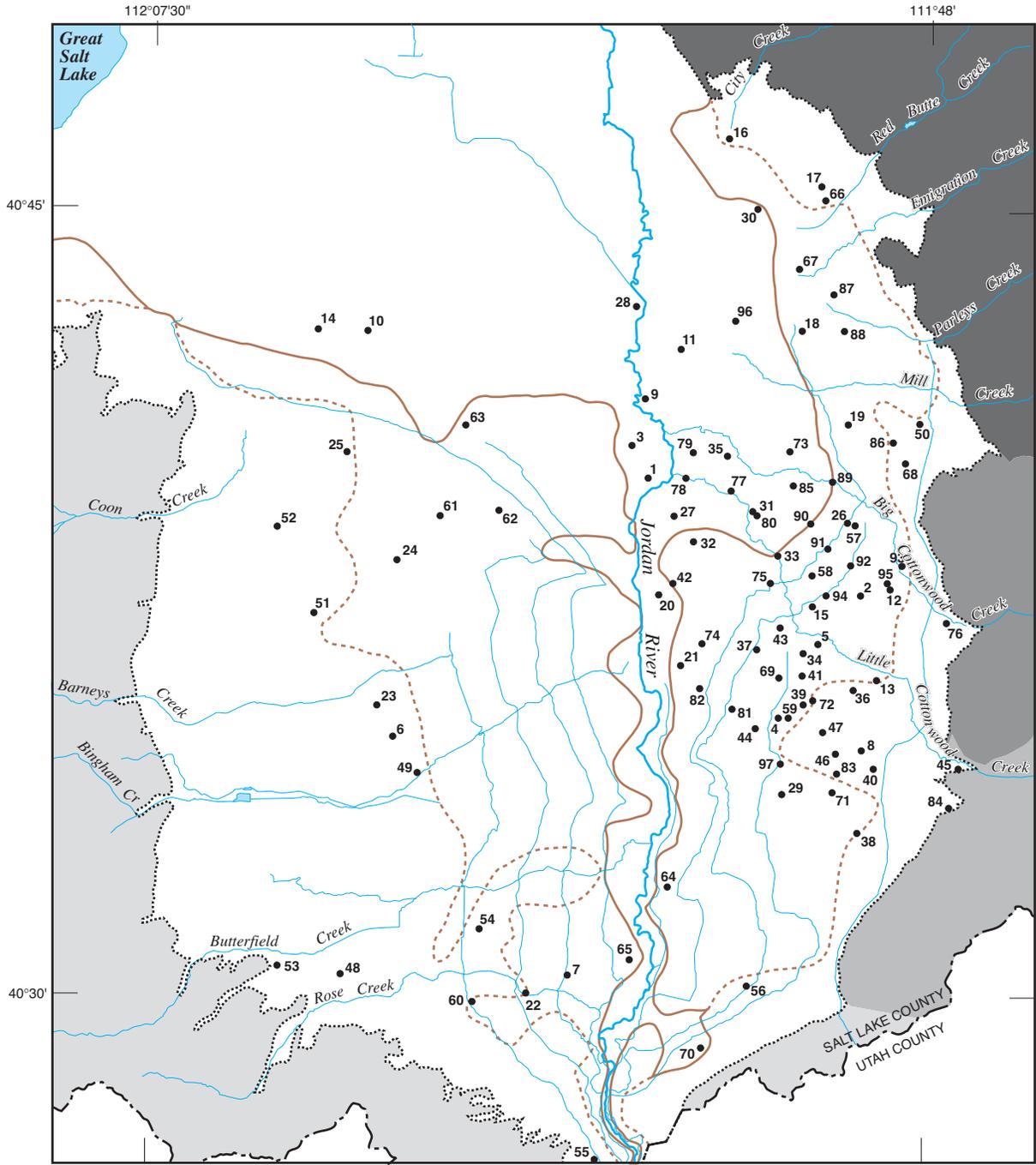
should, therefore, have less susceptibility than those receiving dominantly younger recharge, at least in the near future.

Stable Isotopes

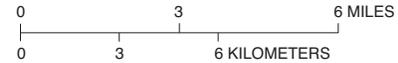
Deuterium (D or ^2H) and oxygen-18 (^{18}O) are stable isotopes of hydrogen and oxygen naturally incorporated into water molecules in small quantities. Water molecules with an ^{18}O or a ^2H atom are heavier than typical water molecules, which consist of ^{16}O and ^1H atoms. This mass difference causes the heavier water molecules to behave differently from typical water molecules during evaporation and condensation, often resulting in different sources of ground-water recharge having different isotopic signatures. Because ^{18}O and ^2H generally are conservative in shallow ground-water systems, stable isotope measurements can reveal information about the relative contributions of different recharge sources. Oxygen-18 and ^2H concentrations, expressed as delta (δ) ^{18}O and ^2H , are reported in parts per thousand (‰, per mil) deviation from a reference standard called Vienna Standard Mean Ocean Water (VSMOW). Water with lower (typically more negative) ^{18}O or ^2H values is lighter, having less ^{18}O and ^2H relative to ^{16}O and ^1H , respectively.

As discussed in the “Ground-Water Hydrology” section of this report, major sources of recharge to the principal aquifer include mountain-block recharge (MBR), stream loss, canal loss, and infiltration of valley precipitation and unconsumed irrigation water. Stable-isotope data from previous studies define the general isotopic signatures of these different sources. The following discussion covers ^{18}O data only, but ^2H data follow similar trends and provide similar insights into recharge to the principal aquifer.

Delta ^{18}O values for MBR should be similar to those of mountain springs and mine-tunnel discharge waters. Delta ^{18}O values for 21 samples collected from springs and mines located on the western slope of the Wasatch Range adjacent to Salt Lake Valley vary from -15.5 to -18.0 per mil (Mayo and Loucks, 1995, table 3; Parry and others, 2000, table 2; Thiros, 1995, pl. 1). One exception is a sample from an anomalously warm (22°C) spring in Parleys Canyon with a measured ^{18}O value of -13.6 per mil (Mayo and Loucks, 1995, table 3). However, this sample is clearly an outlier and is therefore not considered to be generally representative of MBR. Because gaining streams at base flow



Base from U.S. Geological Survey digital line graph data, 1979 and 1980, 1:100,000
 Universal Transverse Mercator projection, Zone 12



EXPLANATION

- Dominantly clastic sedimentary rocks and carbonates
- Dominantly quartzite with interbedded shales
- Granitic intrusive rocks
- Dominantly carbonates and volcanic rocks
- Boundary between secondary recharge area and discharge area
- Boundary between primary and secondary recharge areas
- Approximate boundary of basin-fill deposits in Salt Lake Valley
- 55 • Well completed in principal aquifer—Number is well identifier listed in tables 9, 10, and (or) 11

Figure 16. Map showing Wells with delta oxygen-18, dissolved-gas, recharge-temperature, and (or) tritium/helium-3 age data for water sampled from the principal aquifer in Salt Lake Valley, Utah, 1990-2001.

effectively serve as ground-water integrators, mountain-stream samples collected near the mountain front at base flow conditions should provide an approximate average ^{18}O value for MBR. Delta ^{18}O values for five samples collected at or near base flow from streams entering Salt Lake Valley range from -16.0 to -17.2 per mil, with a mean of -16.5 per mil (Thiros, 1995, table 6). This mean value is only slightly heavier than that of the mountain spring and mine-tunnel samples (-16.8 per mil).

Stream loss should be represented by stream samples collected near the mountain front during both base flow and spring runoff. Delta ^{18}O values for nine such samples collected from Wasatch Range streams on the east side of the valley (Red Butte Creek, Mill Creek, Big Cottonwood Creek, and Little Cottonwood Creek) also range from -16.0 to -17.2 per mil (Thiros, 1995, table 6), but with a mean of -16.6 per mil. Thiros (1995, table 6) reports two stream samples collected part way up Butterfield Creek in the Oquirrh Mountains with ^{18}O values of -16.0 and -16.5 per mil (spring runoff and base flow, respectively). The similarity among these values and those from Wasatch Range streams indicates that stream loss on the west side of the valley has an isotopic signature similar to stream loss on the east side. Existing isotope data from streams, springs, and mine tunnels therefore indicate that mountain-front recharge (MFR, consisting of MBR and stream loss combined) to the valley has a mean ^{18}O value of about -16.6 per mil.

Thiros (2003, table 5) presents $\delta^{18}\text{O}$ values for water samples collected from shallow monitoring wells (generally screened less than about 15 ft below the water table) in the secondary recharge areas of Salt Lake Valley. These wells were installed and sampled to study the effects of residential land use on shallow ground-water quality. Three of the shallow wells are located near Little Cottonwood Creek and appear to be hydraulically connected to the stream on the basis of temperature and water-level data. Water from these wells has $\delta^{18}\text{O}$ values between -16.0 and -16.5 per mil, similar to stream values. The 26 other shallow monitoring wells are a considerable distance from mountain-front streams, and their water should therefore have $\delta^{18}\text{O}$ values representative of recharge sources other than MFR, including canal loss and seepage from valley precipitation and unconsumed irrigation water. Delta ^{18}O values for water from these wells range from -10.8 to -15.0 per mil. Shallow ground water located upgradient from canals diverted from the Jordan River

should not be recharged by canal water. Delta ^{18}O values for water from the seven shallow wells upgradient from canals are from -14.3 to -15.0 per mil, with a mean of -14.7 per mil. Delta ^{18}O values for water samples from the Jordan River and its diversion canals are considerably heavier as a result of evaporation, predominantly ranging from about -9 to -14 per mil (Thiros, 1995, table 6; and Thiros, 2003, table 5).

Delta ^{18}O and ^2H values for water from 67 wells screened in the principal aquifer in Salt Lake Valley are listed in table 9. The distribution of these data is shown in figure 17. These 67 wells include the 31 public-supply wells sampled as part of this study; 20 wells sampled by NAWQA during 1998-2000 as part of other studies; and 16 other wells sampled during 1990-91, the results from which are listed in Thiros (1995, table 7). The range of $\delta^{18}\text{O}$ values (-10.6 to -17.4 per mil) in water from wells screened in the principal aquifer is similar to that of the recharge sources. Water from most of the wells has $\delta^{18}\text{O}$ values of less than or equal to -14.7 per mil, indicating that MFR to the principal aquifer is substantial. Interpretation of this combined data set indicates that $\delta^{18}\text{O}$ values generally are lighter on the east side of the valley than on the west side, indicating that MFR is greater on the east side than on the west side. The $\delta^{18}\text{O}$ value of -17.4 per mil and temperature of 30.5°C for water from well 25 sampled as part of this study is anomalous for the west side of the valley, probably because of the greater depth of the well. Therefore, the stable isotope data generally corroborate the existing conceptual model of ground-water flow in the principal aquifer (see "Ground-Water Hydrology" section of this report).

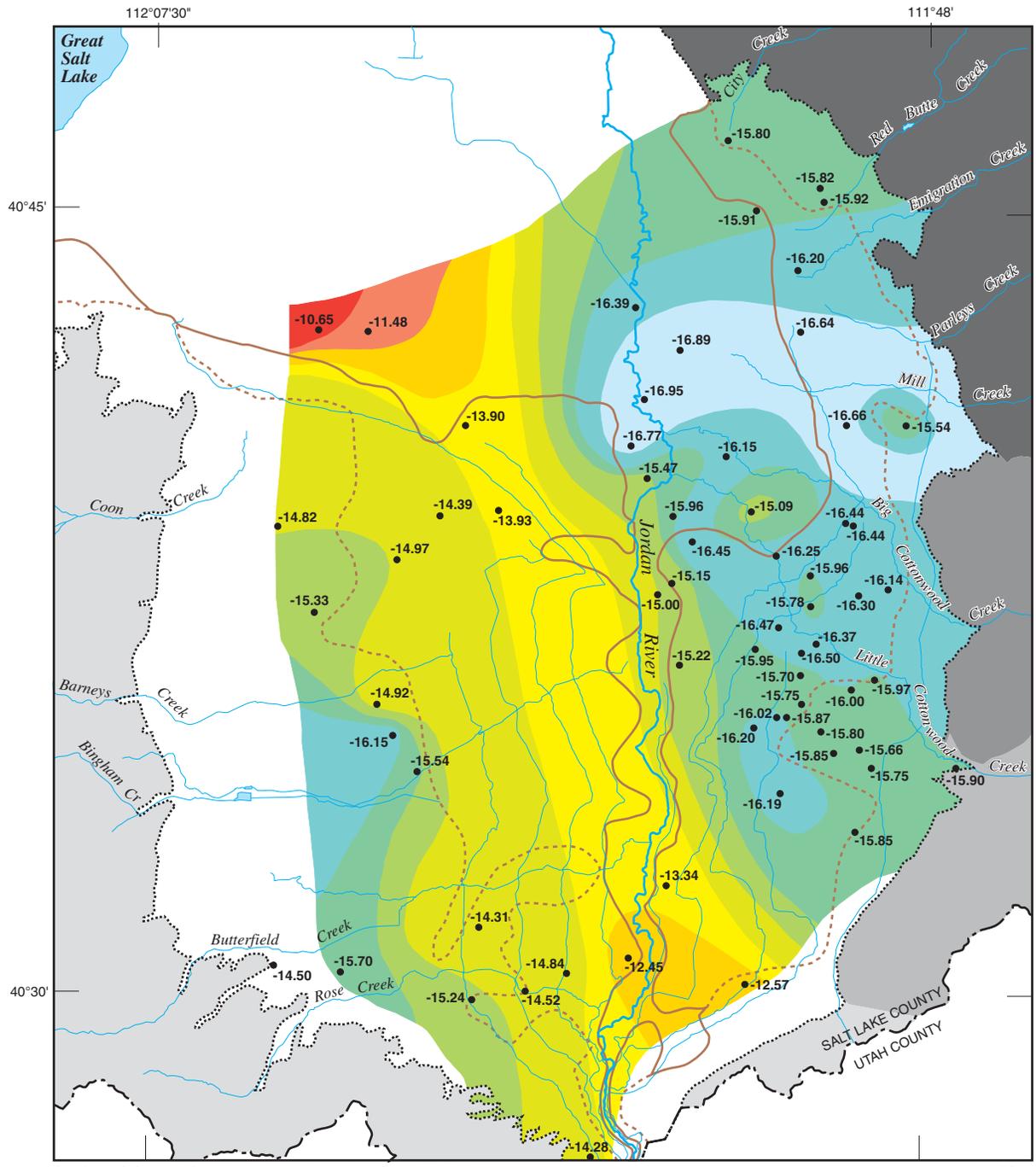
The approximate fraction of MFR in the principal aquifer can be computed from the $\delta^{18}\text{O}$ values by assuming two-component mixing between MFR and non-MFR sources. An approximate minimum MFR fraction was calculated for each well listed in table 9 by assuming that the non-MFR component is free of evaporated canal water (table 9 and fig. 18). The MFR and non-MFR components were thus assumed to have mean $\delta^{18}\text{O}$ values of -16.6 and -14.7 per mil, respectively. Minimum MFR fractions are dominantly greater than 0.5 on the east side of the valley, indicating that MFR constitutes most of the recharge to the eastern part of the principal aquifer. In contrast, minimum MFR fractions are dominantly less than 0.2 on the west side of the valley, indicating that most of the recharge in this area consists of non-MFR sources. MFR fractions are generally the highest (consistently greater

Table 9. Stable-isotope data for water sampled from the principal aquifer in Salt Lake Valley, Utah, 1990-2001

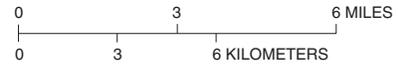
[$\delta^2\text{H}$: delta deuterium value; $\delta^{18}\text{O}$: delta oxygen-18 value; boxed samples were collected from the same well]

Well identifier (fig. 16)	Sample date	$\delta^2\text{H}$ (per mil)	$\delta^{18}\text{O}$ (per mil)	Mountain-front recharge fraction	Well identifier (fig. 16)	Sample date	$\delta^2\text{H}$ (per mil)	$\delta^{18}\text{O}$ (per mil)	Mountain-front recharge fraction
1	05/15/2001	-116.6	-15.47	0.41	36	09/18/1990	-121.0	-16.10	.74
2	05/10/2001	-120.5	-16.30	.84	36	06/20/1991	-119.0	-16.00	.68
3	05/15/2001	-124.2	-16.77	1.0	37	10/22/1991	-119.0	-15.95	.66
4	11/26/1991	-119.0	-16.00	.68	38	06/25/1991	-120.0	-15.85	.61
4	05/09/2001	-117.9	-16.02	.69	39	05/31/1991	-119.0	-15.75	.55
5	05/30/2001	-122.8	-16.37	.88	40	09/30/1991	-118.0	-15.75	.55
6	06/05/2001	-123.1	-16.15	.76	41	05/31/1991	-119.0	-15.70	.53
7	05/08/2001	-114.7	-14.84	.07	42	12/23/1991	-115.0	-15.15	.24
8	06/25/2001	-116.2	-15.66	.51	43	09/17/1990	-123.0	-16.40	.89
9	05/16/2001	-125.0	-16.95	1.0	43	07/13/2000	-123.0	-16.47	.93
10	05/02/2001	-96.5	-11.48	0	44	09/17/1990	-118.0	-16.20	.79
11	06/06/2001	-126.6	-16.89	1.0	45	09/17/1990	-118.0	-15.90	.63
12	05/14/2001	-117.9	-16.14	.76	46	06/20/1991	-118.0	-15.85	.61
13	06/20/1991	-120.0	-16.20	.79	47	09/17/1990	-124.0	-15.80	.58
13	06/12/2001	-118.0	-15.97	.67	48	08/13/1998	-121.0	-15.70	.53
14	05/03/2001	-92.9	-10.65	0	49	07/29/1998	-118.7	-15.54	.44
15	06/13/2001	-117.2	-15.78	.57	50	08/05/1998	-117.0	-15.54	.44
16	06/25/2001	-120.8	-15.80	.58	51	10/29/1998	-120.6	-15.33	.33
17	05/29/2001	-121.0	-15.82	.59	52	09/01/1998	-117.1	-14.82	.06
18	05/24/2001	-125.6	-16.64	1.0	53	07/28/1998	-115.4	-14.50	0
19	05/23/2001	-123.1	-16.66	1.0	54	08/12/1998	-111.1	-14.31	0
20	06/20/1991	-109.0	-13.90	0	55	09/10/1998	-114.6	-14.28	0
20	05/14/2001	-112.8	-15.00	.16	56	08/31/1998	-100.5	-12.57	0
21	06/07/2001	-115.6	-15.22	.27	57	10/07/1998	-121.7	-16.44	.92
22	05/22/2001	-111.2	-14.52	0	58	09/22/1998	-119.3	-15.96	.66
23	06/26/2001	-118.6	-14.92	.12	59	08/10/2000	-119.1	-15.87	.62
24	05/01/2001	-117.0	-14.97	.14	60	09/21/1998	-117.9	-15.24	.28
25	05/21/2001	-132.3	¹ -17.38	1.0	61	08/18/1998	-114.4	-14.39	0
26	05/23/2001	-120.6	-16.44	.92	62	06/07/2000	-110.7	-13.93	0
27	06/11/2001	-119.3	-15.96	.66	63	09/16/1998	-110.6	-13.90	0
28	05/16/2001	-122.7	-16.39	.89	64	09/28/1998	-108.4	-13.34	0
29	05/07/2001	-120.4	-16.19	.78	65	10/14/1998	-102.3	-12.45	0
30	06/05/2001	-121.1	-15.91	.64	66	11/10/1998	-121.8	-15.92	.64
31	06/12/2001	-114.2	-15.09	.21	67	11/14/1990	-122.0	-16.20	.79
32	06/20/1991	-122.0	-16.45	.92					
33	06/21/1991	-120.0	-16.25	.82					
34	09/18/1990	-122.0	-16.50	.95					
35	05/31/1991	-120.0	-16.15	.76					

¹ The $\delta^{18}\text{O}$ value is not shown on figure 17.



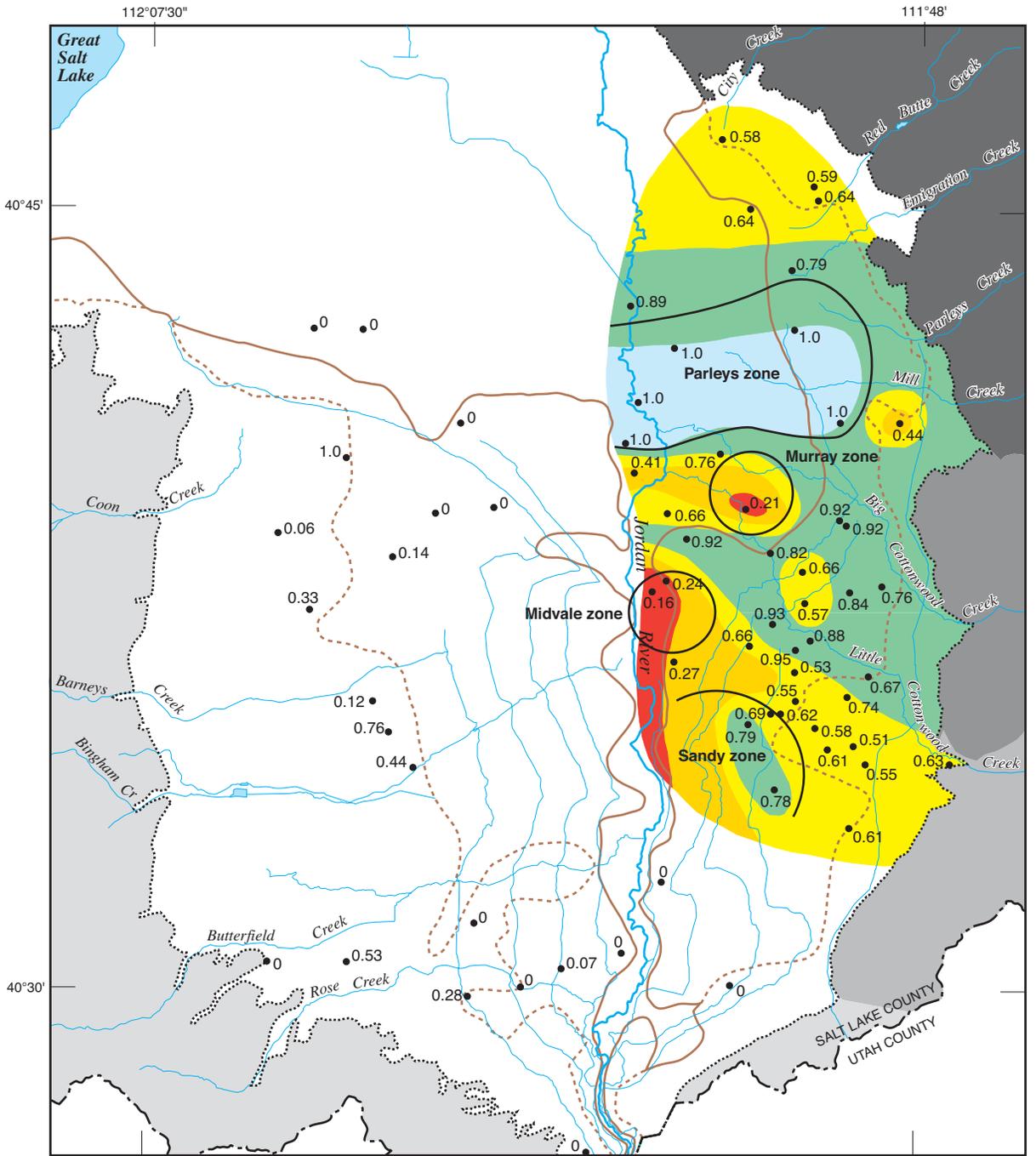
Base from U.S. Geological Survey digital line graph data, 1979 and 1980, 1:100,000
 Universal Transverse Mercator projection, Zone 12



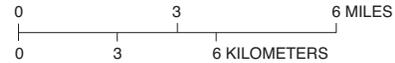
EXPLANATION

- | | | | | |
|------------------------------------|----------------|----------------|----------------|----------------|
| Delta oxygen-18 values, in per mil | | | | |
| | | | | |
| -17.0 to -16.5 | -16.5 to -16.0 | -16.0 to -15.5 | -15.5 to -15.0 | -15.0 to -14.0 |
| | | | | |
| -14.0 to -13.0 | -13.0 to -12.0 | -12.0 to -11.0 | -11.0 to -10.0 | |
-
- | | | | |
|--|---|--|---|
| | Dominantly clastic sedimentary rocks and carbonates | | Boundary between secondary recharge area and discharge area |
| | Dominantly quartzite with interbedded shales | | Boundary between primary and secondary recharge areas |
| | Granitic intrusive rocks | | Approximate boundary of basin-fill deposits in Salt Lake Valley |
| | Dominantly carbonates and volcanic rocks | | Well completed in principal aquifer—Number is delta oxygen-18 value |

Figure 17. Map showing Delta oxygen-18 values for water sampled from the principal aquifer in Salt Lake Valley, Utah, 1990-2001.



Base from U.S. Geological Survey digital line graph data, 1979 and 1980, 1:100,000
 Universal Transverse Mercator projection, Zone 12



EXPLANATION

- | | | | | | |
|---|---|--------------|--------------|-------------|-----|
| Mountain-front recharge fraction | Less than 0.25 | 0.25 to 0.50 | 0.50 to 0.75 | 0.75 to 1.0 | 1.0 |
| Geology | <ul style="list-style-type: none"> █ Dominantly clastic sedimentary rocks and carbonates █ Dominantly quartzite with interbedded shales █ Granitic intrusive rocks █ Dominantly carbonates and volcanic rocks | | | | |
| Boundaries | <ul style="list-style-type: none"> — Boundary between secondary recharge area and discharge area - - - Boundary between primary and secondary recharge areas Approximate boundary of basin-fill deposits in Salt Lake Valley | | | | |
| Wells | <ul style="list-style-type: none"> ● Well completed in principal aquifer—Number is minimum mountain-front recharge fraction | | | | |

Figure 18. Map showing Distribution of minimum mountain-front recharge fractions for water sampled from the principal aquifer in Salt Lake Valley, Utah, 1990-2001.

than 0.9) in the Parleys zone on the east side of the valley. Delta ^{18}O values are well above -14.7 per mil in the northwestern part of the valley (-11.5 and -10.7 per mil in wells 10 and 14, respectively, table 9), indicating that canal water is the primary source of recharge in this area.

The minimum MFR fraction may be an important indicator of well susceptibility. Wells with lower minimum MFR fractions probably receive more valley recharge than wells with higher minimum MFR fractions. The lower minimum MFR fractions observed on the west side of the valley indicate that west-side wells generally are more susceptible than east-side wells. A few wells on the east side of the valley have water with anomalously low minimum MFR fractions (less than 0.5) relative to other east-side wells, indicating that these too have a higher level of susceptibility.

Dissolved Gas Recharge Temperatures

Recharge temperature (T_r) is the temperature at which gas exchange between recharging ground water and the atmosphere last occurs, in other words, the temperature of the water table at the recharge location. The general method of determining recharge temperature from dissolved noble-gas concentrations is presented in Stute and Schlosser (2000). Whereas oxygen-18 and deuterium data can be used to determine the relative magnitude of MFR (MBR and stream loss combined) to intermountain basin-fill aquifers, recharge temperature can be used to calculate the relative contribution of MBR, specifically (Manning and Solomon, 2003). For typical water-table depths, T_r should be approximately equal to (within about 2°C) the mean annual air temperature at the recharge location. Because mean annual air temperature decreases markedly with increasing altitude (about 10.5°C per mi of altitude gain in northern Utah (Hely and others, 1971)), MBR should have a colder T_r than valley recharge. MBR generally cannot be distinguished from stream infiltration that occurs near the mountain front on the basis of stable-isotope ratios because both sources carry a light, high-altitude signal. The ability to identify MBR specifically is important because, as noted above, MBR is considerably less likely to contain elevated levels of anthropogenic chemical compounds than recharge from stream loss or any other form of valley recharge. Both stream loss and MBR

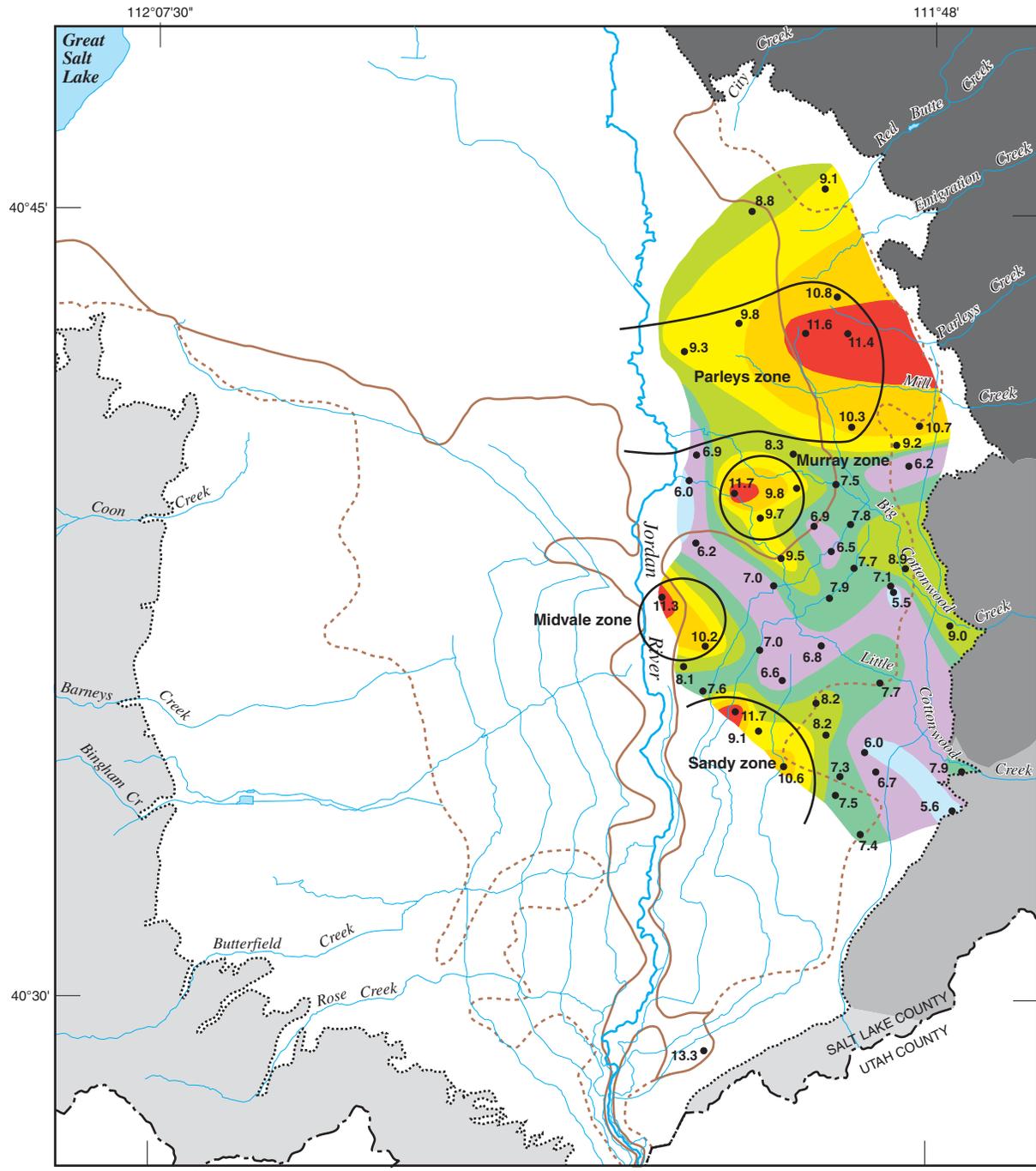
are potentially large components of recharge to intermountain basin-fill aquifers.

Dissolved-gas data for water from wells in Salt Lake Valley are presented in table 10. Samples collected with diffusion samplers and associated recharge temperature determinations are from Manning (2002). Recharge temperatures were not computed for samples collected in clamped copper tubes as part of this study because the University of Utah laboratory did not provide krypton determinations for samples collected in this manner. Hence, T_r data are not available for wells on the west side of the valley.

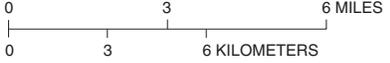
Determining T_r in cases where the recharge altitude is initially unknown is not straightforward. Manning and Solomon (2003) present a detailed description of the method by which the maximum T_r (T_{rmax}) and probable T_r (T_{rprob}) were computed for water from wells in the eastern part of Salt Lake Valley by using dissolved concentrations of krypton, argon, neon, and nitrogen. The approach relies on initially determining a solution zone in recharge-altitude/recharge-temperature space by using valley water-table temperature measurements and T_r data from mountain springs with constrained recharge-altitude values. Uncertainty in T_{rmax} is approximately plus or minus 1°C (Manning and Solomon, 2003).

Minimum and probable fractions of MBR in the sampled well waters were determined from T_{rmax} and T_{rprob} , respectively, assuming simple two-component mixing between MBR and valley recharge. A mean T_r of 13°C was assumed for valley recharge because valley water-table temperatures are dominantly 12-14°C (Manning and Solomon, 2003, fig. 7). Recharge temperatures for springs in the central Wasatch Mountains range from 0 to 10°C (Manning and Solomon, 2003, fig. 7). A mean T_r of 2°C was thus assumed for the MBR component in computing the minimum MBR fraction, considering the very low likelihood that T_r values for MBR are dominantly less than 2°C throughout the Wasatch Mountains (the colder the assumed mean T_r for MBR, the smaller the computed MBR fraction). Probable MBR fractions were computed by using T_{rprob} instead of T_{rmax} and a more likely mean T_r of 5°C for MBR. Note that assuming a colder mean sample T_r (T_{rprob} instead of T_{rmax}) does not demand a colder mean T_r for the MBR component in the sample.

Maximum recharge temperatures in the eastern part of the valley generally are well below 12 to 14°C (fig. 19), indicating that MBR must constitute a



Base from U.S. Geological Survey digital line graph data, 1:100,000, 1979 and 1980
 Universal Transverse Mercator projection, Zone 12



EXPLANATION

- | | |
|---|----------|
| Maximum recharge temperature in degrees Celsius | |
| 5 to 6 | 6 to 7 |
| 7 to 8 | 8 to 9 |
| 9 to 10 | 10 to 11 |
| 11 to 12 | |
-
- | | |
|--|--|
| <ul style="list-style-type: none"> ■ Dominantly clastic sedimentary rocks and carbonates ■ Dominantly quartzite with interbedded shales ■ Granitic intrusive rocks ■ Dominantly carbonates and volcanic rocks — Boundary of zone of principal aquifer referred to in text | <ul style="list-style-type: none"> — Boundary between secondary recharge area and discharge area - - - Boundary between primary and secondary recharge areas ⋯⋯⋯ Approximate boundary of basin-fill deposits in Salt Lake Valley ● 13.3 • Public-supply well—Number is maximum recharge temperature determined for water from the well |
|--|--|

Figure 19. Map showing Distribution of maximum recharge temperatures for water sampled from the principal aquifer on the east side of Salt Lake Valley, Utah, 2000.

Table 10. Dissolved-gas and recharge-temperature data for water sampled from public-supply wells in Salt Lake Valley, Utah, 2000-01

[Well identifier, wells 1-31 are the public-supply wells sampled for water quality and dissolved gases as part of this study and (or) by Manning (2002) and the others are public-supply wells sampled by Manning (2002); cm³STP/g, cubic centimeters at standard temperature and pressure per gram of water; °C, degrees Celsius; —, not analyzed; NC, not calculated because krypton data were not available; clamps, clamped copper tubes; DS, diffusion samplers; boxed samples were collected from the same well with both sample methods]

Well identifier (fig. 16)	Sample date	Sample method	Helium	Neon	Argon	Krypton	Nitrogen
			(cm ³ STP/g)				
1	05/2001	clamps	1.11x10 ⁻⁶	1.83x10 ⁻⁷	3.61x10 ⁻⁴	—	1.48x10 ⁻²
2	05/2001	clamps	6.31x10 ⁻⁸	2.69x10 ⁻⁷	4.65x10 ⁻⁴	—	1.87x10 ⁻²
3	05/2001	clamps	5.71x10 ⁻⁷	2.23x10 ⁻⁷	4.09x10 ⁻⁴	—	1.56x10 ⁻²
4	05/2001	clamps	6.58x10 ⁻⁸	2.66x10 ⁻⁷	4.46x10 ⁻⁴	—	1.78x10 ⁻²
5	08/2000	DS	5.65x10 ⁻⁸	2.29x10 ⁻⁷	3.73x10 ⁻⁴	8.79x10 ⁻⁸	1.54x10 ⁻²
6	06/2001	clamps	6.24x10 ⁻⁸	2.14x10 ⁻⁷	4.05x10 ⁻⁴	—	1.49x10 ⁻²
7	05/2001	clamps	7.32x10 ⁻⁸	2.82x10 ⁻⁷	4.50x10 ⁻⁴	—	1.93x10 ⁻²
8	07/2001	DS	5.86x10 ⁻⁸	2.48x10 ⁻⁷	3.93x10 ⁻⁴	8.84x10 ⁻⁸	1.67x10 ⁻²
9	05/2001	clamps	1.60x10 ⁻⁷	2.24x10 ⁻⁷	4.32x10 ⁻⁴	—	1.65x10 ⁻²
10	05/2001	clamps	6.13x10 ⁻⁷	2.86x10 ⁻⁷	4.35x10 ⁻⁴	—	1.82x10 ⁻²
11	07/2000	DS	9.92x10 ⁻⁸	1.82x10 ⁻⁷	3.26x10 ⁻⁴	8.10x10 ⁻⁸	1.32x10 ⁻²
12	08/2000	DS	7.32x10 ⁻⁸	3.08x10 ⁻⁷	4.28x10 ⁻⁴	9.42x10 ⁻⁸	1.92x10 ⁻²
13	07/2000	DS	7.02x10 ⁻⁸	2.90x10 ⁻⁷	3.97x10 ⁻⁴	8.98x10 ⁻⁸	1.80x10 ⁻²
14	05/2001	clamps	4.34x10 ⁻⁷	2.30x10 ⁻⁷	3.58x10 ⁻⁴	—	1.50x10 ⁻²
15	06/2001	clamps	6.31x10 ⁻⁸	2.71x10 ⁻⁷	4.53x10 ⁻⁴	—	1.84x10 ⁻²
16	06/2001	clamps	1.17x10 ⁻⁷	3.65x10 ⁻⁷	4.83x10 ⁻⁴	—	2.54x10 ⁻²
17	07/2000	DS	6.70x10 ⁻⁸	2.67x10 ⁻⁷	3.74x10 ⁻⁴	8.63x10 ⁻⁸	1.65x10 ⁻²
18	05/2001	clamps	1.27x10 ⁻⁷	2.42x10 ⁻⁷	3.52x10 ⁻⁴	—	1.36x10 ⁻²
18	07/2000	DS	1.04x10 ⁻⁷	1.88x10 ⁻⁷	3.17x10 ⁻⁴	7.67x10 ⁻⁸	1.29x10 ⁻²
19	05/2001	clamps	2.52x10 ⁻⁷	2.06x10 ⁻⁷	3.55x10 ⁻⁴	—	1.38x10 ⁻²
19	08/2000	DS	2.41x10 ⁻⁷	2.01x10 ⁻⁷	3.35x10 ⁻⁴	7.89x10 ⁻⁸	1.36x10 ⁻²
20	05/2001	clamps	1.84x10 ⁻⁶	2.56x10 ⁻⁷	4.21x10 ⁻⁴	—	1.77x10 ⁻²
20	07/2000	DS	1.01x10 ⁻⁶	1.67x10 ⁻⁷	3.25x10 ⁻⁴	7.38x10 ⁻⁸	1.30x10 ⁻²
21	08/2000	DS	2.39x10 ⁻⁷	2.09x10 ⁻⁷	3.56x10 ⁻⁴	8.25x10 ⁻⁸	1.45x10 ⁻²
22	05/2001	clamps	6.92x10 ⁻⁸	2.81x10 ⁻⁷	4.31x10 ⁻⁴	—	1.80x10 ⁻²
23	06/2001	clamps	6.05x10 ⁻⁸	2.11x10 ⁻⁷	3.64x10 ⁻⁴	—	1.43x10 ⁻²
24	05/2001	clamps	7.29x10 ⁻⁸	2.41x10 ⁻⁷	4.19x10 ⁻⁴	—	1.65x10 ⁻²
25	05/2001	clamps	1.57x10 ⁻⁶	2.20x10 ⁻⁷	4.26x10 ⁻⁴	—	1.67x10 ⁻²
26	05/2001	clamps	8.97x10 ⁻⁸	2.48x10 ⁻⁷	4.37x10 ⁻⁴	—	1.77x10 ⁻²
26	07/2000	DS	7.59x10 ⁻⁸	2.15x10 ⁻⁷	3.56x10 ⁻⁴	8.55x10 ⁻⁸	1.48x10 ⁻²
27	06/2001	clamps	5.22x10 ⁻⁷	2.24x10 ⁻⁷	4.33x10 ⁻⁴	—	1.68x10 ⁻²
28	05/2001	clamps	2.25x10 ⁻⁷	4.92x10 ⁻⁷	6.10x10 ⁻⁴	—	3.09x10 ⁻²
29	05/2001	clamps	6.85x10 ⁻⁷	2.08x10 ⁻⁷	3.60x10 ⁻⁴	—	1.43x10 ⁻²
30	06/2001	clamps	6.24x10 ⁻⁸	2.26x10 ⁻⁷	4.00x10 ⁻⁴	—	1.58x10 ⁻²
30	08/2001	DS	5.41x10 ⁻⁸	1.83x10 ⁻⁷	3.34x10 ⁻⁴	7.74x10 ⁻⁸	1.34x10 ⁻²
31	06/2001	clamps	5.32x10 ⁻⁸	2.18x10 ⁻⁷	3.93x10 ⁻⁴	—	1.54x10 ⁻²
32	08/2000	DS	5.40x10 ⁻⁸	2.09x10 ⁻⁷	3.62x10 ⁻⁴	8.96x10 ⁻⁸	1.47x10 ⁻²

Table 10. Dissolved-gas and recharge-temperature data for water sampled from public-supply wells in Salt Lake Valley, Utah, 2000-01—Continued

Well identifier (fig. 16)	Maximum recharge temperature (°C)	Minimum excess air concentration (cm ³ STP/g)	Minimum recharge altitude (feet)	Minimum mountain-block recharge fraction	Probable recharge temperature (°C)	Probable excess air concentration (cm ³ STP/g)	Probable recharge altitude (feet)	Probable mountain-block recharge fraction
1	NC	NC	NC	NC	NC	NC	NC	NC
2	NC	NC	NC	NC	NC	NC	NC	NC
3	NC	NC	NC	NC	NC	NC	NC	NC
4	NC	NC	NC	NC	NC	NC	NC	NC
5	6.8	.0029	4,801	.56	3.4	.0036	7,863	1.00
6	NC	NC	NC	NC	NC	NC	NC	NC
7	NC	NC	NC	NC	NC	NC	NC	NC
8	6.0	.0040	4,872	.64	2.3	.0048	8,284	1.00
9	NC	NC	NC	NC	NC	NC	NC	NC
10	NC	NC	NC	NC	NC	NC	NC	NC
11	9.3	.0005	4,544	.34	7.1	.0009	6,414	.73
12	5.5	.0072	4,905	.69	1.4	.0080	8,612	1.00
13	7.7	.0064	4,700	.48	4.7	.0069	7,349	1.00
14	NC	NC	NC	NC	NC	NC	NC	NC
15	NC	NC	NC	NC	NC	NC	NC	NC
16	NC	NC	NC	NC	NC	NC	NC	NC
17	9.1	.0051	4,672	.36	7.0	.0055	6,463	.75
18	NC	NC	NC	NC	NC	NC	NC	NC
18	11.6	.0010	4,413	.13	10.9	.0011	4,970	.26
19	NC	NC	NC	NC	NC	NC	NC	NC
19	10.3	.0016	4,501	.25	8.7	.0019	5,807	.54
20	NC	NC	NC	NC	NC	NC	NC	NC
20	11.3	.0000	4,331	.16	9.6	.0000	5,348	.42
21	8.1	.0020	4,675	.45	5.2	.0025	7,185	.97
22	NC	NC	NC	NC	NC	NC	NC	NC
23	NC	NC	NC	NC	NC	NC	NC	NC
24	NC	NC	NC	NC	NC	NC	NC	NC
25	NC	NC	NC	NC	NC	NC	NC	NC
26	NC	NC	NC	NC	NC	NC	NC	NC
26	7.8	.0022	4,692	.47	4.8	.0028	7,327	1.00
27	NC	NC	NC	NC	NC	NC	NC	NC
28	NC	NC	NC	NC	NC	NC	NC	NC
29	NC	NC	NC	NC	NC	NC	NC	NC
30	NC	NC	NC	NC	NC	NC	NC	NC
30	8.8	.0006	4,528	.38	7.3	.0011	6,332	.71
31	NC	NC	NC	NC	NC	NC	NC	NC
32	6.2	.0018	4,839	.62	2.5	.0025	8,202	1.00

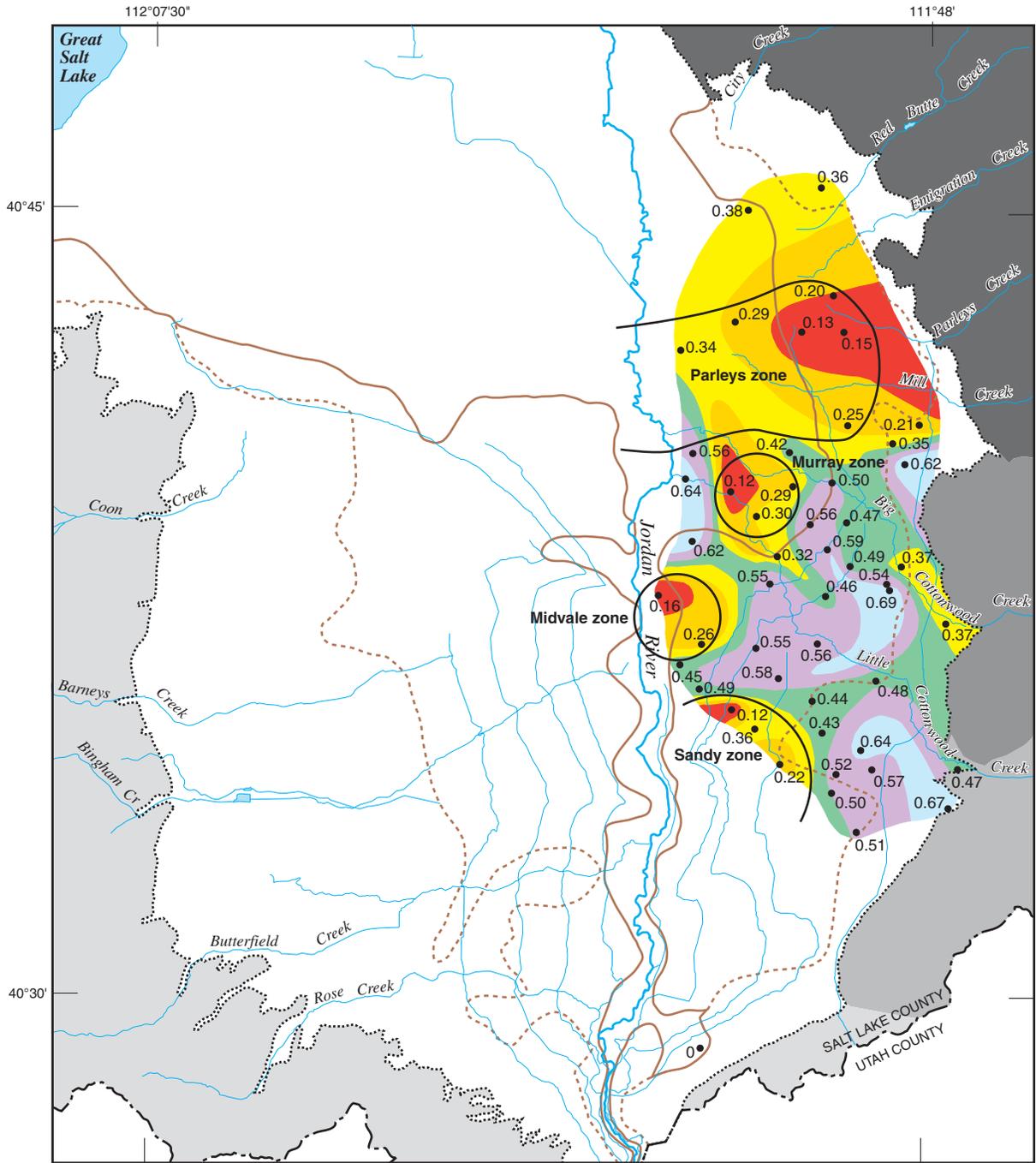
Table 10. Dissolved-gas and recharge-temperature data for water sampled from public-supply wells in Salt Lake Valley, Utah, 2000-01—Continued

Well identifier (fig. 16)	Sample date	Sample method	Helium	Neon	Argon	Krypton	Nitrogen
			(cm ³ STP/g)				
33	07/2000	DS	4.76x10 ⁻⁸	2.00x10 ⁻⁷	3.40x10 ⁻⁴	7.99x10 ⁻⁸	1.39x10 ⁻²
37	08/2000	DS	5.86x10 ⁻⁸	2.40x10 ⁻⁷	3.74x10 ⁻⁴	8.90x10 ⁻⁸	1.59x10 ⁻²
38	08/2000	DS	5.03x10 ⁻⁸	2.09x10 ⁻⁷	3.52x10 ⁻⁴	8.59x10 ⁻⁸	1.44x10 ⁻²
40	08/2000	DS	7.46x10 ⁻⁸	3.08x10 ⁻⁷	4.14x10 ⁻⁴	9.15x10 ⁻⁸	1.90x10 ⁻²
44	08/2000	DS	9.15x10 ⁻⁷	1.75x10 ⁻⁷	3.30x10 ⁻⁴	8.07x10 ⁻⁸	¹ 1.33x10 ⁻²
45	09/2000	DS	5.36x10 ⁻⁸	2.01x10 ⁻⁷	3.45x10 ⁻⁴	8.18x10 ⁻⁸	1.41x10 ⁻²
47	08/2000	DS	5.38x10 ⁻⁸	2.24x10 ⁻⁷	3.63x10 ⁻⁴	8.25x10 ⁻⁸	1.52x10 ⁻²
50	07/2000	DS	1.42x10 ⁻⁷	2.54x10 ⁻⁷	3.62x10 ⁻⁴	7.93x10 ⁻⁸	1.59x10 ⁻²
68	08/2000	DS	1.30x10 ⁻⁷	2.06x10 ⁻⁷	3.60x10 ⁻⁴	8.88x10 ⁻⁸	1.48x10 ⁻²
69	08/2000	DS	5.37x10 ⁻⁸	2.21x10 ⁻⁷	3.69x10 ⁻⁴	8.82x10 ⁻⁸	1.51x10 ⁻²
70	08/2000	DS	5.27x10 ⁻⁸	2.05x10 ⁻⁷	3.19x10 ⁻⁴	7.28x10 ⁻⁸	¹ 1.44x10 ⁻²
71	08/2000	DS	5.00x10 ⁻⁸	2.09x10 ⁻⁷	3.55x10 ⁻⁴	8.45x10 ⁻⁸	1.46x10 ⁻²
72	08/2000	DS	6.32x10 ⁻⁸	2.60x10 ⁻⁷	3.84x10 ⁻⁴	8.48x10 ⁻⁸	1.66x10 ⁻²
73	08/2000	DS	7.22x10 ⁻⁸	2.07x10 ⁻⁷	3.53x10 ⁻⁴	8.19x10 ⁻⁸	1.44x10 ⁻²
74	08/2000	DS	5.09x10 ⁻⁸	2.07x10 ⁻⁷	3.44x10 ⁻⁴	7.78x10 ⁻⁸	1.40x10 ⁻²
75	07/2000	DS	5.25x10 ⁻⁸	1.90x10 ⁻⁷	3.53x10 ⁻⁴	8.37x10 ⁻⁸	1.39x10 ⁻²
76	08/2000	DS	5.09x10 ⁻⁸	1.80x10 ⁻⁷	3.30x10 ⁻⁴	7.99x10 ⁻⁸	1.30x10 ⁻²
77	08/2000	DS	5.02x10 ⁻⁸	2.11x10 ⁻⁷	3.36x10 ⁻⁴	7.66x10 ⁻⁸	¹ 1.50x10 ⁻²
78	07/2000	DS	9.45x10 ⁻⁸	2.05x10 ⁻⁷	3.61x10 ⁻⁴	8.92x10 ⁻⁸	1.47x10 ⁻²
79	07/2000	DS	1.44x10 ⁻⁷	1.96x10 ⁻⁷	3.49x10 ⁻⁴	8.71x10 ⁻⁸	1.42x10 ⁻²
80	07/2000	DS	4.67x10 ⁻⁸	1.96x10 ⁻⁷	3.34x10 ⁻⁴	8.00x10 ⁻⁸	1.38x10 ⁻²
81	08/2000	DS	2.91x10 ⁻⁷	1.98x10 ⁻⁷	3.29x10 ⁻⁴	7.45x10 ⁻⁸	1.32x10 ⁻²
82	08/2000	DS	1.88x10 ⁻⁷	2.15x10 ⁻⁷	3.62x10 ⁻⁴	8.45x10 ⁻⁸	1.47x10 ⁻²
83	08/2000	DS	5.03x10 ⁻⁸	2.11x10 ⁻⁷	3.61x10 ⁻⁴	8.49x10 ⁻⁸	1.46x10 ⁻²
84	08/2000	DS	7.88x10 ⁻⁸	2.14x10 ⁻⁷	3.65x10 ⁻⁴	8.82x10 ⁻⁸	1.53x10 ⁻²
85	07/2000	DS	5.38x10 ⁻⁸	2.07x10 ⁻⁷	3.43x10 ⁻⁴	7.95x10 ⁻⁸	1.42x10 ⁻²
86	07/2000	DS	8.97x10 ⁻⁸	2.37x10 ⁻⁷	3.58x10 ⁻⁴	8.36x10 ⁻⁸	1.55x10 ⁻²
87	07/2000	DS	9.90x10 ⁻⁸	2.08x10 ⁻⁷	3.40x10 ⁻⁴	7.62x10 ⁻⁸	1.41x10 ⁻²
88	07/2000	DS	9.05x10 ⁻⁸	2.07x10 ⁻⁷	3.29x10 ⁻⁴	7.75x10 ⁻⁸	1.37x10 ⁻²
89	07/2000	DS	8.75x10 ⁻⁸	2.49x10 ⁻⁷	3.78x10 ⁻⁴	8.74x10 ⁻⁸	1.61x10 ⁻²
90	07/2000	DS	5.69x10 ⁻⁸	2.17x10 ⁻⁷	3.66x10 ⁻⁴	8.63x10 ⁻⁸	1.50x10 ⁻²
91	07/2000	DS	5.12x10 ⁻⁸	2.17x10 ⁻⁷	3.70x10 ⁻⁴	8.64x10 ⁻⁸	1.52x10 ⁻²
92	08/2000	DS	5.58x10 ⁻⁸	2.32x10 ⁻⁷	3.69x10 ⁻⁴	8.56x10 ⁻⁸	1.55x10 ⁻²
93	07/2000	DS	9.61x10 ⁻⁸	2.09x10 ⁻⁷	3.48x10 ⁻⁴	8.26x10 ⁻⁸	1.42x10 ⁻²
94	07/2000	DS	5.51x10 ⁻⁸	2.32x10 ⁻⁷	3.68x10 ⁻⁴	8.67x10 ⁻⁸	1.55x10 ⁻²
95	07/2000	DS	6.59x10 ⁻⁸	2.36x10 ⁻⁷	3.74x10 ⁻⁴	8.73x10 ⁻⁸	1.59x10 ⁻²
96	07/2000	DS	1.75x10 ⁻⁷	1.92x10 ⁻⁷	3.31x10 ⁻⁴	8.15x10 ⁻⁸	¹ 1.39x10 ⁻²
97	08/2000	DS	1.98x10 ⁻⁷	1.88x10 ⁻⁷	3.27x10 ⁻⁴	7.62x10 ⁻⁸	1.33x10 ⁻²

¹ Nitrogen gas concentration was excluded in determination of recharge temperature, excess air concentration, and recharge elevation because denitrification was likely.

Table 10. Dissolved-gas and recharge-temperature data for water sampled from public-supply wells in Salt Lake Valley, Utah, 2000-01—Continued

Well identifier (fig. 16)	Maximum recharge temperature (°C)	Minimum excess air concentration (cm ³ STP/g)	Minimum recharge altitude (feet)	Minimum mountain-block recharge fraction	Probable recharge temperature (°C)	Probable excess air concentration (cm ³ STP/g)	Probable recharge altitude (feet)	Probable mountain-block recharge fraction
33	9.5	.0016	4,511	.32	7.5	.0020	6,283	.69
37	7.0	.0035	4,774	.55	3.6	.0042	7,759	1.00
38	7.4	.0019	4,961	.51	4.7	.0025	7,349	1.00
40	6.7	.0074	4,941	.57	3.7	.0080	7,726	1.00
44	9.1	.0000	4,555	.36	6.5	.0005	6,660	.81
45	7.9	.0017	5,282	.47	6.1	.0020	6,808	.86
47	8.2	.0029	4,721	.43	5.6	.0034	7,021	.92
50	10.7	.0049	4,783	.21	10.2	.0049	5,200	.35
68	6.2	.0017	4,856	.62	2.5	.0024	8,202	1.00
69	6.6	.0025	4,806	.58	3.1	.0032	8,005	1.00
70	13.3	.0021	4,662	.00	13.3	.0021	4,662	.00
71	7.5	.0020	4,872	.50	4.7	.0025	7,365	1.00
72	8.2	.0047	4,734	.44	5.6	.0053	7,021	.93
73	8.3	.0020	4,626	.42	5.6	.0025	7,021	.92
74	10.2	.0020	4,462	.26	8.5	.0023	5,873	.56
75	7.0	.0009	4,774	.55	3.7	.0016	7,776	1.00
76	9.0	.0005	4,800	.37	7.1	.0008	6,441	.74
77	11.7	.0022	4,324	.12	10.8	.0023	5,003	.27
78	6.0	.0016	4,888	.64	2.2	.0023	8,317	1.00
79	6.9	.0011	4,774	.56	3.4	.0018	7,874	1.00
80	9.7	.0014	4,506	.30	7.7	.0018	6,190	.66
81	11.7	.0016	4,452	.12	11.3	.0017	4,823	.22
82	7.6	.0022	4,692	.49	4.6	.0028	7,431	1.00
83	7.3	.0020	4,790	.52	4.2	.0026	7,579	1.00
84	5.6	.0023	5,400	.67	2.6	.0029	8,202	1.00
85	9.8	.0020	4,495	.29	7.8	.0024	6,135	.64
86	9.2	.0036	4,623	.35	7.0	.0040	6,480	.75
87	10.8	.0021	4,439	.20	9.6	.0024	5,446	.43
88	11.4	.0021	4,508	.15	10.8	.0022	4,970	.27
89	7.5	.0040	4,708	.50	4.4	.0047	7,480	1.00
90	6.9	.0023	4,774	.56	3.5	.0030	7,841	1.00
91	6.5	.0023	4,806	.59	2.9	.0031	8,071	1.00
92	7.7	.0032	4,692	.49	4.6	.0038	7,431	1.00
93	8.9	.0019	4,578	.37	6.4	.0024	6,693	.82
94	7.9	.0034	4,675	.46	4.9	.0040	7,283	1.00
95	7.1	.0034	4,757	.54	3.8	.0040	7,726	1.00
96	9.8	.0010	4,478	.29	7.8	.0014	6,168	.65
97	10.6	.0010	4,541	.22	9.4	.0013	5,512	.45



Base from U.S. Geological Survey digital line graph data, 1:100,000, 1979 and 1980
 Universal Transverse Mercator projection, Zone 12

EXPLANATION

- | | | | | | |
|---|---|------------|--|------------|------------|
| Minimum mountain-block recharge fraction | | | | | |
| 0.7 to 0.6 | 0.6 to 0.5 | 0.5 to 0.4 | 0.4 to 0.3 | 0.3 to 0.2 | 0.2 to 0.1 |
| Dominantly clastic sedimentary rocks and carbonates | Boundary between secondary recharge area and discharge area | | Boundary between primary and secondary recharge areas | | |
| Dominantly quartzite with interbedded shales | Approximate boundary of basin-fill deposits in Salt Lake Valley | | Well completed in principal aquifer—Number is minimum mountain-block recharge fraction | | |
| Granitic intrusive rocks | | | | | |
| Dominantly carbonates and volcanic rocks | | | | | |
| Boundary of zone of principal aquifer referred to in text | | | | | |

Figure 20. Map showing Distribution of minimum mountain-block recharge fractions for water sampled from the principal aquifer on the east side of Salt Lake Valley, Utah, 2000.

substantial fraction of recharge to the principal aquifer in this area. Maximum recharge temperatures are particularly low in the southeastern part of the valley where T_{rmax} generally ranges from 6 to 9°C. Minimum fractions of MBR computed from T_{rmax} values indicate that MBR constitutes at least 30 percent of recharge throughout most of the east side of the valley, and at least 45 percent in the southeastern part (fig. 20). Probable fractions of MBR (table 10) indicate that water in the southeastern area more likely consists of 80 to 100 percent MBR. An important consideration in interpreting the recharge-temperature data is that, although low T_{rmax} values can be explained only by high MBR fractions, high T_{rmax} values do not necessarily indicate low MBR fractions. Another possible explanation of high T_{rmax} values is that the T_r of MBR is high because either (1) MBR occurs mainly at lower altitudes in the mountains, or (2) the water table in the mountains is deep. A deep water table in the mountain block could result in water-table temperatures well above the mean annual air temperature at the surface because of the geothermal gradient.

To a first order, minimum MBR fractions are consistent with the minimum MFR fractions on the east side of the valley (figs. 18 and 20). The recharge-temperature and stable-isotope data together indicate that MBR, and thus MFR, constitutes a significant percentage of recharge to the principal aquifer on the east side of the valley. In turn, this result generally is consistent with previous estimates of MBR and MFR to the principal aquifer in Salt Lake Valley (Hely and others, 1971; Waddell and others, 1987b; Lambert, 1995). In the most recently published ground-water flow model of the valley (Lambert, 1995), MBR accounts for more than 70 percent of recharge throughout most of the east side. Because MFR includes both MBR and stream loss, the minimum MBR fraction should not significantly exceed the minimum MFR fraction in a given location. This is indeed the case for water from wells where both values were calculated, except for well 21 (minimum MFR fraction = 0.27, minimum MBR fraction = 0.45). This discrepancy may be a result of the non-MFR fraction containing evaporated canal water, thus having a $\delta^{18}\text{O}$ ratio heavier than -14.7 per mil. Increasing the non-MFR component to -13.5 per mil, for example, results in a MFR fraction of 0.55, consistent with the minimum MBR fraction. Well 21 is in one of the two small areas of canal loss on the east side of the valley (north of Little Cottonwood Canyon) in

Lambert's (1995) model of Salt Lake Valley. The distribution of minimum MBR fractions and minimum MFR fractions also indicates that the valley recharge component is probably large in the Murray and Midvale zones, which are defined on figures 18 and 20 (see following discussion regarding well susceptibility).

Substantial discrepancies do exist, however, between the minimum MBR and MFR fractions in the Parleys and Sandy zones (figs. 18 and 20). In both of these areas, the MBR fractions are relatively low (0.12 to 0.36), whereas the MFR fractions are relatively high (0.69 to 1.0). In fact, MFR fractions in the Parleys zone are the highest calculated for the principal aquifer. One possible explanation for this discrepancy is that stream loss constitutes an exceptionally high percentage of MFR in these two areas. This is unlikely in the Parleys zone, however, where stream data coupled with water-budget analysis (Hely and others, 1971) and numerical modeling (Waddell and others, 1987b; Lambert, 1995) indicates that stream seepage accounts for only about 5 to 10 percent of total recharge. This compares to 10 to 30 percent farther south. Although some error in these stream-loss percentages is to be expected, the very large errors demanded in the case of stream loss comprising a high percentage of recharge in the Parleys zone are unlikely. High stream-loss rates also are unlikely in the Sandy zone because several wells located between the Sandy zone and Little Cottonwood Creek have higher MBR fractions (and lower MFR fractions) than wells in the Sandy zone; stream seepage increasing with distance from the stream is not likely.

Another possible explanation for the discrepancy between minimum MBR and MFR fractions in the Parleys and Sandy zones is that the ground water in these areas is dominantly valley recharge that infiltrated several thousand years ago (paleowater). Ground water of this age might have recharged when the local climate was colder. Recharge from precipitation in a colder paleoclimate would have lighter $\delta^{18}\text{O}$ values than recent recharge. Given this scenario, noble gas concentrations from most wells in the Parleys and Sandy zones indicate that valley recharge temperatures were 2 to 3°C colder several thousand years ago, in turn indicating a climatic shift in the mean annual air temperature of 2 to 3°C. Assuming a reasonable isotopic shift of 0.7 per mil/°C (Mazor, 1991, p. 177), this climatic shift in the mean annual air temperature would result in $\delta^{18}\text{O}$ values generally consistent with those observed in the Parleys and Sandy areas (-16 to -17 per mil). Ground water in the study area has not been dated with

techniques appropriate for ages on this time scale. Tritium concentrations (“Tritium and Tritium/Helium-3 Ages” section of this report) in the Sandy zone and the western part of the Parleys zone are approximately 1 TU or less, consistent with the possibility of ground water in these areas being dominantly paleowater (which would be tritium free). In the eastern part of the Parleys zone, however, where disagreement between minimum MBR and MFR fractions is the greatest, ^3H concentrations are 4 to 14 TU, indicating that a substantial fraction of the ground water is younger than 50 years. The presence of paleowater is therefore capable of explaining, by itself, the discrepancy between the minimum MBR and MFR fractions in the Sandy zone and western Parleys zone, but not in the eastern Parleys zone.

A third possible explanation for the discrepancy is that MBR in the Parleys and Sandy zones has a warm mean T_r as a result of a deep mountain water table in the MBR source area. Recharge temperatures for springs in the mountains adjacent to these areas are not anomalously warm (Manning, 2002, tables A.5 and A.6). However, it is possible that these springs are fed by a shallow ground-water system perched above a deeper regional ground-water table, as is thought to be the case in some mountains in the Basin and Range Province (Maurer and others, 1996). The general lack of perennial side-canyon streamflow in Parleys and Emigration Canyons is consistent with a deep water table in the mountains adjacent to the Parleys zone.

Both deep mountain water tables and the occurrence of paleowater are consistent with anomalously warm ground-water temperatures (Manning, 2002, figure 4.4) and elevated terrigenic ^4He concentrations (generally greater than or equal to $5 \times 10^{-8} \text{ cm}^3\text{STP/g}$, see “Tritium and Tritium/Helium-3 Ages” section of this report) in the Parleys and Sandy zones. Terrigenic He originates from radioactive decay of natural uranium- and thorium-series elements in aquifer solids and has been used to date ground water over timescales of 1,000 to 1,000,000 years (Solomon, 2000). Warmer temperatures and elevated terrigenic ^4He concentrations are indicative of deeper ground-water circulation and longer ground-water residence times. Deep ground-water circulation is a corollary of a deep water table. Note, however, that circulation is not necessarily shallower in other parts of the mountain block where water tables are shallower.

Deeper ground-water circulation in the mountains adjacent to the Parleys zone is consistent with the mountain block geology (fig. 18). Rocks from Mill Creek Canyon northward are dominantly sedimentary, with bedding planes and major faults striking approximately perpendicular to the mountain front. Rocks farther south are dominantly crystalline, and major faults strike more parallel to the mountain front. The mountain block adjacent to the Parleys zone may therefore be more permeable, particularly at depth, allowing deeper ground-water circulation. Such is not the case for the mountain block adjacent to the Sandy zone, which consists of relatively undeformed granitic intrusive rocks. It is possible, however, that the source area for MBR in the Sandy zone is south of the study area, where sedimentary rocks predominate.

In summary, the cause of the discrepancy between minimum MBR and MFR fractions in the Sandy and Parleys zones is unclear. The discrepancy may be the result of a deep mountain water table (causing MBR to have a warm mean T_r), the occurrence of paleowater, some combination of these two factors, or other conditions we have not considered here. Because MBR may have an anomalously warm T_r in these areas, MBR may not be low as indicated by the low minimum MBR fractions. It is important to note that low MBR rates in the Parleys zone would conflict with previous MBR estimates for this part of the basin, which are similar to or greater than MBR rates farther south (Hely and others, 1971; Waddell and others, 1987b; Lambert, 1995). More data from the Parleys and Sandy zones are clearly needed.

A close correlation exists between dissolved-solids concentration and minimum MBR fractions on the east side of Salt Lake Valley (figs. 8 and 20). Ground water with a dissolved-solids concentration of less than 250 mg/L in the southeastern part of the valley also is characterized by high minimum MBR fractions. This correlation could be the result of MBR generally having lower dissolved-solids concentrations than valley recharge, coupled with MBR fractions being higher in the south than in the north. However, it is also possible that MBR fractions are not significantly higher in the southeastern part of the valley (see above discussion), and that the correlation is instead primarily a function of the mountain-block geology. As previously noted, rocks in the mountain block adjacent to the southeastern part of the valley are dominantly crystalline, whereas rocks adjacent to the northeastern part are dominantly sedimentary (fig. 8). Spring data from

the central Wasatch Range (Mayo and Loucks, 1995, table 1) indicate that MBR in the southeastern area should have a dissolved-solids concentration that ranges from 100 to 200 mg/L, and MBR in the northeastern area should have a concentration of from 200 to 600 mg/L. Concentrations in the southeastern and northeastern parts of the valley do generally fall within these ranges (fig. 8).

The minimum MBR fraction potentially could serve as an important indicator of well susceptibility. Wells with low minimum MBR fractions (possibly high valley recharge fractions) should be more susceptible than wells with high minimum MBR fractions. Wells with minimum MBR fractions substantially lower than nearby upgradient wells should be the most susceptible because in this case the low minimum MBR fraction probably indicates a high valley recharge fraction (as opposed to MBR with a warmer T_r).

Together, the stable-isotope and recharge-temperature data define two zones of apparently high susceptibility on the east side of the valley, the Murray zone and the Midvale zone (figs. 18 and 20). The Murray zone includes wells 31, 77, 80, and 85, and the Midvale zone includes wells 20, 42, and 74 (fig. 16). In these two zones, both minimum MFR fractions and minimum MBR fractions are low, and minimum MBR fractions are considerably lower than upgradient wells to the east and southeast. The Murray zone may extend farther southeast to well 33 because this well has a low minimum MBR fraction (0.32), but the minimum MFR fraction for well 33 is not low (0.82). Similarly, the Midvale zone may extend farther south to well 21 because this well has a low minimum MFR fraction (0.27), but the minimum MBR fraction for this well is not low (0.45).

Other areas on the east side of the valley have potentially high levels of susceptibility. Minimum MFR and MBR fractions are both low in the area just south of Mill Creek near the mountain front (wells 50 and 86 (MFR = 0.44, MBR = 0.21, 0.32)). However, it is possible that this area simply receives more MBR from lower altitudes. Well 1 west of the Murray zone near the Jordan River has a low minimum MFR fraction (0.41). No recharge temperature data were collected in the vicinity of this well. Minimum MBR fractions are low in the Sandy and eastern Parleys zones, but, as discussed above, minimum MFR fractions are not. Minimum MBR fractions in the Sandy zone are considerably lower than in areas to the east

and southeast. However, ground water might flow to the Sandy zone largely from the south where minimum MBR fractions are unknown.

Tritium and Tritium/Helium-3 Ages

Tritium (^3H) is a radioactive isotope of hydrogen with a half-life of 12.43 years. It decays to the noble-gas isotope ^3He . Tritium naturally produced in the upper atmosphere occurs in precipitation, bound in water molecules, at concentrations of about 6 to 8 TU. Thermonuclear testing in the 1950s and 1960s introduced large amounts of ^3H to the atmosphere, causing ^3H concentrations in precipitation to peak in the early 1960s at more than 1,000 TU throughout the northern hemisphere. The measured ratio of ^3H to tritiogenic ^3He ($^3\text{He}_{\text{trit}}$) provides an age of the sampled water from the time it enters the saturated zone and becomes isolated from the atmosphere. Accuracy of the determined age can be affected by mixing between waters with different ages, dispersion, and other factors and, therefore, is qualified by using the term "apparent age." Given present analytical capabilities, the $^3\text{H}/^3\text{He}$ method can be used to date water younger than about 50 years. Details regarding the $^3\text{H}/^3\text{He}$ dating technique can be found in Solomon and Cook (2000).

$^3\text{H}/^3\text{He}$ age data for water from wells in Salt Lake Valley are presented in table 11. The 2001 samples were collected as part of this study (February and August 2001 samples from well 30 being the only exception). Data for samples collected in 2000 are from Manning (2002). More than one sample was collected at selected wells. For ^3H samples collected without a concurrent dissolved-gas sample, an age was calculated by using the $^3\text{He}_{\text{trit}}$ concentration determined for another sample from the same well. Apparent $^3\text{H}/^3\text{He}$ ages were computed for samples collected by Manning (2002) by using the probable recharge temperature and altitude (table 10). For samples collected as part of this study (in clamped copper tubes), apparent age was calculated by using a recharge temperature and altitude similar to those determined for neighboring wells, when possible; otherwise, a T_r of 9°C and a recharge altitude of 5,250 ft (corresponding to the valley/mountain transition) were assumed. Uncertainty in the apparent age resulting from uncertainty in the recharge temperature and altitude, along with analytical uncertainty, is plus or minus 3 years or less (Manning, 2002, appendix B).

Table 11. Tritium/helium-3 age data for water sampled from public-supply wells in Salt Lake Valley, Utah, 2000-01

[Well identifier, wells 1-31 are the public-supply wells sampled for water quality and tritium as part of this study and (or) by Manning (2002) and the others are public-supply wells sampled by Manning (2002); TU, tritium units; R, measured $^3\text{He}/^4\text{He}$ ratio of the sample; R_a , atmospheric $^3\text{He}/^4\text{He}$ ratio; $^4\text{He}_{\text{terr}}$, terrigenic helium-4; $\text{cm}^3\text{STP/g}$, cubic centimeters at standard temperature and pressure per gram of water; ^3He , helium-3; ^4He , helium-4; $^3\text{He}_{\text{trit}}$, tritiogenic helium-3; Interpreted age category: modern or mixture, modern or mixture of modern and pre-bomb water; modern, dominantly modern water; pre-bomb, dominantly pre-bomb water; —, not analyzed or applicable; >, greater than; boxed samples were collected from the same well]

Well identifier (fig. 16)	Sample date	Tritium (TU)	R/ R_a	$^4\text{He}_{\text{terr}}$ ($\text{cm}^3\text{STP/g}$)	Terrigenic $^3\text{He}/^4\text{He}$ ratio	$^3\text{He}_{\text{trit}}$ (TU)	Apparent age (year)	Apparent recharge year	Initial tritium (TU)	Interpreted age category
1	05/2001	8.5	0.28	1.07×10^{-6}	9.00×10^{-8}	111.0	47	1954	119.5	modern or mixture
2	05/2001	25.7	1.98	-3.08×10^{-9}	2.77×10^{-8}	33.3	15	1986	59.0	modern or mixture
3	05/2001	.3	.23	5.19×10^{-7}	1.70×10^{-7}	7.7	>50	pre-1950	8.0	pre-bomb
¹ 3	05/2001	.5	—	—	1.70×10^{-7}	—	50	1951	8.2	
3	average	.4	.23	5.19×10^{-7}	1.70×10^{-7}	7.7	>50	pre-1950	8.1	
4	05/2001	1.7	1.22	3.67×10^{-10}	2.77×10^{-8}	8.6	32	1969	10.3	pre-bomb
5	08/2000	4.0	1.74	1.51×10^{-9}	2.77×10^{-8}	24.2	35	1965	28.1	modern or mixture
¹ 5	05/2001	² 6.6	—	—	2.77×10^{-8}	—	28	1973	30.8	
5	average	5.3	1.74	1.51×10^{-9}	2.77×10^{-8}	24.2	31	1969	29.4	
6	06/2001	.5	.85	1.10×10^{-8}	1.00×10^{-8}	1.2	21	1980	1.7	pre-bomb
7	05/2001	13.3	2.24	2.41×10^{-9}	2.77×10^{-8}	51.9	29	1972	65.2	modern
¹ 7	05/2001	15.1	—	—	2.77×10^{-8}	—	27	1974	67.0	
¹ 7	05/2001	² 16.0	—	—	2.77×10^{-8}	—	26	1975	67.9	
7	average	14.8	2.24	2.41×10^{-9}	2.77×10^{-8}	51.9	27	1974	66.7	
8	07/2000	22.3	2.01	-2.08×10^{-9}	2.77×10^{-8}	32.0	16	1984	54.2	modern
¹ 8	06/2001	² 21.4	—	—	2.77×10^{-8}	—	16	1985	53.4	
8	average	21.9	2.01	-2.08×10^{-9}	2.77×10^{-8}	32.0	16	1984	53.8	
9	05/2001	.2	.37	1.06×10^{-7}	1.00×10^{-8}	3.4	>50	pre-1950	3.6	pre-bomb
10	05/2001	12.4	.36	5.41×10^{-7}	2.77×10^{-8}	78.4	36	1965	90.9	modern or mixture
11	07/2000	.5	.49	5.77×10^{-8}	1.00×10^{-8}	3.7	38	1962	4.2	pre-bomb
¹ 11	06/2001	² 2.2	—	—	1.00×10^{-8}	—	>50	pre-1950	3.9	
11	average	.4	.49	5.77×10^{-8}	1.00×10^{-8}	3.7	38	pre-1950	4.0	
12	08/2000	21.2	1.51	-4.13×10^{-9}	2.77×10^{-8}	18.6	11	1989	39.9	modern
¹ 12	05/2001	² 20.6	—	—	2.77×10^{-8}	—	12	1989	39.2	
12	average	20.9	1.51	-4.13×10^{-9}	2.77×10^{-8}	18.6	12	1989	39.6	
13	07/2000	13.4	1.43	-2.66×10^{-9}	2.77×10^{-8}	15.5	14	1986	28.9	modern
¹ 13	06/2001	² 11.9	—	—	2.77×10^{-8}	—	15	1986	27.4	
13	average	12.7	1.43	-2.66×10^{-9}	2.77×10^{-8}	15.5	14	1986	28.1	
14	05/2001	13.8	.40	3.78×10^{-7}	2.77×10^{-8}	62.0	31	1970	75.8	modern or mixture
15	06/2001	17.7	1.57	-3.49×10^{-9}	2.77×10^{-8}	18.2	13	1988	35.8	modern
16	06/2001	5.3	1.04	2.37×10^{-8}	2.77×10^{-8}	16.1	25	1976	21.4	modern or mixture
17	07/2000	12.5	1.44	5.06×10^{-10}	2.77×10^{-8}	16.6	15	1985	29.0	modern
¹ 17	05/2001	² 11.0	—	—	2.77×10^{-8}	—	17	1984	27.6	
17	average	11.8	1.44	5.06×10^{-10}	2.77×10^{-8}	16.6	16	1985	28.3	
18	05/2001	6.1	.68	6.76×10^{-8}	2.77×10^{-8}	14.5	22	1979	20.6	modern or mixture
¹ 18	05/2001	5.9	—	—	2.77×10^{-8}	—	22	1979	20.4	
¹ 18	05/2001	² 6.6	—	—	2.77×10^{-8}	—	21	1980	21.1	
18	07/2000	7.3	.73	6.04×10^{-8}	2.77×10^{-8}	17.2	22	1978	24.5	
18	average	6.5	.71	6.40×10^{-8}	2.77×10^{-8}	15.9	22	1979	21.7	

Table 11. Tritium/helium-3 age data for water sampled from public-supply wells in Salt Lake Valley, Utah, 2000-01—Continued

Well identifier (fig. 16)	Sample date	Tritium (TU)	R/R _a	⁴ He _{terr} (cm ³ STP/g)	Terrigenic ³ He/ ⁴ He ratio	³ He _{trit} (TU)	Apparent age (year)	Apparent recharge year	Initial tritium (TU)	Interpreted age category
19	05/2001	² 3.0	.31	2.02x10 ⁻⁷	2.77x10 ⁻⁸	13.7	31	1970	16.7	
19	08/2000	4.5	.31	1.97x10 ⁻⁷	2.77x10 ⁻⁸	12.8	24	1976	17.4	
19	average	3.8	.31	2.00x10 ⁻⁷	2.77x10 ⁻⁸	13.3	27	1973	17.0	modern or mixture
20	05/2001	9.1	.24	1.77x10 ⁻⁶	1.30x10 ⁻⁷	116.8	47	1954	125.9	
20	07/2000	15.3	0.33	9.74x10 ⁻⁷	2.77x10 ⁻⁸	152.7	43	1957	168.0	
20	average	12.2	.28	1.37x10 ⁻⁶	7.89x10 ⁻⁸	134.7	45	1955	147.0	modern or mixture
21	08/2000	8.9	.59	1.91x10 ⁻⁷	2.77x10 ⁻⁸	48.5	33	1967	57.4	
¹ 21	06/2001	² 7.6	—	—	2.77x10 ⁻⁸	—	36	1965	56.1	
21	average	8.3	.59	1.91x10 ⁻⁷	2.77x10 ⁻⁸	48.5	35	1966	56.7	modern or mixture
22	05/2001	10.7	1.47	-1.34x10 ⁻⁹	2.77x10 ⁻⁸	17.9	18	1983	28.6	modern
23	06/2001	.1	.79	9.83x10 ⁻⁹	1.00x10 ⁻⁸	-1.2	> 50	pre-1950	-1.2	pre-bomb
24	05/2001	.4	.77	1.36x10 ⁻⁸	1.00x10 ⁻⁸	-1.4	> 50	pre-1950	-1.0	
¹ 24	05/2001	² .0	—	—	1.00x10 ⁻⁸	—	> 50	pre-1950	-1.4	
24	average	.2	.77	1.36x10 ⁻⁸	1.00x10 ⁻⁸	-1.4	> 50	pre-1950	-1.2	pre-bomb
25	05/2001	.3	.15	1.52x10 ⁻⁶	1.50x10 ⁻⁷	7.8	>50	pre-1950	8.0	pre-bomb
26	05/2001	² 9.6	1.25	2.89x10 ⁻⁸	2.77x10 ⁻⁸	28.4	25	1976	38.0	
26	07/2000	8.7	1.27	2.50x10 ⁻⁸	2.77x10 ⁻⁸	25.1	24	1976	33.8	
26	average	9.2	1.26	2.70x10 ⁻⁸	2.77x10 ⁻⁸	26.7	25	1976	35.9	modern or mixture
27	06/2001	2.2	.32	4.70x10 ⁻⁷	1.80x10 ⁻⁷	29.0	48	1953	31.2	pre-bomb
28	05/2001	.1	.62	9.54x10 ⁻⁸	2.77x10 ⁻⁸	4.8	>50	pre-1950	4.9	pre-bomb
29	05/2001	.1	.19	6.36x10 ⁻⁷	1.50x10 ⁻⁷	8.2	>50	pre-1950	8.3	pre-bomb
30	06/2001	11.3	1.42	7.77x10 ⁻⁹	2.77x10 ⁻⁸	18.9	18	1983	30.1	
¹ 30	06/2001	² 11.8	—	—	2.77x10 ⁻⁸	—	17	1984	30.7	
30	08/2001	11.2	1.45	1.12x10 ⁻⁸	2.77x10 ⁻⁸	19.8	19	1982	31.0	
¹ 30	02/2001	9.4	—	—	2.77x10 ⁻⁸	—	20	1981	29.2	
30	average	10.9	1.43	9.49x10 ⁻⁹	2.77x10 ⁻⁸	19.3	19	1982	30.3	modern
31	06/2001	12.1	1.48	8.00x10 ⁻¹⁰	2.77x10 ⁻⁸	15.0	14	1987	27.1	modern
32	08/2000	4.3	1.29	5.25x10 ⁻⁹	2.77x10 ⁻⁸	11.7	24	1976	16.0	modern or mixture
33	07/2000	20.7	3.58	-5.10x10 ⁻¹¹	2.77x10 ⁻⁸	68.6	26	1974	89.2	modern
37	08/2000	3.6	1.49	6.71x10 ⁻¹⁰	2.77x10 ⁻⁸	16.5	31	1969	20.1	modern or mixture
38	08/2000	15.1	2.09	8.93x10 ⁻¹⁰	2.77x10 ⁻⁸	31.1	20	1980	46.2	modern
44	08/2000	.3	.20	8.84x10 ⁻⁷	2.10x10 ⁻⁷	6.7	>50	pre-1950	7.0	pre-bomb
45	09/2000	12.2	.97	5.96x10 ⁻⁹	2.77x10 ⁻⁸	2.3	3	1997	14.5	modern
47	08/2000	3.9	1.38	-5.40x10 ⁻¹⁰	2.77x10 ⁻⁸	11.2	24	1976	15.1	modern or mixture
50	07/2000	14.9	.52	7.87x10 ⁻⁸	2.77x10 ⁻⁸	4.7	5	1995	19.7	modern
68	08/2000	12.0	.49	8.23x10 ⁻⁸	2.77x10 ⁻⁸	7.6	9	1991	19.5	modern
69	08/2000	2.2	1.15	1.06x10 ⁻⁹	2.77x10 ⁻⁸	5.2	22	1978	7.4	pre-bomb
70	08/2000	3.5	1.16	2.64x10 ⁻⁹	2.77x10 ⁻⁸	6.3	18	1982	9.8	modern or mixture
72	08/2000	7.7	1.71	-1.29x10 ⁻⁹	2.77x10 ⁻⁸	24.4	26	1974	32.1	modern or mixture
73	08/2000	9.4	1.33	2.29x10 ⁻⁸	2.77x10 ⁻⁸	25.7	24	1976	35.1	modern or mixture
75	07/2000	.4	.99	7.91x10 ⁻⁹	1.00x10 ⁻⁸	4.0	43	1957	4.3	pre-bomb
76	08/2000	14.1	1.00	9.25x10 ⁻⁹	2.77x10 ⁻⁸	4.9	5	1995	19.0	modern
77	08/2000	13.4	1.82	-7.47x10 ⁻¹⁰	2.77x10 ⁻⁸	22.5	18	1982	36.0	modern
78	07/2000	.2	.61	4.75x10 ⁻⁸	2.77x10 ⁻⁸	5.1	>50	pre-1950	5.4	pre-bomb
79	07/2000	.4	.38	1.00x10 ⁻⁷	1.00x10 ⁻⁸	4.5	45	1955	4.9	pre-bomb

Table 11. Tritium/helium-3 age data for water sampled from public-supply wells in Salt Lake Valley, Utah, 2000-01—Continued

Well identifier (fig. 16)	Sample date	Tritium (TU)	R/R _a	⁴ He _{terr} (cm ³ STP/g)	Terrigenic ³ He/ ⁴ He ratio	³ He _{trit} (TU)	Apparent age (year)	Apparent recharge year	Initial tritium (TU)	Interpreted age category
80	07/2000	15.4	1.60	8.97x10 ⁻¹¹	2.77x10 ⁻⁸	15.7	13	1987	31.2	modern
81	08/2000	17.8	.69	2.35x10 ⁻⁷	2.77x10 ⁻⁸	78.9	30	1970	96.7	modern or mixture
83	08/2000	8.8	1.67	1.67x10 ⁻¹⁰	2.77x10 ⁻⁸	18.8	21	1979	27.6	modern
84	08/2000	14.7	1.26	2.82x10 ⁻⁸	2.77x10 ⁻⁸	27.0	19	1981	41.7	modern
85	07/2000	14.5	2.14	4.12x10 ⁻⁹	2.77x10 ⁻⁸	36.5	23	1977	51.0	modern
86	07/2000	16.8	.97	3.21x10 ⁻⁸	2.77x10 ⁻⁸	15.8	12	1988	32.6	modern
87	07/2000	10.1	.71	4.91x10 ⁻⁸	2.77x10 ⁻⁸	10.6	13	1987	20.6	modern
88	07/2000	13.9	.94	4.08x10 ⁻⁸	2.77x10 ⁻⁸	19.1	16	1984	33.0	modern
89	07/2000	14.4	1.27	2.68x10 ⁻⁸	2.77x10 ⁻⁸	27.8	19	1981	42.2	modern
90	07/2000	19.1	3.29	5.36x10 ⁻⁹	2.77x10 ⁻⁸	75.8	29	1971	95.0	modern
92	08/2000	29.6	3.10	-4.89x10 ⁻¹⁰	2.77x10 ⁻⁸	65.1	21	1979	94.7	modern
93	07/2000	16.5	1.10	4.66x10 ⁻⁸	2.77x10 ⁻⁸	30.7	19	1981	47.2	modern
94	07/2000	9.0	1.50	5.82x10 ⁻¹⁰	2.77x10 ⁻⁸	15.6	18	1982	24.6	modern
96	07/2000	1.1	.30	1.32x10 ⁻⁷	1.00x10 ⁻⁸	3.3	25	1975	4.5	pre-bomb
97	08/2000	1.2	.34	1.54x10 ⁻⁷	2.77x10 ⁻⁸	11.4	42	1958	12.6	pre-bomb

¹ Replicate tritium sample. Data from corresponding dissolved-gas sample collected from the same well were used to determine age.

² Tritium analysis done by U.S. Geological Survey laboratory. All other tritium analyses done by University of Utah, Department of Geology and Geophysics, Tritium and Noble Gases Laboratory.

Uncertainty in the apparent ³H/³He ages is controlled mainly by the terrigenic ⁴He (⁴He_{terr}) concentration (Plummer and others, 2000; Holocher and others, 2001). As noted above, terrigenic ⁴He results from subsurface nuclear reactions (uranium- and thorium-series decay within the Earth's crust). Helium-3 also is produced in these reactions. The ratio of ³He to ⁴He produced (terrigenic ³He/⁴He ratio) is poorly constrained, so apparent ages for samples with elevated ⁴He_{terr} concentrations are more uncertain. Water from most of the sampled wells (43 of 64) has relatively low ⁴He_{terr} (concentrations less than 5x10⁻⁸ cm³STP/g) (table 11). Uncertainties in apparent ages from these wells are generally plus or minus 3 years or less (Manning, 2002, appendix B). Apparent ages for wells with ⁴He_{terr} concentrations greater than 5x10⁻⁸ cm³STP/g have greater uncertainties. Apparent ³H/³He ages determined for different water samples collected from the same well generally differ by less than 5 years (table 11), even though these samples were collected about a year apart in many cases.

Because the sampled wells are public-supply wells that generally have long open intervals (typically 150 to 500 ft), the samples likely contain a mixture of waters with different ages. The manner in which mixing complicates the interpretation of apparent ³H/³He ages is discussed in Maloszewski and Zuber

(1982). The most significant concern for the purposes of this study is potential mixing between water recharged before thermonuclear testing began in the early 1950s and water recharged during and after the testing period. The apparent ³H/³He age of such mixtures of modern water (younger than about 50 years) and pre-bomb water (older than about 50 years) is approximately the age of the modern fraction, meaning that the apparent age can be substantially younger than the flow-weighted mean age.

Whether or not a sample might contain a substantial fraction of pre-bomb water can be determined by comparing the initial ³H concentration of the sample (measured ³H + measured ³He_{trit}) to that of local precipitation at the apparent time of recharge (apparent recharge year). For an unmixed sample, the initial ³H concentration represents the ³H concentration of the sampled water at the time of recharge, and it should be approximately equal to the ³H concentration in precipitation at the time of recharge. A sample with an initial ³H concentration less than that expected based on the local precipitation ³H record may contain an appreciable fraction of pre-bomb water, meaning that its apparent age may be biased young. Initial ³H concentrations for water from the public-supply wells are plotted in figure 21 along with mean annual ³H concentrations in precipitation in Salt Lake City from 1953 to 2000.

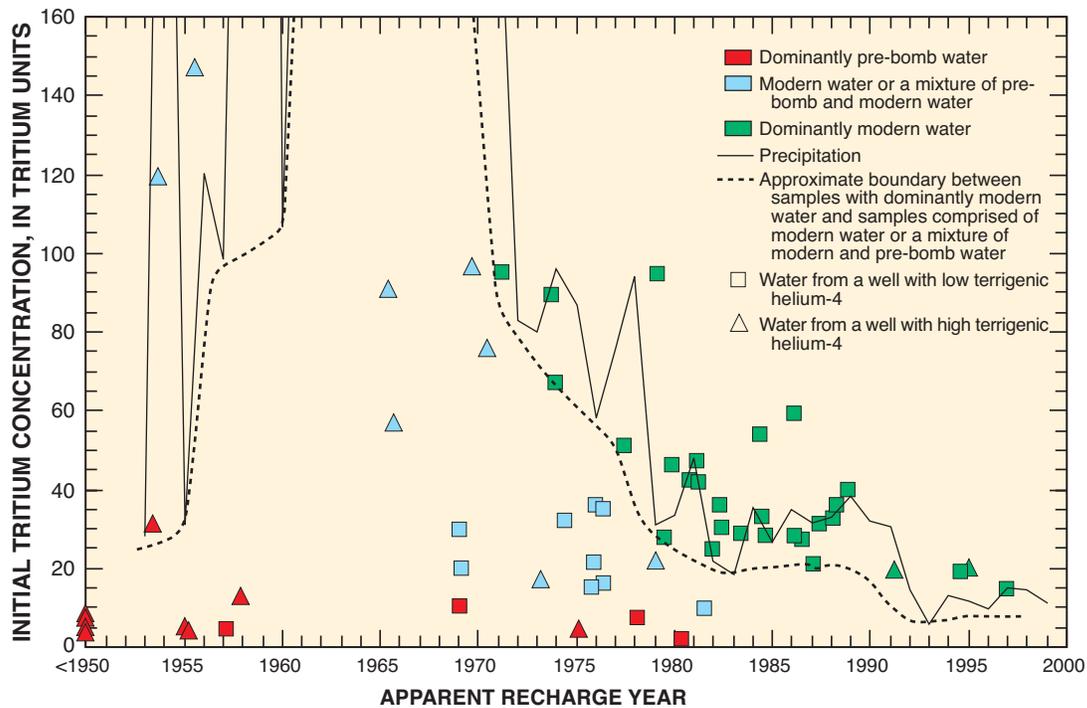


Figure 21. Graph showing Tritium concentration in precipitation and the relation between initial tritium concentration and apparent recharge year for water sampled from the principal aquifer in Salt Lake Valley, Utah, 2000-01.

Monthly precipitation data are available for most of 1963-84 (International Atomic Energy Agency, 2002). Mean annual ^3H concentrations prior to 1963 and after 1984 were estimated by correlation with the precipitation ^3H record for Ottawa, Canada (International Atomic Energy Agency, 2002).

Data from figure 21 along with the ^3H concentration of the water samples were used to place each well in one of three interpreted-age categories (table 11). Waters plotting near or above the precipitation line are dominantly modern and do not contain a substantial fraction of pre-bomb water. Waters with ^3H concentrations less than about 2 TU are dominantly pre-bomb, containing less than about 20 percent modern water. Waters that plot below the precipitation line and have ^3H concentrations greater than about 2 TU may be either modern or a mixture of modern and pre-bomb water (note that modern water may plot below the precipitation line if it is a mixture of modern waters of different ages). Waters with elevated $^4\text{He}_{\text{terr}}$ (greater than $5 \times 10^{-8} \text{ cm}^3 \text{STP/g}$) are distinguished from those with low $^4\text{He}_{\text{terr}}$ (less than $5 \times 10^{-8} \text{ cm}^3 \text{STP/g}$) in figure 21

because initial ^3H concentrations for waters with elevated $^4\text{He}_{\text{terr}}$ are less certain. Initial ^3H concentrations for waters with low $^4\text{He}_{\text{terr}}$ have an uncertainty of less than about plus or minus 4 TU. Uncertainty in initial ^3H may be considerably greater for waters with high $^4\text{He}_{\text{terr}}$. Waters from wells 1, 20, and 27, with apparent ages in the 1950s, were designated as dominantly pre-bomb or a mixture of modern and pre-bomb waters even though their initial ^3H concentrations plot near the precipitation line. Because of high $^4\text{He}_{\text{terr}}$, initial ^3H concentrations for waters from these three wells are highly uncertain and may actually be considerably less than precipitation ^3H concentrations in the 1950s.

Distributions of apparent $^3\text{H}/^3\text{He}$ age and interpreted-age category for water from public-supply wells in Salt Lake Valley are shown in figures 22 and 23, respectively. Apparent ages range from 3 years to more than 50 years. The two distributions are generally in good agreement. Both the apparent age and the fraction of pre-bomb water generally increase with distance from the mountain front on the east side of the valley. Generally, waters with apparent ages of less than 20

years are dominantly modern, waters with apparent ages of 20 to 40 years are modern or a mixture of modern and pre-bomb waters, and waters with apparent ages of more than 40 years are dominantly pre-bomb. Wells containing larger fractions of modern water should be more susceptible than those containing smaller fractions of modern water.

The ^3H and ^3He data are generally consistent with the Murray and Midvale zones being areas of particularly high susceptibility as a result of locally recharged water from the shallow unconfined aquifer entering the principal aquifer. Because locally recharged water follows relatively short flow pathways, wells containing such water should yield ages that are anomalously young compared to other wells located a similar distance from the mountain front. Both the apparent age and age-category distributions (figs. 22 and 23) indicate that this is indeed the case for wells in the Murray zone. Water in the Midvale zone is not younger than water in immediately adjacent areas. However, if the boundary of the Midvale zone were extended to the north to include well 1 and to the southeast to include wells 21 and 81, the Midvale zone would clearly constitute an area of anomalously young water, indicative of local recharge.

Apparent ages of water in the primary recharge areas, secondary recharge areas, and discharge areas in the valley generally are consistent with the conceptual model for the ground-water flow system. Ages of ground water in the primary and secondary recharge areas are generally younger on the east side of the valley than on the west side (fig. 24), indicating that recharge rates are generally larger on the east side. On the east side of the valley, the youngest water is generally in the primary recharge area. Water becomes older with distance from the mountain front, the oldest water being in the discharge area (fig. 24). Outliers to this trend are the Sandy and Murray zones. Water from wells 29 and 44 in the Sandy zone has an apparent age more than 50 years even though the wells are in the secondary recharge area. Isotopic values are lighter in water from these wells than in those to the east (fig. 17). As discussed in the "Dissolved Gas Recharge Temperatures" section of this report, wells in the Sandy zone may receive recharge from a different source than wells to the north and east. Water from wells 31, 77, and 80 in the Murray zone has an apparent age of 13 to 18 years with no substantial component of pre-bomb water even though the wells are located in the discharge area.

On the west side of the valley, the median apparent age of water from wells in the secondary recharge and discharge areas is younger than that of water from wells located in the primary recharge area (fig. 24). This is probably because loss from canals diverted from the Jordan River and infiltration from irrigated fields are major components of recharge on the west side of the valley and the primary recharge area is located above most of these sources. All four of the sampled wells upgradient from the irrigation canals, three in the primary recharge area and one in the secondary recharge area, have dominantly pre-bomb water (fig. 23).

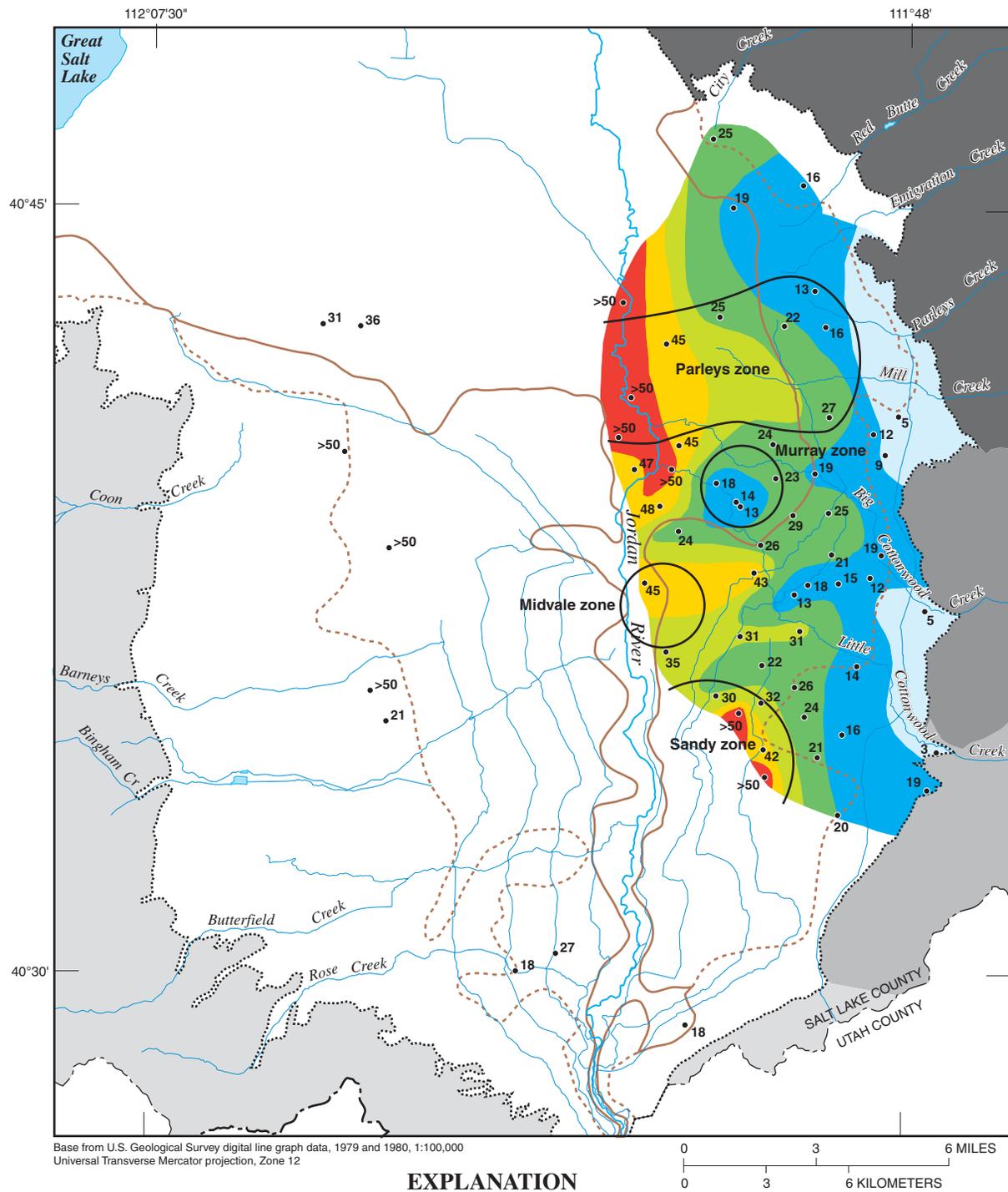
The apparent ages of the dominantly modern waters should not have a significant young-age bias and should approximate the flow-weighted mean age of water in the well. The age gradient indicated by wells with dominantly modern water can therefore be used to estimate a recharge rate by using the simple relation:

$$Q = vnA, \quad (1)$$

where:

- Q is the recharge rate in the form of a volumetric flow rate;
- v is the average linear ground-water flow velocity;
- n is the average effective porosity; and
- A is the cross-sectional area normal to the flow direction.

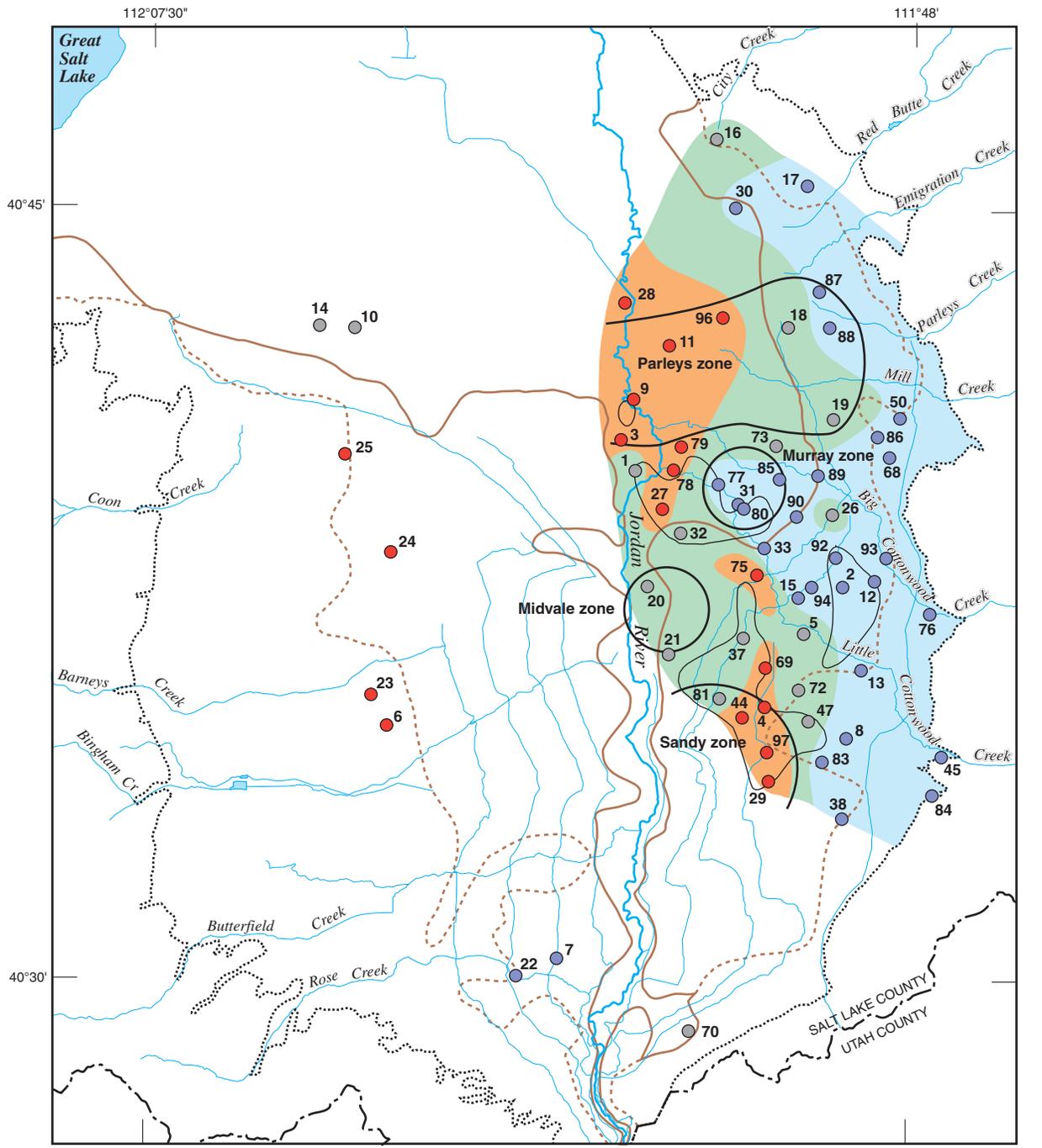
An approximate recharge rate was derived for the southeastern part of the valley where most of the public-supply wells are located. This includes the area from the mouth of Mill Creek Canyon southward to about 2 mi south of the mouth of Little Cottonwood Canyon. If wells in the Murray zone are excluded on the basis that they are likely drawing water from the shallow unconfined aquifer (fig. 22 and above discussion), the apparent ages of the dominantly modern waters increase from about 5 to about 20 years within approximately 2 mi of the mountain front. This yields a typical age gradient of about 7.5 years per mi, corresponding to an average linear ground-water flow velocity of about 1.9 ft/d. Freethey and others (1994) calculated local average linear velocities for the valley area extending outward from Big and Little Cottonwood Canyons by using measured and estimated water levels, hydraulic conductivity, and porosity. They reported that average linear velocity ranged from



EXPLANATION

Apparent tritium/helium-3 age, in years					
Less than 10	10 to 20	20 to 30	30 to 40	40 to 50	Greater than 50
Dominantly clastic sedimentary rocks and carbonates	Dominantly quartzite with interbedded shales	Granitic intrusive rocks	Dominantly carbonates and volcanic rocks	Boundary of zone of principal aquifer referred to in text	Boundary between secondary recharge area and discharge area
					Boundary between primary and secondary recharge area
					Approximate boundary of basin-fill deposits in Salt Lake Valley
					Public-supply well—Number is apparent age of water, in years

Figure 22. Map showing Distribution of apparent tritium/helium-3 ages for water sampled from the principal aquifer in Salt Lake Valley, Utah, 2000-01.



Base from U.S. Geological Survey digital line graph data, 1:100,000, 1979 and 1980
 Universal Transverse Mercator projection, Zone 12

EXPLANATION

- Interpreted-age categories for water from principal aquifer**
- Pre-bomb ● Modern or a mixture of modern and pre-bomb ● Modern
- —Number is well identifier listed in table 11
- Boundary between secondary recharge area and discharge area
- - - Boundary between primary and secondary recharge areas
- Approximate boundary of basin-fill deposits in Salt Lake Valley
- Boundary of area where the dissolved-solids concentration in water from more than one well increased 20 percent or more during 1988–2002
- Boundary of zone of principal aquifer referred to in text

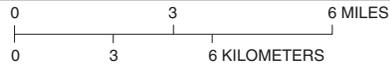


Figure 23. Map showing Distribution of interpreted-age category for water sampled from the principal aquifer in Salt Lake Valley, Utah, 2000-01.

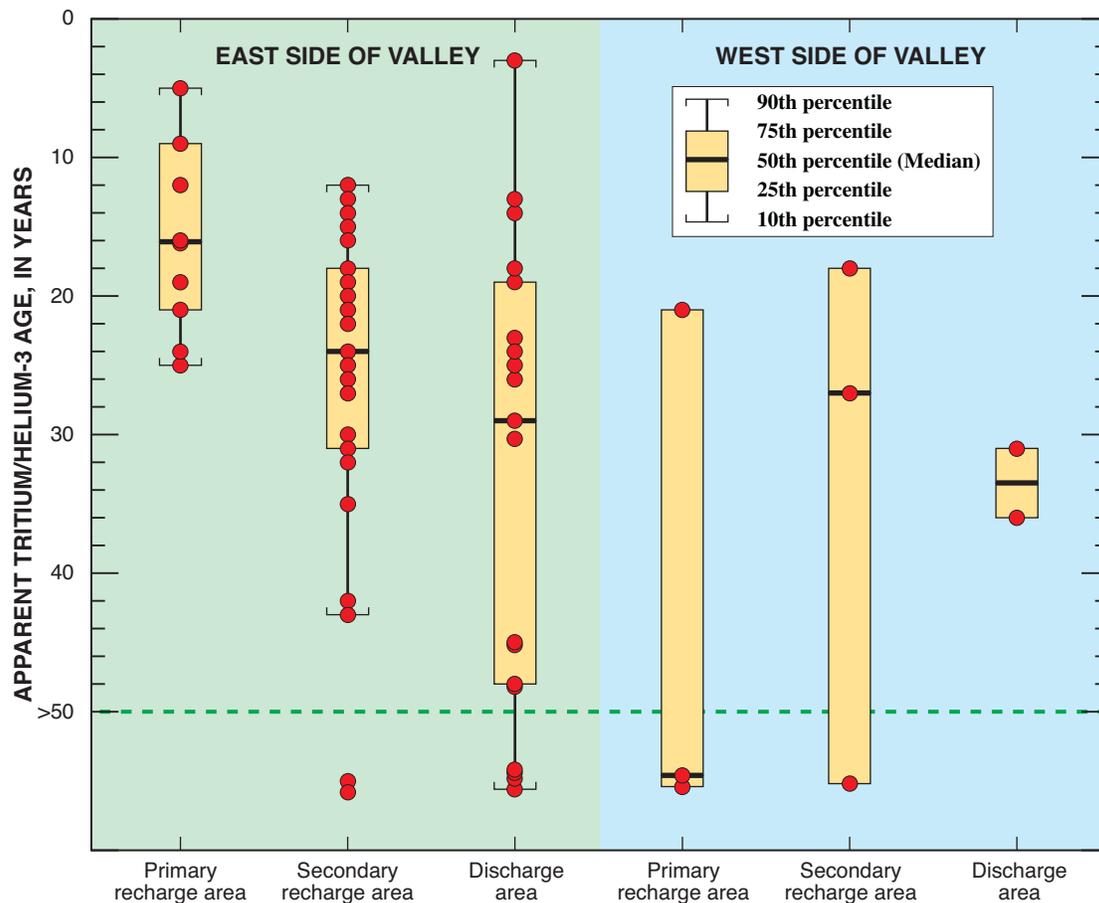


Figure 24. Graph showing Range and distribution of apparent tritium/helium-3 age for water from the principal aquifer by area in Salt Lake Valley, Utah.

0.06 to 144 ft/d, with a median value of 3 ft/d. The average linear velocity derived from the age data is thus in general agreement with the results of Freethey and others (1994), albeit about 40 percent lower than their median value.

Assuming $v = 1.9$ ft/d, $n = 0.2$ (this takes into account low flow in fine-grained lenses), an average saturated thickness of 330 ft (generally ranges from 150 to 500 ft), and a north-south length of 10 mi (this assumes dominantly westward flow in the area of computation), the approximate recharge rate for the southeastern part of the valley is about 55,000 acre-ft/yr. This generally is consistent with, though slightly lower than, the recharge rate of 59,000 acre-ft/yr for this area in the ground-water flow model developed by Lambert (1995).

It should be recognized that the above estimation involves significant generalizations regarding the aquifer geometry and ground-water flow pathways. The purpose of the estimation is to determine whether the age data are roughly consistent with prior recharge estimates for the southeastern part of the valley (which they are). However, the age data do not rule out the possibility that MBR rates in this highly used part of the valley have been overestimated in prior studies. Manning (2002) took a considerably more rigorous approach in using the age distribution to constrain MBR rates, and concluded that the average MBR rate for the southeast area is probably 10 to 70 percent less than that in Lambert's (1995) model. The age distribution and well-water temperature distribution were used to calibrate a three-dimensional finite-element model of heat and fluid transport in the southeastern part of

the valley that included both the valley and the mountain block. MBR rates greater than 90 percent of Lambert's (1995) estimate were ruled out because they result in colder well-water temperatures than those observed. However, Manning's (2002) model is highly generalized, also. Ideally, the tracer data presented in this report and the extensive hydrologic data utilized by Lambert (1995) should be used together to calibrate a three-dimensional heat and fluid flow model similar to that of Manning (2002), but spatially more refined. Such a model has the potential to place powerful constraints on MBR rates to the eastern part of Salt Lake Valley.

Chlorofluorocarbon Ages

CFCs are stable organic compounds that are solely anthropogenic. After their introduction in the 1930s, atmospheric concentrations increased nearly exponentially until the 1990s. Because ground water becomes isolated from the atmosphere after entering the saturated zone, CFC concentrations in ground water can be correlated with atmospheric CFC concentrations at the time of recharge, providing a ground-water age. As with the $^3\text{H}/^3\text{He}$ method, the CFC method is typically used to date ground water younger than about 50 years (modern water). CFCs generally are conservative in aerobic systems. Under anaerobic conditions, however, they may undergo microbial degradation. In populous areas, CFC contamination from leaking sewage systems and other sources is a common problem in the application of the CFC dating method. Details regarding the CFC dating method are published in Busenberg and Plummer (1992).

Water samples for CFC analysis were collected from 31 wells, and the results are presented in table 12. All of the samples were collected during 2001 as part of this study. Apparent CFC ages were calculated by using the procedure described in Plummer and Busenberg (2000). The same T_r and recharge altitude used in the computation of the $^3\text{H}/^3\text{He}$ ages were used in the CFC age derivations. Apparent CFC ages determined for different samples collected from the same well in most cases differ by less than or equal to 3 years. An average value is also listed in table 12.

As mentioned in the "Tritium and Tritium/Helium-3 Ages" section of this report, the ground water sampled likely contains a mixture of water with different ages as a result of long open intervals in the

public-supply wells. In some cases, CFC concentrations can be used by themselves to determine the fraction of pre-bomb water in a sample, assuming that the modern fraction is of a single age (simple binary mixture) (Plummer and Busenberg, 2000). This is done by considering the CFC concentrations relative to one another (for example, the CFC-113/CFC-12 ratio) in addition to the absolute CFC concentrations. The pre-bomb fraction of water in a sample also can be determined if CFC concentrations are measured in conjunction with ^3H and ^3He . As previously noted, the apparent $^3\text{H}/^3\text{He}$ age of modern/pre-bomb mixtures is very nearly that of the modern fraction. The apparent CFC age of modern/pre-bomb mixtures increases with the magnitude of the pre-bomb fraction, and should be older than the apparent $^3\text{H}/^3\text{He}$ age. Therefore, the pre-bomb fraction should be the fraction by which the CFC concentration must be divided to result in agreement between the apparent CFC age and the apparent $^3\text{H}/^3\text{He}$ age. Finally, CFC concentrations near detection limits should indicate a sample almost entirely composed of pre-bomb water.

Water samples with CFC concentrations greater than water equilibrated with the atmosphere in 2001 are considered CFC contaminated. Contamination may occur in the aquifer or during sample collection. However, because established sampling protocols were carefully followed (see "Sample Collection" section of this report), the former is considered more likely. Water sampled from nearly half of the wells (14 of 31) is contaminated with at least 1 of the CFCs analyzed (table 12). Seven of the wells contained water contaminated with two of the three CFCs analyzed. The frequency of CFC-contaminated samples indicates the possibility that many of the water samples that appear uncontaminated with CFCs may actually be contaminated. A comparison of apparent $^3\text{H}/^3\text{He}$ ages and apparent CFC ages (fig. 25) indicates that this is the case. Uncontaminated samples containing all modern water or mixed modern/pre-bomb water should plot near or above the 1:1 line in figure 25, respectively, because apparent $^3\text{H}/^3\text{He}$ ages are biased to the modern-water component. Several of the samples plot well below the 1:1 line (apparent CFC age is younger than apparent $^3\text{H}/^3\text{He}$ age), indicating CFC contamination. It should be recognized that a sample plotting near the 1:1 line is not necessarily uncontaminated; it could be a contaminated sample containing a mixture of modern and pre-bomb water that would have plotted above the 1:1 line in the absence of contamination.

Table 12. Chlorofluorocarbon age data for water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001

[CFC-11, trichlorofluoromethane; CFC-12, dichlorodifluoromethane; CFC-113, trichlorotrifluoroethane; pg/kg, picogram per kilogram; C, contaminated; E, exceeds calibration range; bold lettering represents averages for multiple ampoules collected from each well]

Well identifier (fig. 5)	Measured concentration			Apparent age			Apparent recharge year		
	CFC-11 (pg/kg)	CFC-12 (pg/kg)	CFC-113 (pg/kg)	CFC-11 (years)	CFC-12 (years)	CFC-113 (years)	CFC-11	CFC-12	CFC-113
1	253.4	344.2	204.3	30	13	C	1971.5	1988.5	C
1	254.8	365.4	203.3	30	11	C	1971.5	1990.5	C
1	284.9	356.2	213.2	29	12	C	1972	1989.5	C
1	264.4	355.3	206.9	30	12	C	1972	1990	C
2	686.9	186.6	28.9	17	24	22	1984.5	1977	1979
2	687.0	181.6	18.1	17	25	26	1984.5	1976.5	1975.5
2	683.4	169.9	27.4	17	26	23	1984.5	1975.5	1978.5
2	685.8	179.3	24.8	17	25	24	1985	1976	1978
3	2.4	3.1	0	51	53	46	1950.5	1948	1955
3	2.7	10.9	0	51	47	46	1950.5	1954	1955
3	1.9	2.0	0	51	55	46	1950	1946.5	1955
3	2.3	5.3	0	51	52	46	1950	1950	1955
4	8.7	15.5	4.4	47	44	35	1954	1957	1966
4	8.7	18.5	4.4	47	43	35	1954	1958.5	1966
4	9.0	23.7	3.7	47	41	36	1954	1960	1965
4	8.8	19.2	4.2	47	43	36	1954	1959	1966
5	10.2	5.5	9.5	47	51	30	1954.5	1950	1971
5	9.7	5.1	9.5	47	51	31	1954	1950	1970.5
5	9.3	5.0	6.1	47	52	34	1954	1949.5	1967.5
5	9.8	5.2	8.4	47	52	32	1954	1950	1970
6	10,907.2	2,397.2	35,592.7	C	C	C	C	C	C
6	E	2,331.3	E	C	C	C	C	C	C
6	¹ 10,907.2	2,364	¹ 35,592.7	C	C	C	C	C	C
7	2,300.4	345.7	22.7	C	C	22	C	C	1979
7	2,273.3	340.0	22.4	C	C	22	C	C	1979
7	2,235.9	335.3	22.5	C	C	22	C	C	1979
7	2,269.9	340.3	22.5	C	C	22	C	C	1979
8	2,719.6	274.3	175.5	C	18	C	C	1983.5	C
8	2,682.9	267.7	167.5	C	18	C	C	1983	C
8	2,820.1	305.8	187.5	C	15	C	C	1986	C
8	2,740.8	282.6	176.8	C	17	C	C	1984	C
9	1.1	2.5	0	52	54	46	1949	1947.5	1955
9	1.9	1.3	0	51	56	46	1950	1945.5	1955
9	1.6	13.6	0	52	45	46	1949.5	1956	1955
9	1.5	5.8	0	52	52	46	1950	1950	1955
10	706.5	271.7	79.9	8	12	12	1993.5	1989.5	1989.5
10	715.5	276.6	34.9	8	11	19	1993.5	1990	1982.5
10	706.5	276.8	75.0	8	11	12	1993.5	1990	1989
10	709.5	275.0	63.3	8	12	14	1994	1990	1987
11	7.0	6.9	7.3	48	49	31	1953.5	1952.5	1970.5
11	2.6	3.6	4.3	50	52	35	1951	1949	1966.5

Table 12. Chlorofluorocarbon age data for water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001—Continued

Well identifier (fig. 5)	Measured concentration			Apparent age			Apparent recharge year		
	CFC-11 (pg/kg)	CFC-12 (pg/kg)	CFC-113 (pg/kg)	CFC-11 (years)	CFC-12 (years)	CFC-113 (years)	CFC-11	CFC-12	CFC-113
11	3.8	4.9	.0	49	51	46	1952	1950.5	1955
11	4.5	5.1	3.9	49	51	37	1952	1951	1964
12	4,520.7	348.8	108.4	C	14	13	C	1987.5	1988.5
12	4,866.3	337.0	120.5	C	14	12	C	1987	1989.5
12	5,136.8	359.2	128.5	C	13	10	C	1988	1991
12	4,841.3	348.4	119.1	C	14	12	C	1988	1990
13	4,872.5	374.2	72.0	C	C	14	C	C	1987
13	1,889.2	342.6	71.4	C	6	14	C	1995	1987
13	2,039.5	343.5	73.6	C	6	14	C	1995.5	1987
13	2,933.7	353.4	72.3	C	6	14	C	1995	1987
14	366.2	236.6	23,551.8	24	15	C	1977	1986.5	C
14	370.6	240.4	23,797.6	24	15	C	1977.5	1986.5	C
14	366.8	239.4	23,435.6	24	15	C	1977	1986.5	C
14	367.8	238.8	23,595.0	24	15	C	1977	1987	C
15	1,100.0	361.8	105.9	C	7	11	C	1994.5	1990
15	1,096.4	362.4	100.0	C	6	12	C	1995.5	1989.5
15	1,118.4	323.3	102.8	C	12	12	C	1989	1989.5
15	1,104.9	349.2	102.9	C	8	12	C	1993	1990
16	491.8	125.7	29.6	21	28	21	1980	1973.5	1980
16	494.8	132.2	28.4	21	27	21	1980	1974	1980
16	502.6	128.9	28.6	21	27	21	1980.5	1974	1980
16	496.4	128.9	28.9	21	28	21	1980	1974	1980
17	E	4421.0	E	C	C	C	C	C	C
17	E	4203.0	E	C	C	C	C	C	C
17	E	4312.0	E	C	C	C	C	C	C
18	467.6	204.3	18.1	17	16	23	1984	1985	1978.5
18	466.4	204.3	19.0	17	16	23	1984	1985	1978.5
18	456.1	187.7	16.6	18	18	23	1983.5	1983	1978
18	463.4	198.8	17.9	18	17	23	1984	1984	1978
19	15.8	132.8	0	44	26	46	1957	1975.5	1955
19	17.7	122.0	0	44	26	46	1957.5	1975	1955
19	18.2	122.3	0	44	26	46	1957.5	1975	1955
19	17.2	125.7	0	44	26	46	1957	1975	1955
20	1,348.5	748.5	7,659.1	C	C	C	C	C	C
20	1,345.0	732.6	7,539.3	C	C	C	C	C	C
20	1,335.6	763.7	7,437.0	C	C	C	C	C	C
20	1,343.0	748.3	7,545.1	C	C	C	C	C	C
21	8,771.2	350.9	17.7	C	1	25	C	2000	1976
21	8,827.3	356.4	18.8	C	0	25	C	2001	1976.5
21	8,947.5	342.3	17.9	C	7	25	C	1994	1976
21	8,848.7	349.9	18.2	C	3	25	C	1999	1976
22	583.5	357.5	27.6	15	C	21	1986.5	C	1980.5
22	568.0	384.4	25.8	15	C	21	1986	C	1980
22	585.9	343.9	26.5	15	C	21	1986.5	C	1980.5

Table 12. Chlorofluorocarbon age data for water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001—Continued

Well identifier (fig. 5)	Measured concentration			Apparent age			Apparent recharge year		
	CFC-11 (pg/kg)	CFC-12 (pg/kg)	CFC-113 (pg/kg)	CFC-11 (years)	CFC-12 (years)	CFC-113 (years)	CFC-11	CFC-12	CFC-113
22	579.2	361.9	26.6	15	C	21	1986	C	1980
23	3.2	3.3	0	50	52	46	1951.5	1949	1955
23	2.4	3.9	0	50	52	46	1951	1949.5	1955
23	3.1	9.8	0	50	46	46	1951.5	1955	1955
23	2.9	5.7	0	50	50	46	1951	1951	1955
24	10.3	7.6	2.6	46	48	38	1955.5	1953	1963.5
24	12.0	3.7	1.6	45	52	41	1956	1949.5	1960.5
24	12.0	3.2	5.6	45	52	32	1956	1949	1969
24	11.4	4.8	3.3	45	51	37	1956	1951	1964
25	1.5	2.0	46.7	51	54	16	1950	1947	1985
25	1.4	1.9	43.1	51	54	17	1950	1947	1984.5
25	1.4	.9	42.0	52	57	17	1949.5	1944.5	1984
25	1.5	1.6	43.9	52	55	17	1950	1946	1985
26	74.3	205.3	0	37	21	46	1964.5	1980.5	1955
26	74.2	174.7	0	37	24	46	1964.5	1977.5	1955
26	73.5	165.1	0	37	25	46	1964.5	1976.5	1955
26	74.0	181.7	0	37	23	46	1965	1978	1955
27	340.2	494.0	3.5	28	C	38	1973.5	C	1963
27	339.5	511.2	4.3	28	C	37	1973.5	C	1964.5
27	358.1	514.5	5.1	27	C	35	1974	C	1966
27	345.9	506.6	4.3	28	C	37	1974	C	1965
28	8.7	24.5	3.6	47	40	36	1954.5	1961	1965
28	8.0	23.1	3.6	47	41	36	1954	1960.5	1965.5
28	8.4	17.3	4.4	47	43	35	1954.5	1958.5	1966.5
28	8.4	21.6	3.9	47	41	36	1954	1960	1966
29	5.8	1.6	2.2	48	55	39	1953.5	1946.5	1962
29	5.1	6.0	0	48	50	46	1953	1951.5	1955
29	5.0	22.1	0	48	41	46	1953	1960.5	1955
29	5.3	9.9	.7	48	49	44	1953	1953	1957
30	92.6	219.5	14.1	35	18	26	1966.5	1983	1975
30	89.7	204.8	15.2	35	20	26	1966	1981.5	1975.5
30	89.4	201.7	15.1	35	20	26	1966	1981.5	1975.5
30	91.7	199.3	14.2	35	20	26	1966	1981	1975
30	90.8	206.3	14.6	35	20	26	1966	1982	1975
31	2,195.8	526.2	1,797.8	C	C	C	C	C	C
31	2,295.4	556.8	1,822.2	C	C	C	C	C	C
31	5,553.3	531.6	1,520.2	C	C	C	C	C	C
31	3,348.2	538.2	1,713.4	C	C	C	C	C	C

¹Average excludes samples that are contaminated or exceed calibration range.

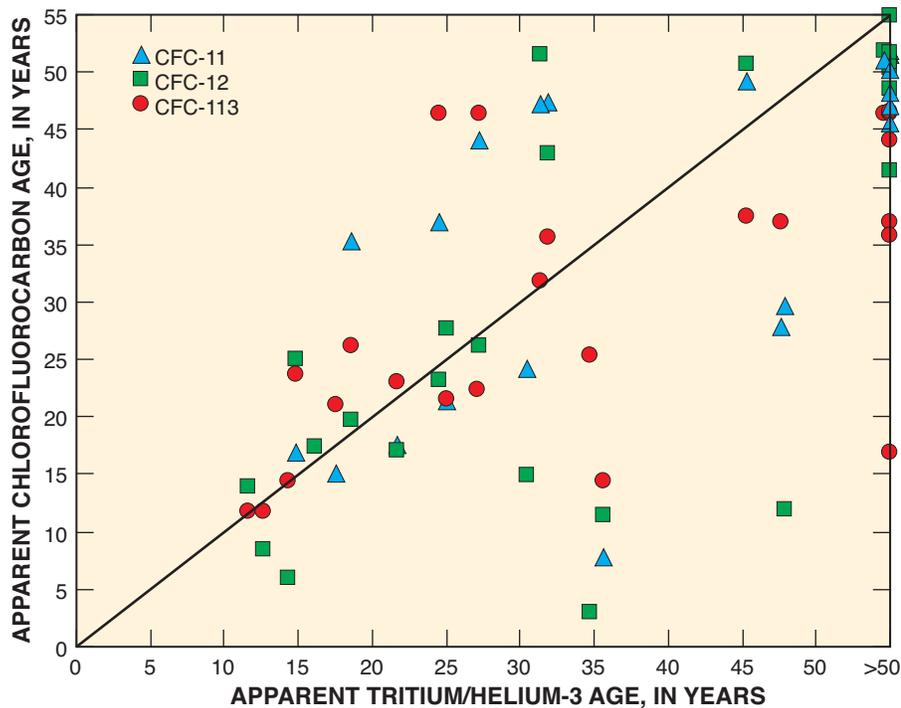


Figure 25. Graph showing Apparent chlorofluorocarbon age and apparent tritium/helium-3 age for water sampled from selected public-supply wells in Salt Lake Valley, Utah.

The frequency of CFC contamination significantly compromises the reliability of modern ages determined by the CFC method. Another consequence of the contamination is that determination of the pre-bomb fraction from CFC-concentration ratios generally is not possible. As a result of the general unreliability of the modern ages, pre-bomb fractions were not computed by adjusting apparent CFC ages to match apparent $^3\text{H}/^3\text{He}$ ages. CFC concentrations indicating recharge prior to 1955, however, are still useful in evaluating well susceptibility because wells that contain water with very low CFC concentrations likely contain a high fraction of pre-bomb water. Seven of the wells have water with concentrations of two or more CFCs that indicate recharge before 1955. Of these, all but one (well 5) also contains dominantly pre-bomb water based on ^3H concentrations. General agreement between the CFC and ^3H data sets regarding the occurrence of pre-bomb water is further indicated by the fact

that all but two of the wells containing dominantly pre-bomb water based on ^3H have apparent CFC recharge years in or prior to the mid-1960s. These apparent CFC ages are consistent with simple bimodal mixtures containing greater than 80 percent pre-bomb water, assuming the modern component is of a single age.

Contamination levels of CFCs also are potentially useful in gauging well susceptibility because wells with CFC-contaminated water most likely contain an appreciable component of modern water (assuming contamination did not occur during sampling). This generally is supported by the interpreted-age categories derived from initial ^3H concentrations. Of the 14 wells that contain water contaminated with at least 1 CFC, 8 have dominantly modern water, 4 have modern water or a mixture of modern and pre-bomb waters, and 2 have dominantly pre-bomb water.

RELATION BETWEEN GROUND-WATER QUALITY AND SOURCES OF RECHARGE

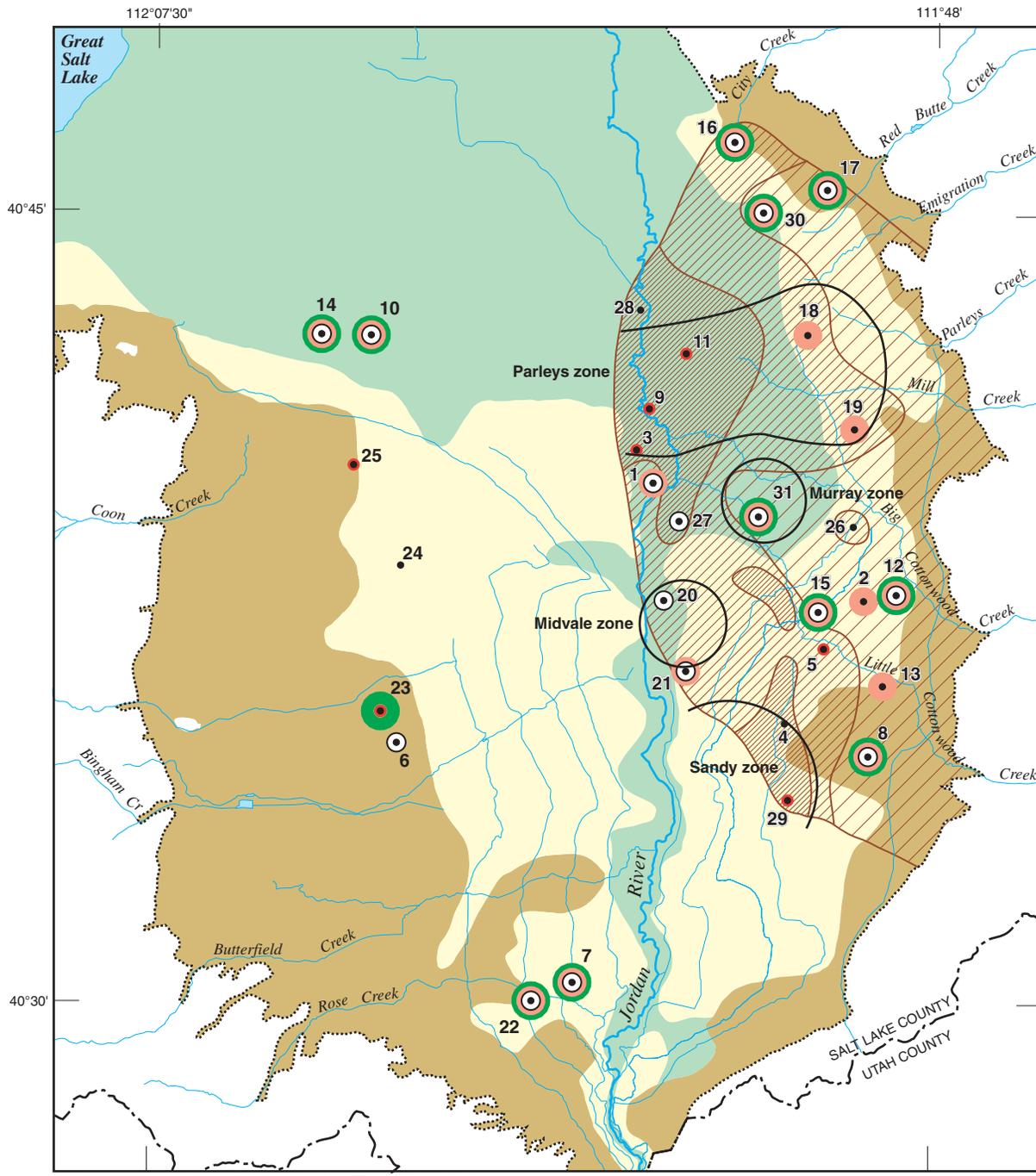
Pesticides and (or) VOCs were detected, mostly at very low concentrations, in water from 23 of the 31 public-supply wells sampled. Produced and used exclusively by humans, pesticides and VOCs are known as anthropogenic compounds. Although measured concentrations of these compounds are not a health concern, their widespread occurrence indicates the presence of water young enough to be affected by humans in much of the principal aquifer. Detection of these compounds in water from a well indicates the possibility that water with higher concentrations may enter the well in the near future. Wells with water samples in which low levels of VOCs (mainly chloroform) and pesticides (mainly atrazine and (or) its degradation products) were measured at concentrations greater than laboratory or method reporting levels (LRLs or MRLs) are shown in figure 26. Also shown are wells that contain water with nitrate concentrations greater than 2 mg/L, an estimated background level. The source of nitrate concentrations above the background level is probably the application of fertilizers and leaking or improperly functioning septic systems and sewer pipes in the valley. Wells with water that contains anthropogenic compounds above reporting levels and (or) nitrate concentrations above 2 mg/L are referred to below as "affected wells." Eighteen of the 31 public-supply wells sampled (58 percent) are affected wells. The fact that a well is affected confirms that it has a reasonably high level of susceptibility.

The presence of anthropogenic compounds at concentrations above reporting levels and elevated nitrate concentrations in the principal aquifer (fig. 26) generally is not well correlated with the distribution of minimum MFR (fig. 18) and minimum MBR (fig. 20) fractions of water derived from $\delta^{18}\text{O}$ and T_r data, respectively. Many of the affected wells have high MFR and MBR fractions of water, indicating that wells containing even small amounts of valley recharge (probably 10 to 20 percent) are reasonably susceptible. Only two of the wells sampled for anthropogenic compounds fall into the highest susceptibility group according to both $\delta^{18}\text{O}$ and T_r data: well 31 in the Murray zone and well 20 in the Midvale zone. Well 31 is affected, but well 20 is not. It should be noted, however, that $\delta^{18}\text{O}$ data indicate that the Midvale zone may extend farther to the north and southeast to include

wells 1 and 21, and both of these wells are indeed affected. Therefore, the minimum MFR and MBR fractions may still be useful tools for identifying those highest susceptibility areas where wells are clearly drawing in a substantial amount of valley recharge.

The presence of anthropogenic compounds and elevated nitrate concentrations in the principal aquifer (fig. 26) is very well correlated with the distribution of interpreted-age categories (fig. 23 and 26). Nearly all of the affected wells (17 of 18) have either dominantly modern water or a mixture of modern and pre-bomb waters, meaning that they probably contain more than 20 percent modern water. Well 23 is the only affected well that contains dominantly pre-bomb water. Well 23 is also the only affected well that does not contain anthropogenic compounds above reporting levels. Most of the unaffected wells (10 of 13) contain dominantly pre-bomb water and thus contain little modern water (less than 20 percent). All of the wells (10 of 10) with dominantly modern water are affected. Seventy percent (7 of 10) of the wells with dominantly modern or a mixture of modern and pre-bomb waters are affected. Nine percent (1 of 11) of the wells with dominantly pre-bomb water are affected. These results indicate that much of the modern ground water in Salt Lake Valley contains anthropogenic-compound concentrations above reporting levels or nitrate concentrations greater than the estimated background level of 2 mg/L. As expected, pre-bomb water generally is free of these human effects. Therefore, $^3\text{H}/^3\text{He}$ data appear to be of great value in evaluating well susceptibility in the principal aquifer.

Wells that contain water contaminated with at least one CFC and with CFC concentrations indicative of recharge prior to 1955 (low CFC concentrations) are also shown in figure 26. Eleven of the 14 wells that contain CFC-contaminated water also are affected wells, indicating that the presence of CFC contamination may be a relatively useful indicator of high susceptibility. Six of the seven wells that contain water with low CFC concentrations are not affected, indicating that low CFC concentrations may be a reliable indicator of low susceptibility. Well 23 is the single affected well (elevated nitrate concentrations) that has water with low CFC concentrations (indicative of recharge prior to 1955). This is consistent with the $^3\text{H}/^3\text{He}$ results that indicate dominantly pre-bomb water from well 23.



Base from U.S. Geological Survey digital line graph data, 1979 and 1980, 1:100,000
 Universal Transverse Mercator projection, Zone 12

EXPLANATION

- | | |
|---|---|
| Interpreted-age categories of water from principal aquifer | |
| | Dominantly pre-bomb |
| | Modern or a mixture of modern and pre-bomb |
| | Dominantly modern |
| | Discharge area |
| | Primary recharge area |
| | Secondary recharge area |
| | Approximate boundary of basin-fill deposits in Salt Lake Valley |
| | 22● Public-supply well sampled as part of this study—Number is well identifier |
| | ● Apparent chlorofluorocarbon age of water is pre-1955 |
| | ○ Water is contaminated with at least one chlorofluorocarbon |
| | ○ Volatile organic compound or pesticide detected in water at concentrations above laboratory reporting levels or method detection levels |
| | ○ Nitrate concentration of water greater than 2 milligrams per liter |

Figure 26. Map showing Interpreted-age category, chlorofluorocarbon, anthropogenic-compound, and nitrate information for water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001.

The relation between the occurrence and concentration of anthropogenic compounds, nitrate, and other variables was examined with the Spearman rank correlation test (Helsel and Hirsch, 1992, p. 209-218). The correlation coefficient (ρ) varies from 1 to -1 and describes the strength of the correlation. Values closer to 1 indicate a positive correlation, values closer to -1 indicate an inverse correlation, and values closer to 0 indicate no correlation. The p-value (probability of no correlation) was used to evaluate the significance of the correlation. P-values less than 0.10 are considered statistically significant, whereas larger p-values indicate a greater probability of no correlation.

The number of anthropogenic compounds detected (includes estimated concentrations less than LRL or MRLs) in water sampled from each well is inversely correlated with the apparent $^3\text{H}/^3\text{He}$ age (fig. 27). Anthropogenic compounds were not detected in water with an apparent age older than 50 years, except for water from well 25. Interpretation of the trace amount of atrazine detected in water from this well (0.004 $\mu\text{g}/\text{L}$) and application to the aquifer as a whole should be done with caution because of the large depth to the well openings (636-1,202 ft below land surface). Nitrate concentration in water from the 31 sampled public-supply wells is correlated with many factors, such as depth to the top of the well's open interval, the $\delta^{18}\text{O}$ ratio of the water, the apparent age of the water determined from the $^3\text{H}/^3\text{He}$ method, and the number of anthropogenic compounds detected in water per well. Generally, nitrate concentration in water from the sampled wells increased as the depth to the top of the well's open interval became shallower; as the $\delta^{18}\text{O}$ ratios became heavier and, therefore, the MFR fraction became smaller; as the apparent age of the water became younger; and as the number of anthropogenic compounds detected in water per well increased (fig. 27). On the basis of these correlations, nitrate concentration in water from many of the wells is related to the occurrence of modern valley recharge.

The concentration of anthropogenic compounds in a water sample was considered to be the sum of all VOC and pesticide compounds detected. For most wells where VOC or pesticide compounds were detected in the water, total concentrations decreased as the apparent $^3\text{H}/^3\text{He}$ age increased (fig. 28). Generally, wells with dominantly pre-bomb water had very low or undetected total concentrations of anthropogenic compounds. All of the samples that contained mostly modern water contained at least one anthropogenic

compound. Anomalously high concentrations of chloroform, bromodichloromethane, and chlorodibromomethane were measured in water samples from wells 8 and 13, likely the result of chlorinated surface water occasionally injected into the principal aquifer at these wells as artificial recharge. Note, however, that these wells are only used as injection wells for a short duration each spring, and the injected water constitutes a very small fraction of the total volume removed from these wells since the initiation of the artificial recharge program in 2000. Well 26 is the only well containing modern or a mixture of pre-bomb and modern waters in which no anthropogenic compounds were detected.

Total concentration of VOCs and pesticides in water generally decreased as the depth to the top of the open interval in the well became deeper (fig. 28). Artesian conditions exist at all six of the wells where the top of the open interval is less than 150 ft below land surface. Anthropogenic compounds or CFC contamination occur in water from five of these wells, indicating that wells with shallow openings are susceptible to receiving recently recharged water despite the natural upward gradient in a discharge area. Human activities in the adjacent recharge area may be the source of these compounds in water from wells 10, 14, and 30. Wells 27 and 31 are farther from the primary recharge area and CFC contamination in water samples from these wells may be the result of a reversal in the water-level gradient near the wells.

Areas with an increase in dissolved-solids concentration greater than 20 percent from 1988-92 to 1998-2002 (figs. 7 and 8) generally correspond to areas with relatively large components of modern water (fig. 23), except for near the Jordan River west of the Murray zone and in the Sandy zone. Although in the discharge area, water sampled from wells 1 and 27 contained tritium and CFC contamination indicating mixing with a modern component of water. Withdrawals from the principal aquifer in the area may have allowed recently recharged water to move downward into the aquifer in the vicinity of these wells. Ground water with dissolved-solids concentrations greater than 500 mg/L has extended farther into the Sandy zone during the last decade. As discussed in previous sections, water in this area is isotopically lighter than water from the Jordan River, has a warmer recharge temperature than ground water to the east, and was recharged before the 1950s. Lateral movement of

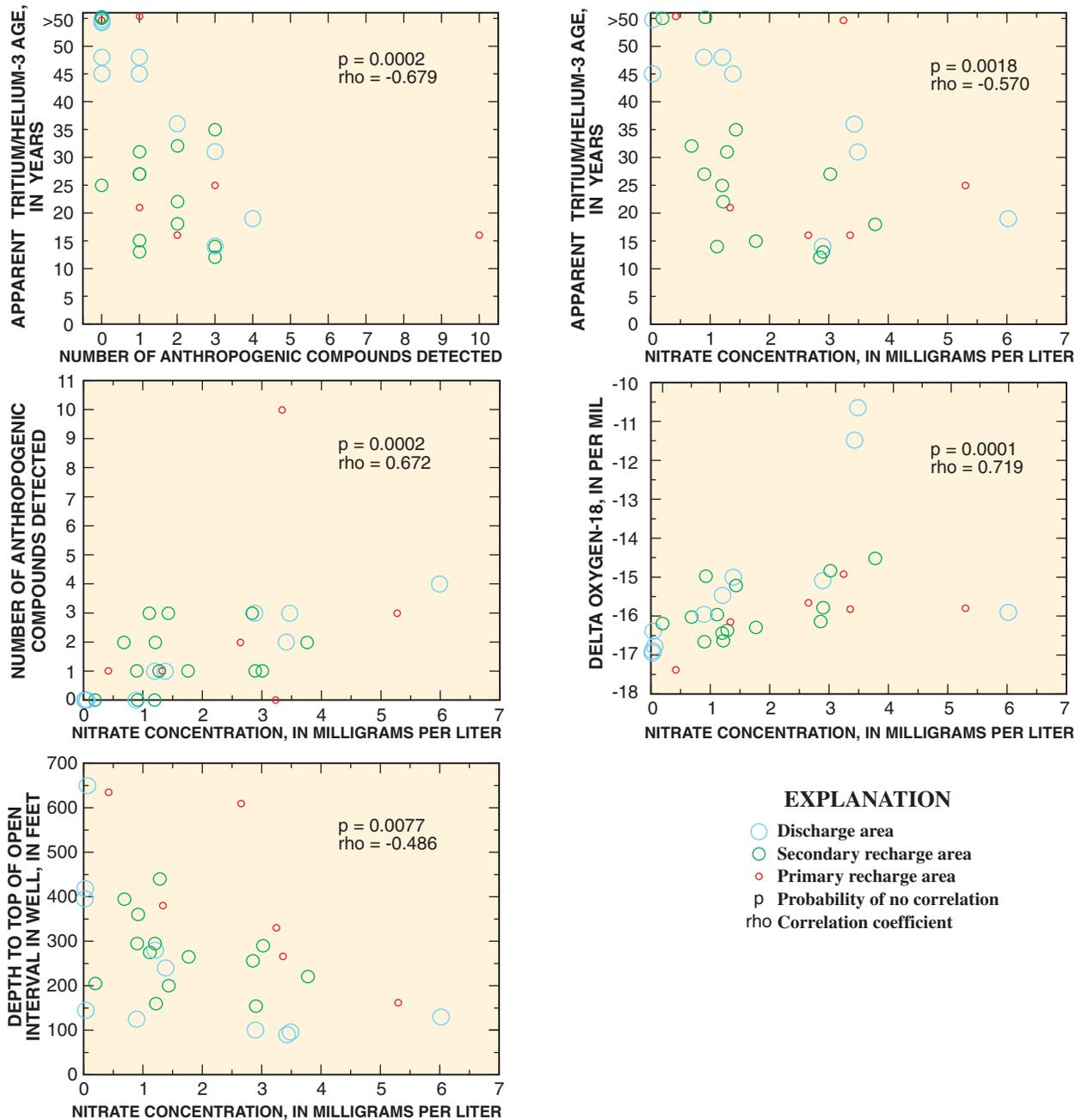


Figure 27. Graphs showing Relation among the occurrence of anthropogenic compounds detected, nitrate concentration, and other factors for water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001.

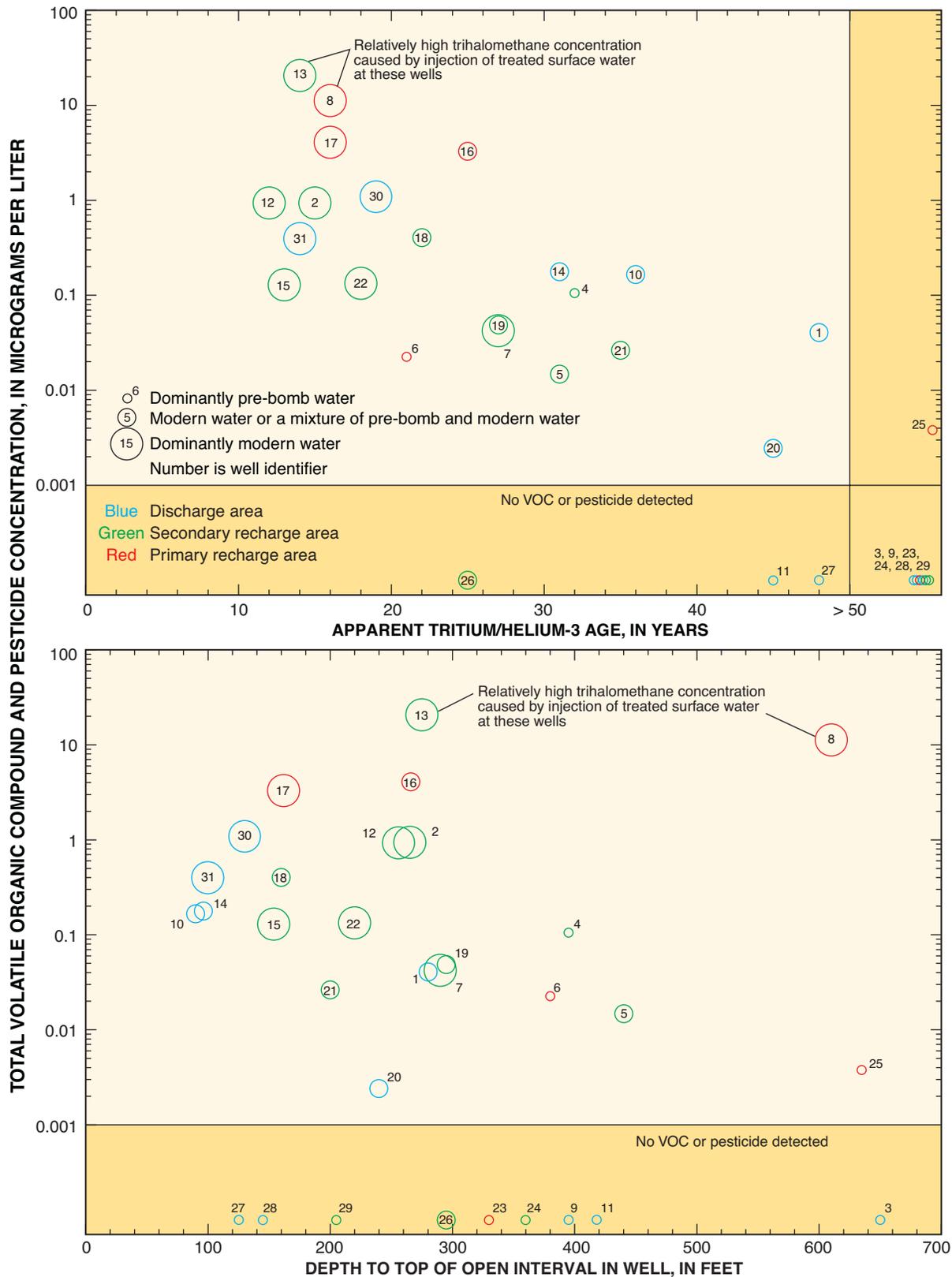


Figure 28. Graphs showing Relation of total concentration of volatile organic compounds and pesticides to apparent tritium/helium-3 age and to depth to top of open interval for water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001.

ground water with higher dissolved-solids concentrations from the west and southwest may have been induced by withdrawals in the area.

SUMMARY

Ground water supplies about one-third of the water used by the public in Salt Lake Valley, Utah. The purpose of this study is to evaluate the occurrence and distribution of natural and anthropogenic compounds in ground water used for public supply in the valley and to determine the general sources of recharge to the principal aquifer. Water samples were collected from 31 public-supply wells. Water-quality data for the wells consist of analyses of field parameters, major ions, trace elements, radon, nutrients, dissolved organic carbon, methylene blue active substances, pesticides, and volatile organic compounds.

Dissolved-solids concentration ranged from 157 to 1,280 mg/L in water from the 31 public-supply wells. Comparison of water sampled from the principal aquifer during 1988-92 and 1998-2002 shows a reduction in the area where the dissolved-solids concentration is less than 500 mg/L. Ground water with a dissolved-solids concentration less than 500 mg/L in an area extending to the northwest, past the Jordan River, receded to the southeast likely because of pumping in the area and in upgradient areas to the southeast. Dissolved-arsenic concentrations in water from five wells exceeded the drinking-water maximum contaminant level of 10 µg/L. Water from wells in much of the western part of the study area generally had higher arsenic concentrations than water from other areas. Nitrate concentration in water sampled from 12 of the 31 public-supply wells was higher than an estimated background level of 2 mg/L, indicating a likely human influence.

At least one pesticide or pesticide degradation product was detected at concentrations much lower than year 2002 U.S. Environmental Protection Agency drinking-water standards in water from 13 of the 31 wells sampled. The relatively high detection frequency of atrazine in water samples from the west side of the valley may be the result of application in agricultural or industrial areas that also are recharge areas for the aquifer.

The most frequently detected volatile organic compounds were chloroform (54.8 percent), bromodichloromethane (35.5 percent), and 1,1,1-trichloroethane (19.4 percent). The widespread occurrence of chloroform and bromodichloromethane in deeper ground water is likely a result of the recharge of chlorinated public-supply water used to irrigate lawns and gardens in residential areas of Salt Lake Valley.

Environmental tracers were used to determine the sources of recharge to the principal aquifer used for public supply in the valley. The stable isotopes of water (deuterium and oxygen-18) and recharge temperatures computed from dissolved noble gases in the ground water were used to differentiate between mountain and valley recharge. Tritium, helium-3, and chlorofluorocarbons were used to identify and date ground water recharged within the past 50 years. Because the local population resides in the valley, along with most of the local industry, water that enters the ground-water system in the valley has a greater likelihood of containing anthropogenic compounds than does mountain-block recharge.

Maximum recharge temperatures in the eastern part of the valley generally are below the range of valley water-table temperatures indicating that mountain-block recharge must constitute a substantial fraction of recharge to the principal aquifer in this area. Together, the recharge temperature and stable-isotope data define two zones that contain large fractions of valley recharge on the east side of the valley.

To determine if a sample contains a substantial fraction of pre-bomb water (more than 50 years old) the initial tritium concentration of each sample (measured tritium plus measured tritiogenic helium-3) is compared to that of local precipitation at the apparent time of recharge. Three interpreted-age categories were determined for water from the sampled wells: (1) dominantly pre-bomb; (2) dominantly modern; and (3) modern or a mixture of pre-bomb and modern. Apparent tritium/helium-3 ages range from 3 years to more than 50 years. Ground water on the east side of the valley generally becomes older with distance from the mountain front, the oldest water being in the discharge area. Generally, wells with apparent ages for water less than 20 years contain dominantly modern water, wells with apparent ages for water of 20-40 years contain modern water or a mixture of modern and pre-bomb waters, and wells with apparent ages for water greater than 40 years contain dominantly pre-bomb water.

Chlorofluorocarbon-age data were collected for the 31 wells sampled during this study. Water sampled from nearly half of the wells was contaminated with at least 1 of the CFCs analyzed. Contamination levels of CFCs are potentially useful in gauging well susceptibility because wells with CFC-contaminated water most likely contain an appreciable component of modern water.

The presence of anthropogenic compounds at concentrations above reporting levels and elevated nitrate concentrations (affected wells) in the principal aquifer is very well correlated with the distribution of interpreted-age categories. All of the wells (10 of 10) with dominantly modern water are affected. Seventy percent (7 of 10) of the wells with dominantly modern or a mixture of modern and pre-bomb waters are affected. Only 9 percent (1 of 11) of the wells with dominantly pre-bomb water are affected. Both the number and total concentration of anthropogenic compounds detected in water sampled from each well is inversely correlated with the apparent $^3\text{H}/^3\text{He}$ age. Anthropogenic compounds were not detected in water with an apparent age of more than 50 years, except for water from one well. All of the samples made up mostly of modern water contained at least one anthropogenic compound.

Areas with an increase in dissolved-solids concentration greater than 20 percent from 1988-92 to 1998-2002 generally correspond to areas with relatively large components of modern water. Although in the discharge area, water sampled from two wells did contain tritium and CFC contamination, an indication of mixing with a modern component of water. Withdrawals from the principal aquifer in the area may have allowed recently recharged water to move downward into the aquifer in the vicinity of these wells.

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Table 13. Field parameters for water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001

[$\mu\text{S/cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; NTU, nephelometric turbidity units; number in parentheses is the U.S. Geological Survey National Water Information System parameter code]

Well identifier (fig. 5)	Sample date	Depth of well (feet)	Temperature (degrees Celsius) (00010)	Specific conductance ($\mu\text{S/cm}$) (00095)	pH (standard units) (00400)	Alkalinity, dissolved (mg/L as CaCO_3) (39086)	Oxygen, dissolved (mg/L) (00300)	Turbidity (NTU) (00076)
1	05/15/2001	678	16.0	810	7.6	108	2.6	0.1
2	05/10/2001	544	11.0	370	8.0	114	7.9	.1
3	05/15/2001	935	19.0	580	7.7	105	.4	.1
4	05/09/2001	650	11.5	280	8.0	114	7	.1
5	05/30/2001	861	14.5	250	8.0	84	5.8	.1
6	06/05/2001	590	15.5	980	7.3	158	8.2	.1
7	05/08/2001	500	13.5	1,310	7.3	256	6.6	.1
8	06/25/2001	950	13.0	360	7.3	115	9	.1
9	05/16/2001	965	20.0	500	7.9	155	.3	.1
10	05/02/2001	250	17.0	1,940	7.7	275	5.7	.1
11	06/06/2001	1,004	16.0	570	7.7	174	.5	.1
12	05/14/2001	453	11.5	590	7.5	161	8.1	.1
13	06/12/2001	700	9.5	410	7.4	109	9.9	.1
14	05/03/2001	177	14.5	2,030	7.5	292	5.1	.1
15	06/13/2001	560	11.0	700	7.5	207	6.5	.1
16	06/25/2001	464	14.0	1,070	7.1	267	8.7	.1
17	05/29/2001	510	12.5	930	7.1	234	7.2	.1
18	05/24/2001	502	16.5	1,030	7.0	200	5.7	.5
19	05/23/2001	657	16.5	930	7.2	182	5.7	.1
20	05/14/2001	391	16.0	1,040	7.4	143	4.6	.1
21	06/07/2001	701	16.0	580	7.5	112	5.9	.1
22	05/22/2001	410	12.5	1,630	7.4	302	7.4	.1
23	06/26/2001	620	16.0	1,140	7.2	152	8.6	.1
24	05/01/2001	900	18.0	770	7.4	209	2.3	.1
25	05/21/2001	1,212	30.5	1,430	7.4	181	.9	.2
26	05/23/2001	590	13.5	550	7.4	162	5	.1
27	06/11/2001	468	16.0	460	7.7	94	4.5	.1
28	05/16/2001	840	14.0	1,020	7.6	193	1.3	.3
29	05/07/2001	515	15.0	1,170	7.5	177	4.4	.1
30	06/05/2001	130	14.0	1,310	7.0	280	6.9	.1
31	06/12/2001	496	13.5	880	7.2	219	4.5	.1

Table 14. Concentration of dissolved major ions in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001

[mg/L, milligrams per liter; µg/L, micrograms per liter; °C, degrees Celsius; number in parentheses is the U.S. Geological Survey National Water Information System parameter code; <, less than; E, estimated value; M, presence of constituent verified but not quantified]

Well identifier (fig. 5 and table 13)	Bicarbonate (mg/L as HCO ₃) (00453)	Bromide (mg/L as Br) (71870)	Calcium (mg/L as Ca) (00915)	Chloride (mg/L as Cl) (00940)	Fluoride (mg/L as F) (00950)	Iron (µg/L as Fe) (01046)	Magnesium (mg/L as Mg) (00925)
1	132	0.11	53.5	112	0.3	<10	22.8
2	139	.03	42.1	27.5	.2	<10	12.9
3	128	.05	41.7	46.3	.3	10	16.9
4	140	.03	32.5	14.8	.2	<10	7.28
5	103	.01	25.9	8.6	.3	<10	9.55
6	193	.12	106	115	.2	<10	36.5
7	312	.23	131	177	E.1	<10	36.3
8	140	.03	43.1	20.9	.3	<10	11.1
9	189	.03	42.9	23.7	.5	50	13.6
10	336	.29	29.6	298	.5	<30	17.1
11	212	.02	63.5	13.2	.4	40	21.1
12	198	.04	63.7	60.2	.2	<10	24.8
13	133	.01	51.4	35.5	.2	<10	11.7
14	356	.30	54.0	308	.5	E20	30.8
15	253	.09	82.2	63.4	.2	<10	23.6
16	326	.08	107	132	.2	<10	39.1
17	286	.09	107	77.2	E.1	<10	37.6
18	244	.04	122	45.4	.3	<10	44.1
19	221	.03	107	30.4	.3	<10	45.3
20	175	.18	56.7	188	.2	<10	25.2
21	137	.07	45.7	72.2	.3	<10	17.4
22	369	.30	172	249	E.1	<10	43.0
23	186	.23	105	246	.2	M	38.4
24	255	.09	53.3	92.4	.4	M	28.3
25	220	.20	59.2	279	.8	<10	30.9
26	197	.04	64.3	27.4	.2	<10	21.4
27	115	.04	34.2	49.2	.3	<10	13.5
28	235	.12	92.3	108	.4	320	40.2
29	175	.15	81.5	270	E.1	<10	18.3
30	342	.12	144	150	.2	<10	55.3
31	267	.10	77.2	107	.3	<10	28.4

Table 14. Concentration of dissolved major ions in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001—Continued

Well identifier (fig. 5 and table 13)	Manganese (µg/L as Mn) (01056)	Potassium (mg/L as K) (00935)	Silica (mg/L as SiO ₂) (00955)	Sodium (mg/L as Na) (00930)	Sulfate (mg/L as SO ₄) (00945)	Solids, residue at 180 °C (mg/L) (70300)	Solids, sum of constituents (mg/L) (70301)
1	<3.0	2.35	14.8	66.9	117	488	460
2	<3.2	1.62	10.1	10.4	29.4	228	210
3	<3.0	2.27	17.6	45.8	111	370	345
4	<3.2	2.07	12.8	12.0	12.0	171	166
5	<3.0	1.42	11.6	8.0	23.9	157	146
6	<3.0	2.83	31.4	39.9	167	678	600
7	<3.2	4.19	32.5	82.0	150	854	780
8	<3.0	3.01	13.2	13.1	24.5	210	210
9	35.2	1.99	23.8	38.5	68.9	321	308
10	E1.8	34.7	76.9	330	222	1,200	1,190
11	54	1.68	20.6	28.6	108	377	362
12	<3.0	1.82	9.9	13.8	38.3	337	323
13	<3.0	2.28	11.1	10.2	39.2	241	232
14	<3.2	33.3	67.9	303	254	1,280	1,240
15	<3.0	3.29	13.3	21.6	54.6	407	399
16	<3.0	3.33	20.1	55.9	77.1	616	618
17	<3.0	1.89	17.3	31.5	134	474	562
18	<3.0	2.97	18.1	34.8	285	632	678
19	<3.0	3.55	15.2	28.9	269	661	613
20	<3.0	4.57	13.5	106	75.2	566	562
21	<3.0	2.93	14.1	41.4	52.6	341	320
22	<3.0	6.89	39.5	95.3	167	986	971
23	<3.0	3.60	33.0	52.8	31.9	734	617
24	E2.3	11.2	71.4	49.1	42.0	496	478
25	<3.0	31.2	105	134	75.5	834	825
26	<3.0	1.68	10.1	13.1	75.6	327	316
27	<3.0	1.85	12.6	33.0	50.8	266	256
28	160	6.60	21.8	50.5	183	660	622
29	<3.2	3.49	21.5	110	11.1	684	603
30	7.0	2.80	19.7	50.4	171	842	788
31	<3.0	4.36	14.5	56.8	71.7	523	504

Table 15. Concentration of trace elements in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001

[Water samples for radon-222 analysis were not filtered; µg/L, micrograms per liter; pCi/L, picocuries per liter; number in parentheses is the U.S. Geological Survey National Water Information System parameter code; <, less than; E, estimated value]

Well identifier (fig. 5 and table 13)	Dissolved aluminum (µg/L as Al) (01106)	Dissolved antimony (µg/L as Sb) (01095)	Dissolved arsenic (µg/L as As) (01000)	Dissolved barium (µg/L as Ba) (01005)	Dissolved beryllium (µg/L as Be) (01010)	Dissolved boron (µg/L as B) (01020)	Dissolved cadmium (µg/L as Cd) (01025)	Dissolved chromium (µg/L as Cr) (01030)	Dissolved cobalt (µg/L as Co) (01035)	Dissolved copper (µg/L as Cu) (01040)	Dissolved lead (µg/L as Pb) (01049)	Dissolved lithium (µg/L as Li) (01130)
1	<1	0.17	1.7	50.9	<0.06	48	0.15	1.0	0.08	0.7	0.12	11.8
2	1	.10	1.1	102	<.06	11	<.04	<.8	.07	1.1	.46	2.8
3	<1	.16	2.2	36.3	<.06	30	E.02	E.4	.05	.9	.22	10.2
4	1	.10	.7	79.0	<.06	14	.05	E.6	.05	2.0	.67	1.4
5	<1	<.05	.9	59.2	<.06	9	E.03	2.2	.02	.7	.69	1.2
6	<1	.09	6.8	112	<.06	47	.09	4.3	.15	2.5	.58	29.4
7	<1	.12	3.6	60.3	<.06	97	<.04	3.3	.21	2.5	.35	25.3
8	8	.11	.9	89.9	<.06	25	E.03	1.1	.07	1.5	.33	4.7
9	1	E.04	.4	74.4	<.06	57	<.04	<.8	.06	.4	.12	19.9
10	<1	.13	11.8	51.1	<.06	243	<.04	E.7	.05	1.9	.69	137
11	<1	<.05	1.3	46.7	<.06	39	<.04	<.8	.10	.6	<.08	14.1
12	<1	.12	.4	77.7	<.06	21	.14	E.7	.09	1.0	.27	3.1
13	7	.10	.5	85.1	<.06	19	.09	<.8	.10	1.4	.21	4.9
14	<1	.12	11.3	54.0	<.06	284	<.04	1.1	.09	2.5	.49	143
15	<1	.12	.6	212	<.06	32	.20	E.4	.15	1.9	1.02	4.1
16	<1	.06	1.2	111	<.06	95	.06	2.9	.20	5.5	1.82	22.4
17	<1	<.05	.4	26.8	<.06	53	<.04	E1.6	.10	5.9	.54	14.7
18	<1	E.03	.4	19.6	<.06	83	<.04	E.6	.17	5.5	2.12	28.8
19	<1	E.04	.5	30.0	<.06	42	.07	E.7	.14	2.5	1.10	22.0
20	<1	.15	.9	224	<.06	157	.11	1.3	.08	.8	.83	49.4
21	2	.13	1.1	103	<.06	60	E.04	.8	.07	1.6	.70	12.1
22	<1	.13	3.7	155	<.06	183	.14	.9	.27	3.4	.36	32.6
23	<1	.07	8.2	144	<.06	53	.11	4.6	.18	1.6	.46	27.0
24	<1	.10	17.9	122	<.06	102	<.04	1.1	.07	.7	.17	38.4
25	<1	.08	11.1	71.8	<.06	199	.06	<.8	.09	1.7	2.70	75.8
26	<1	.07	.7	66.0	<.06	18	E.03	E.7	.10	1.3	.40	5.1
27	1	.14	1.9	77.6	<.06	32	.17	.8	.06	.9	.41	5.1
28	<1	E.04	11.8	119	<.06	72	<.04	<.8	.13	.7	<.08	35.0
29	<1	.06	.4	774	<.06	101	.05	E.6	.13	2.8	2.70	6.7
30	<1	.05	1.0	42.0	<.06	93	<.04	1.4	.22	1.3	<.08	27.2
31	<1	.12	1.3	146	<.06	83	.04	1.0	.16	4.3	1.14	11.8

¹ 2-sigma precision estimate.

Table 15. Concentration of trace elements in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001—Continued

Well identifier (fig. 5 and table 13)	Dissolved molybdenum (µg/L as Mo) (01060)	Dissolved nickel (µg/L as Ni) (01065)	Total radon-222 (pCi/L) (82303)	Radon-222 2-sigma ¹ (pCi/L) (76002)	Dissolved selenium (µg/L as Se) (01145)	Dissolved silver (µg/L as Ag) (01075)	Dissolved strontium (µg/L as Sr) (01080)	Dissolved thallium (µg/L as Tl) (01057)	Dissolved uranium (µg/L as U) (22703)	Dissolved vanadium (µg/L as V) (01085)	Dissolved zinc (µg/L as Zn) (01090)
1	5.1	0.12	344	20	1.0	<1.0	916	E0.03	1.15	2.0	3
2	2.0	<.06	683	35	.6	<1.0	270	.09	5.01	1.1	2
3	4.0	.11	581	24	E.2	<1.0	737	.08	.91	2.5	4
4	3.5	<.06	704	26	E.3	<1.0	191	E.03	5.45	1.2	3
5	4.2	<.06	702	27	E.3	<1.0	179	<.04	4.15	.7	4
6	.4	<.06	744	28	2.3	<1.0	371	E.04	1.81	5.0	6
7	.5	<.06	1,210	32	3.1	<1.0	628	.10	5.80	6.1	5
8	4.3	.22	1,050	30	.4	<1.0	204	<.04	11.5	1.0	6
9	2.0	<.06	412	22	<.3	<1.0	739	E.03	.04	1.5	1
10	1.5	E.04	820	27	1.0	<1.0	568	<.04	4.24	16.8	2
11	1.3	<.06	509	24	<.3	<1.0	884	<.04	.34	.8	23
12	1.5	.60	696	26	.8	<1.0	487	<.04	1.87	1.4	9
13	2.1	.30	1,980	44	.3	<1.0	354	<.04	6.02	1.0	5
14	2.1	<.06	784	40	1.1	<1.0	885	<.04	3.30	14.8	4
15	2.9	.47	701	27	.6	<1.0	506	<.04	13.0	1.4	5
16	1.5	.46	452	22	1.7	<1.0	607	.17	2.12	2.6	10
17	.5	<.06	781	27	1.0	<1.0	936	<.04	1.32	1.6	7
18	.7	<.06	251	18	1.4	<1.0	1,730	<.04	1.62	1.0	4
19	.4	<.06	751	28	1.1	<1.0	1,430	<.04	1.49	.9	5
20	1.6	<.06	792	27	1.6	<1.0	983	E.04	10.4	2.3	6
21	3.5	<.06	841	28	.9	<1.0	385	E.03	9.09	1.7	4
22	1.0	<.06	850	29	3.1	<1.0	830	<.04	8.65	5.8	7
23	.9	E.04	1,030	31	3.2	<1.0	523	.08	1.95	5.0	8
24	2.7	<.06	594	24	1.8	<1.0	921	<.04	4.61	8.2	5
25	8.6	3.02	675	25	.9	<1.0	1,280	<.04	3.10	19.2	35
26	1.6	.12	745	28	.7	<1.0	631	<.04	1.14	.4	3
27	6.3	.19	416	22	.5	<1.0	410	<.04	2.75	2.0	3
28	2.4	.62	342	21	<.3	<1.0	1,070	E.02	.08	1.6	9
29	.5	<.06	1,030	30	.3	<1.0	781	.12	15.1	2.3	6
30	1.1	<.06	437	23	2.1	<1.0	1,280	.04	1.89	3.4	2
31	2.6	.47	627	27	1.3	<1.0	517	<.04	11.1	1.3	25

Table 16. Concentration of nutrient constituents and organic carbon in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001

[mg/L, milligrams per liter; number in parentheses is the U.S. Geological Survey National Water Information System parameter code; <, less than; E, estimated value; —, no data]

Well identifier (fig. 5 and table 13)	Dissolved ammonia (mg/L as N) (00608)	Dissolved ammonia plus organic nitrogen (mg/L as N) (00623)	Dissolved organic carbon (mg/L as C) (00681)	Total methylene blue active substances (mg/L) (38260)	Dissolved nitrite (mg/L as N) (00613)	Dissolved nitrite plus nitrate (mg/L as N) (00631)	Dissolved phosphorus (mg/L as P) (00666)	Dissolved ortho-phosphorus (mg/L as P) (00671)
1	<0.041	<0.10	<0.33	<0.02	0.007	1.20	0.009	E0.015
2	<.041	<.10	<.15	<.02	E.003	1.76	.014	<.018
3	<.041	<.10	<.33	<.02	.006	.066	.009	E.011
4	<.041	<.10	<.33	<.02	.007	.686	E.005	E.009
5	<.040	<.10	<.30	<.02	<.006	1.28	E.005	<.020
6	<.040	<.10	<.30	<.02	<.006	1.33	.016	E.011
7	<.041	<.10	.52	<.02	<.006	3.01	.028	.021
8	<.040	<.10	E.31	.02	.007	2.64	E.006	<.020
9	.51	.56	.47	<.02	.007	E.026	.035	.035
10	<.041	<.10	.60	<.04	E.003	3.41	.026	.020
11	.24	.27	E.33	<.02	E.003	E.031	.048	.036
12	<.041	<.10	<.33	<.02	.007	2.84	E.004	E.012
13	.066	E.06	.63	<.02	<.006	1.11	E.006	E.013
14	<.041	E.09	.59	<.02	<.006	3.47	.027	.024
15	<.040	E.06	E.29	<.02	<.006	2.89	E.005	<.020
16	<.040	<.10	E.32	<.02	.006	5.27	.010	<.020
17	<.040	<.10	<.30	<.02	<.006	3.34	E.006	<.020
18	<.040	<.10	<.30	<.02	<.006	1.21	<.006	<.020
19	<.040	<.10	E.20	<.02	<.006	.899	E.004	<.020
20	<.041	<.10	<.33	<.02	.006	1.38	E.004	E.011
21	<.040	<.10	E.24	<.02	<.006	1.43	.006	<.020
22	<.040	E.10	1.2	<.02	<.006	3.76	.039	.022
23	<.040	<.10	<.30	E.02	<.006	3.23	.018	.018
24	<.041	<.10	<.15	<.04	<.006	.921	.013	E.009
25	<.040	<.10	—	<.02	<.006	.421	.008	<.020
26	<.040	<.10	<.30	<.02	<.006	1.20	.017	<.020
27	.043	<.10	<.30	<.02	<.006	.890	.009	E.010
28	2.24	2.5	.76	<.02	.01	E.041	.132	.105
29	<.041	<.10	<.15	<.02	<.006	.199	.013	<.018
30	<.040	<.10	<.30	<.02	<.006	5.99	.038	.030
31	<.040	<.10	.50	<.02	<.006	2.88	.018	E.012

Table 17. Concentration of dissolved pesticides detected in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001

[Number in parentheses is the U.S. Geological Survey National Water Information System parameter code; concentrations reported in micrograms per liter; E, estimated value; <, less than; M, presence of compound verified but not quantified]

Well identifier (fig. 5 and table 13)	Atrazine (39632)	Deethyl-atrazine (04040)	Deethyl-deisopropyl-atrazine (04039)	Bromacil ¹ (04029)	Carbofuran ^{1,2} (82674)	Carbofuran ³ (49309)	Caffeine ¹ (50305)	Imazethapyr (50407)	Metolachlor ¹ (39415)
1	<0.007	<0.006	<0.01	<0.03	<0.020	<0.01	<0.010	<0.017	<0.013
2	<.009	<.028	<.01	<.03	<.020	<.01	<.010	<.017	<.013
3	<.007	<.006	<.01	<.03	<.020	<.01	<.010	<.017	<.013
4	<.007	<.006	<.01	<.03	<.020	<.01	<.010	<.017	<.013
5	<.007	<.006	<.01	<.03	<.020	<.01	<.010	<.017	<.013
6	<.007	<.006	<.01	<.03	<.020	<.01	<.010	<.017	<.013
7	.019	E.023	<.01	<.03	<.020	<.01	<.010	<.017	<.013
8	<.009	E.004	<.01	<.03	<.020	<.01	<.010	<.017	<.013
9	<.007	<.006	<.01	<.03	<.020	<.01	<.010	<.017	<.013
10	E.004	E.009	<.01	<.03	<.020	<.01	<.010	<.017	<.013
11	<.007	<.006	<.01	<.03	<.020	<.01	<.010	<.017	<.013
12	<.007	<.006	<.01	<.03	<.020	<.01	<.010	E.006	<.013
13	E.007	E.005	<.01	<.03	<.020	<.01	<.010	<.017	<.013
14	.034	E.019	<.01	<.03	<.020	<.01	<.010	<.017	<.013
15	<.007	<.006	<.01	<.03	<.020	<.01	<.010	<.017	<.013
16	<.007	<.006	<.01	<.03	<.020	<.01	<.010	<.017	<.013
17	E.002	E.002	<.01	<.03	<.020	<.01	E.003	<.017	<.013
18	<.007	<.006	<.01	<.03	<.020	<.01	<.012	<.017	<.013
19	<.007	<.006	<.01	<.03	<.020	<.01	<.012	<.017	<.013
20	<.007	E.002	<.01	<.03	<.020	<.01	<.010	<.017	<.013
21	<.007	E.007	<.01	<.03	E.008	<.01	<.010	<.017	<.013
22	.024	E.065	E.01	<.03	<.020	<.01	<.010	<.017	<.013
23	<.007	<.006	<.01	<.03	<.020	<.01	<.010	<.017	<.013
24	<.007	<.006	<.01	M	<.020	<.01	<.010	<.017	<.013
25	E.004	<.006	<.01	<.03	<.020	<.01	<.010	<.017	E.004
26	<.007	<.006	<.01	<.03	<.020	<.01	<.015	<.017	<.013
27	<.007	<.006	<.01	<.03	<.020	<.01	<.010	<.017	<.013
28	<.007	<.006	<.01	<.03	<.020	<.01	<.010	<.017	<.013
29	<.007	<.006	<.01	<.03	<.020	<.01	<.010	<.017	<.013
30	<.007	<.006	<.01	<.03	<.020	<.01	<.010	E.014	<.013
31	<.007	E.004	<.01	<.03	<.020	<.01	E.008	<.017	<.013

¹ Presence of compound in sample(s) is likely the result of contamination. Compound was not included in analysis of pesticide data.

² Carbofuran analyzed for by the gas chromatography/mass spectrometry method.

³ Carbofuran analyzed for by the high-performance liquid chromatography method.

Table 18. Concentration of volatile organic compounds detected in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001

[Number in parentheses is the U.S. Geological Survey National Water Information System parameter code; concentrations reported in micrograms per liter; <, less than; E, estimated value; M, presence of compound verified but not quantified]

Well identifier (fig. 5 and table 13)	Benzene ¹ (34030)	Bromo-dichloro-methane (32101)	Chloroform (32106)	cis-1,2-Dichloro-ethylene (77093)	Dibromo-chloro-methane (32105)	Dichloro-methane (34423)	Tetrachloro-ethylene (34475)
1	<0.04	<0.05	<0.02	<0.04	<0.2	<0.2	<0.1
2	<.04	E.06	0.94	<.04	<.2	<.2	<.1
3	<.04	<.05	<.02	<.04	<.2	<.2	<.1
4	<.04	<.05	<.02	<.04	<.2	<.2	E.1
5	<.04	<.05	E.01	<.04	<.2	<.2	<.1
6	<.04	<.05	E.02	<.04	<.2	<.2	<.1
7	<.04	<.05	<.02	<.04	<.2	<.2	<.1
8	<.04	3.15	10.8	<.04	.4	<.2	<.1
9	<.04	<.05	<.02	<.04	<.2	<.2	<.1
10	<.04	E.04	.15	<.04	<.2	<.2	<.1
11	<.04	<.05	<.02	<.04	<.2	<.2	<.1
12	<.04	E.06	.90	<.04	<.2	<.2	<.1
13	<.04	5.4	19.7	<.04	1	<.2	<.1
14	<.04	<.05	E.08	<.04	<.2	<.2	<.1
15	<.04	E.02	.13	<.04	<.2	<.2	<.1
16	<.04	.24	3.25	<.04	<.2	M	<.1
17	<.04	.10	2.73	E.03	<.2	M	1
18	<.04	.11	.38	<.04	<.2	<.2	M
19	<.04	<.05	E.05	<.04	<.2	<.2	<.1
20	<.04	<.05	<.02	<.04	<.2	<.2	<.1
21	<.04	<.05	E.01	<.04	<.2	<.2	<.1
22	<.04	<.05	E.04	<.04	<.2	<.2	<.1
23	<.04	<.05	<.02	<.04	<.2	<.2	<.1
24	<.04	<.05	<.02	<.04	<.2	<.2	<.1
25	E.02	<.05	<.02	<.04	<.2	<.2	<.1
26	<.04	<.05	<.02	<.04	<.2	<.2	<.1
27	<.04	<.05	<.02	<.04	<.2	<.2	<.1
28	<.04	<.05	<.02	<.04	<.2	<.2	<.1
29	<.04	<.05	<.02	<.04	<.2	<.2	<.1
30	<.04	E.10	.99	<.04	<.2	<.2	<.1
31	<.04	E.05	.37	<.04	<.2	<.2	<.1

¹Presence of compound in sample(s) is likely the result of contamination. Compound was not included in analysis of volatile organic compound data.

Table 18. Concentration of volatile organic compounds detected in water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001—
Continued

Well identifier (fig. 5 and table 13)	Tetrachloro- methane (32102)	Toluene ¹ (34010)	1,1,1-Tri- chloroethane (34506)	Trichloro- ethylene (39180)	Trichloro- fluoromethane (CFC-11) (34488)	1,1,2-Trichloro- trifluoroethane (CFC-113) (77652)
1	<0.06	<0.05	E0.04	<0.04	<0.09	<0.06
2	<0.06	<0.05	<.03	<.04	<.09	<.06
3	<0.06	<.05	<.03	<.04	<.09	<.06
4	<0.06	E.01	<.03	E.01	<.09	<.06
5	<0.06	E.03	<.03	<.04	<.09	<.06
6	<0.06	E.02	<.03	<.04	<.09	<.06
7	<0.06	<.05	<.03	<.04	<.09	<.06
8	<0.06	E.03	<.03	<.04	<.09	<.06
9	<0.06	<.05	<.03	<.04	<.09	<.06
10	<0.06	<.05	<.03	<.04	<.09	<.06
11	<0.06	E.02	<.03	<.04	<.09	<.06
12	<0.06	E.01	E.03	<.04	<.09	<.06
13	<0.06	<.05	E.01	<.04	<.09	<.06
14	<0.06	<.05	<.03	<.04	<.09	E.04
15	<0.06	<.05	<.03	<.04	<.09	<.06
16	E.02	E.03	<.03	<.04	<.09	<.06
17	E.04	E.03	E.05	E.02	.12	.28
18	<0.06	E.02	<.03	<.04	<.09	<.06
19	<0.06	E.02	<.03	<.04	<.09	<.06
20	<0.06	M	<.03	<.04	<.09	<.06
21	<0.06	<.05	E.01	<.04	<.09	<.06
22	<0.06	<.05	<.03	<.04	<.09	<.06
23	<0.06	E.02	<.03	<.04	<.09	<.06
24	<0.06	<.05	<.03	<.04	<.09	<.06
25	<0.06	E.02	<.03	<.04	<.09	<.06
26	<0.06	E.01	<.03	<.04	<.09	<.06
27	<0.06	<.05	<.03	<.04	<.09	<.06
28	<0.06	<.05	<.03	<.04	<.09	<.06
29	<0.06	<.05	<.03	<.04	<.09	<.06
30	<0.06	<.05	<.03	<.04	E.02	E.07
31	<0.06	<.05	E.02	<.04	<.09	<.06

APPENDIX

APPENDIX

Table A-1. Quality-control data for dissolved major ions in blank water and water sampled from selected public-supply wells in Salt Lake Valley, Utah, 2001

[mg/L, milligrams per liter; µg/L, micrograms per liter; °C, degrees Celsius; number in parentheses is the U.S. Geological Survey National Water Information System parameter code; —, no data; <, less than; E, estimated value; M, presence of constituent verified but not quantified]

Well identifier (fig. 5)	Sample date	Sample time	Sample type	Bicarbonate (mg/L as HCO ₃) (00453)	Bromide (mg/L as Br) (71870)	Calcium (mg/L as Ca) (00915)	Chloride (mg/L as Cl) (00940)	Fluoride (mg/L as F) (00950)
24	05/01/2001	1306	Equipment blank	—	<0.01	<0.01	<0.1	<0.2
3	05/15/2001	1006	Field blank	—	<.01	<.01	E.1	<.2
17	05/29/2001	1006	Field blank	—	<.01	E.01	E.1	<.2
23	06/26/2001	1106	Field blank	—	<.01	<.01	<.1	<.2
10	05/02/2001	1100	Ground water	336	.29	29.6	298	.5
10	05/02/2001	1101	Replicate	336	.29	29.7	298	.5
19	05/23/2001	1100	Ground water	221	.03	107	30.4	.3
19	05/23/2001	1101	Replicate	221	.03	104	30.3	.3
11	06/06/2001	1100	Ground water	212	.02	63.5	13.2	.4
11	06/06/2001	1101	Replicate	212	.01	62.1	12.9	.4

Well identifier (fig. 5)	Sample date	Sample time	Sample type	Iron (mg/L as Fe) (01046)	Magnesium (mg/L as Mg) (00925)	Manganese (µg/L as Mn) (01056)	Potassium (mg/L as K) (00935)	Silica (mg/L as SiO ₂) (00955)
24	05/01/2001	1306	Equipment blank	<10	<.008	<3.2	<.09	<.1
3	05/15/2001	1006	Field blank	<10	<.008	<3.0	<.09	<.1
17	05/29/2001	1006	Field blank	<10	<.008	<3.0	<.09	<.1
23	06/26/2001	1106	Field blank	<10	<.008	<3.0	<.09	<.1
10	05/02/2001	1100	Ground water	<30	17.1	E1.8	34.7	76.9
10	05/02/2001	1101	Replicate	<30	17.1	E1.8	34.0	76.6
19	05/23/2001	1100	Ground water	<10	45.3	<3.0	3.55	15.2
19	05/23/2001	1101	Replicate	<10	44.7	<3.0	3.54	14.9
11	06/06/2001	1100	Ground water	40	21.1	54.0	1.68	20.6
11	06/06/2001	1101	Replicate	40	21.3	53.2	1.68	20.5

Well identifier (fig. 5)	Sample date	Sample time	Sample type	Sodium (mg/L as Na) (00930)	Sulfate (mg/L as SO ₄) (00945)	Solids, residue at 180°C (mg/L) (00945)	Solids, sum of constituents (mg/L) (70301)
24	05/01/2001	1306	Equipment blank	<.1	<.1	<10	—
3	05/15/2001	1006	Field blank	M	E.1	<10	—
17	05/29/2001	1006	Field blank	<.1	E.1	<10	—
23	06/26/2001	1106	Field blank	<.1	<.1	<10	—
10	05/02/2001	1100	Ground water	330	222	1,200	1,190
10	05/02/2001	1101	Replicate	331	220	1,210	1,190
19	05/23/2001	1100	Ground water	28.9	269	661	613
19	05/23/2001	1101	Replicate	28.5	267	664	606
11	06/06/2001	1100	Ground water	28.6	108	377	362
11	06/06/2001	1101	Replicate	29.4	108	376	361

Table A-2. Quality-control data for trace elements in blank water and water sampled from selected public-supply wells in Salt Lake Valley, Utah, 2001

[Water samples for radon-222 analysis were not filtered; µg/L, micrograms per liter; pCi/L, picocuries per liter; number in parentheses is the U.S. Geological Survey National Water Information System parameter code; <, less than; E, estimated value; —, no data]

Well identifier (fig. 5)	Sample date	Sample time	Sample type	Dissolved aluminum (µg/L as Al) (01106)	Dissolved antimony (µg/L as Sb) (01095)	Dissolved arsenic (µg/L as As) (01000)	Dissolved barium (µg/L as Ba) (01005)	Dissolved beryllium (µg/L as Be) (01010)	Dissolved boron (µg/L as B) (01020)
24	05/01/2001	1311	Equipment blank	<1	<0.05	<0.2	<1.0	<0.06	<7
3	05/15/2001	1011	Field blank	<1	E.05	<.2	<1.0	<.06	<7
17	05/29/2001	1011	Field blank	<1	<.05	<.2	<1.0	<.06	<7
23	06/26/2001	1111	Field blank	<1	<.05	<.2	<1.0	<.06	<7
10	06/06/2001	1109	Ground water	<1	<.05	1.3	46.7	<.06	39
10	06/06/2001	1110	Replicate	<1	<.05	1.3	46.2	<.06	39
19	05/02/2001	1109	Ground water	<1	.13	11.8	51.1	<.06	243
19	05/02/2001	1110	Replicate	<1	.13	12.1	51.1	<.06	244
11	05/23/2001	1109	Ground water	<1	E.04	.5	30.0	<.06	42
11	05/23/2001	1110	Replicate	<1	E.04	.5	30.2	<.06	45
Well identifier (fig. 5)	Sample date	Sample time	Sample type	Dissolved cadmium (µg/L as Cd) (01025)	Dissolved chromium (µg/L as Cr) (01030)	Dissolved cobalt (µg/L as Co) (01035)	Dissolved copper (µg/L as Cu) (01040)	Dissolved lead (µg/L as Pb) (01049)	Dissolved lithium (µg/L as Li) (01130)
24	05/01/2001	1311	Equipment blank	<.04	<.8	<.01	<.2	<.08	E.2
3	05/15/2001	1011	Field blank	<.04	<.8	<.02	.3	E.04	<.3
17	05/29/2001	1011	Field blank	<.04	<.8	<.02	E.2	E.06	<.3
23	06/26/2001	1111	Field blank	<.04	<.8	<.02	.4	<.08	<.3
10	06/06/2001	1109	Ground water	<.04	<.8	.10	.6	<.08	14.1
10	06/06/2001	1110	Replicate	<.04	<.8	.10	.6	<.08	14.0
19	05/02/2001	1109	Ground water	<.04	E.7	.05	1.9	.69	137
19	05/02/2001	1110	Replicate	<.04	E.7	.06	1.9	.71	136
11	05/23/2001	1109	Ground water	.07	E.7	.14	2.5	1.10	22.0
11	05/23/2001	1110	Replicate	E.03	E.7	.17	2.7	1.16	22.0
Well identifier (fig. 5)	Sample date	Sample time	Sample type	Dissolved molybdenum (µg/L as Mo) (01060)	Dissolved nickel (µg/L as Ni) (01065)	Total radon-222 (pCi/L) (82303)	Radon-222 2-sigma ¹ (pCi/L) (76002)	Dissolved selenium (µg/L as Se) (01145)	Dissolved silver (µg/L as Ag) (01075)
24	05/01/2001	1311	Equipment blank	<.2	<.06	—	—	<.3	<1.0
3	05/15/2001	1011	Field blank	<.2	<.06	—	—	<.3	<1.0
17	05/29/2001	1011	Field blank	<.2	<.06	—	—	<.3	<1.0
23	06/26/2001	1111	Field blank	<.2	<.06	—	—	<.3	<1.0
10	06/06/2001	1109	Ground water	1.3	<.06	820	27	<.3	<1.0
10	06/06/2001	1110	Replicate	1.3	.15	890	29	<.3	<1.0
19	05/02/2001	1109	Ground water	1.5	E.04	751	28	1.0	<1.0
19	05/02/2001	1110	Replicate	1.5	<.06	747	28	1.0	<1.0
11	05/23/2001	1109	Ground water	.4	<.06	509	24	1.1	<1.0
11	05/23/2001	1110	Replicate	.4	.37	512	23	1.1	<1.0

Table A-2. Quality-control data for trace elements in blank water and water sampled from selected public-supply wells in Salt Lake Valley, Utah, 2001—
Continued

Well identifier (fig. 5)	Sample date	Sample time	Sample type	Dissolved strontium (µg/L as Sr) (01080)	Dissolved thallium (µg/L as Tl) (01057)	Dissolved uranium (µg/L as U) (22703)	Dissolved vanadium (µg/L as V) (01085)	Dissolved zinc (µg/L as Zn) (01090)
24	05/01/2001	1311	Equipment blank	<.08	<.04	<.02	<.2	<1
3	05/15/2001	1011	Field blank	<.08	<.04	<.02	<.2	4
17	05/29/2001	1011	Field blank	<.08	.04	<.02	<.2	<1
23	06/26/2001	1111	Field blank	<.08	<.04	<.02	<.2	<1
10	06/06/2001	1109	Ground water	884	<.04	.34	.8	23
10	06/06/2001	1110	Replicate	892	<.04	.33	.8	23
19	05/02/2001	1109	Ground water	568	<.04	4.24	16.8	2
19	05/02/2001	1110	Replicate	580	<.04	4.35	16.8	2
11	05/23/2001	1109	Ground water	1,430	<.04	1.49	.9	5
11	05/23/2001	1110	Replicate	1,430	<.04	1.47	.9	5

¹ 2-sigma precision estimate.

Table A-3. Quality-control data for nutrient constituents and organic carbon in blank water and water sampled from selected public-supply wells in Salt Lake Valley, Utah, 2001

[mg/L, milligrams per liter; number in parentheses is the U.S. Geological Survey National Water Information System parameter code; <, less than; E, estimated value; —, no data]

Well identifier (fig. 5)	Sample date	Sample time	Sample type	Dissolved ammonia (mg/L as N) (00608)	Dissolved ammonia plus organic nitrogen (mg/L as N) (00623)	Dissolved nitrite (mg/L as N) (00613)	Dissolved nitrite plus nitrate (mg/L as N) (00631)
24	05/01/2001	1305	Equipment blank	<0.041	<0.10	<0.006	<0.047
24	05/01/2001	1307	Source-solution blank	—	—	—	—
3	05/15/2001	1005	Field blank	<.040	<.10	.007	E.025
3	05/15/2001	1007	Source-solution blank	—	—	—	—
17	05/29/2001	1005	Field blank	<.040	<.10	<.006	<.050
17	05/29/2001	1007	Source-solution blank	—	—	—	—
23	06/26/2001	1105	Field blank	<.040	<.10	<.006	<.050
23	06/26/2001	1107	Source-solution blank	—	—	—	—
10	05/02/2001	1100	Ground water	<.041	<.10	E.003	3.41
10	05/02/2001	1101	Replicate	<.041	E.05	<.006	3.5
19	05/23/2001	1100	Ground water	<.040	<.10	<.006	.899
19	05/23/2001	1101	Replicate	<.040	E.08	<.006	.894
11	06/06/2001	1100	Ground water	.245	.27	E.003	E.031
11	06/06/2001	1101	Replicate	.248	.28	E.003	E.032

Well identifier (fig. 5)	Sample date	Sample time	Sample type	Dissolved organic carbon (mg/L as C) (00681)	Dissolved phosphorus (mg/L as P) (00666)	Dissolved ortho-phosphorus (mg/L as P) (00671)	Total methylene blue active substances (mg/L) (38260)
24	05/01/2001	1305	Equipment blank	<.15	<.006	<.018	<.04
24	05/01/2001	1307	Source-solution blank	<.15	—	—	—
3	05/15/2001	1005	Field blank	E.30	<.006	<.020	<.02
3	05/15/2001	1007	Source-solution blank	<.33	—	—	—
17	05/29/2001	1005	Field blank	<.30	<.006	<.020	<.02
17	05/29/2001	1007	Source-solution blank	<.30	—	—	—
23	06/26/2001	1105	Field blank	<.30	<.006	<.020	E.01
23	06/26/2001	1107	Source-solution blank	<.30	—	—	—
10	05/02/2001	1100	Ground water	.6	.026	.020	<.04
10	05/02/2001	1101	Replicate	<.15	.027	.026	<.02
19	05/23/2001	1100	Ground water	E.20	E.004	<.020	<.02
19	05/23/2001	1101	Replicate	E.20	E.004	<.020	<.02
11	06/06/2001	1100	Ground water	E.33	.048	.036	<.02
11	06/06/2001	1101	Replicate	E.30	.048	.038	<.02

Table A-4. Quality-control data for dissolved pesticides detected in blank water and (or) ground water sampled from selected public-supply wells in Salt Lake Valley, Utah, 2001

[Number in parentheses is the U.S. Geological Survey National Water Information System parameter code; concentrations reported in micrograms per liter; <, less than; E, estimated value; M, presence of compound verified but not quantified]

Well identifier (fig. 5)	Sample date	Sample time	Sample type	Atrazine ¹ (39632)	Deethyl-atrazine ¹ (04040)	Deethyl-deisopropyl-atrazine ² (04039)	Deiso-propyl-atrazine ² (04038)	Bromacil ² (04029)
Blanks								
24	05/01/2001	1305	Equipment blank	<0.007	<0.006	<0.01	<0.04	<0.03
3	05/15/2001	1005	Field blank	<.007	<.006	<.01	<.04	<.03
17	05/29/2001	1005	Field blank	<.007	<.006	<.01	<.04	<.03
23	06/26/2001	1105	Field blank	<.007	<.006	<.01	<.04	<.03
Replicates								
10	05/02/2001	1100	Ground water	E.004	E.009	<.01	<.04	<.03
10	05/02/2001	1101	Replicate	E.004	E.008	<.01	M	<.03
19	05/23/2001	1100	Ground water	<.007	<.006	<.01	<.04	<.03
19	05/23/2001	1101	Replicate	<.007	<.006	<.01	<.04	<.03
11	06/06/2001	1100	Ground water	<.007	<.006	<.01	<.04	<.03
11	06/06/2001	1101	Replicate	<.007	<.006	<.01	<.04	<.03
Well identifier (fig. 5)	Sample date	Sample time	Sample type	Carbofuran ¹ (82674)	Carbofuran ² (49309)	Caffeine ² (50305)	Imazethapyr ² (50407)	Metolachlor ¹ (39415)
Blanks								
24	05/01/2001	1305	Equipment blank	<.020	<.01	<.010	<.017	<.013
3	05/15/2001	1005	Field blank	<.020	<.01	<.010	<.017	<.013
17	05/29/2001	1005	Field blank	<.020	<.01	E.006	<.017	<.013
23	06/26/2001	1105	Field blank	<.020	<.01	<.010	<.017	<.013
Replicates								
10	05/02/2001	1100	Ground water	<.020	<.01	<.010	<.017	<.013
10	05/02/2001	1101	Replicate	<.020	<.01	<.010	<.017	<.013
19	05/23/2001	1100	Ground water	<.020	<.01	<.012	<.017	<.013
19	05/23/2001	1101	Replicate	<.020	<.01	<.012	<.017	<.013
11	06/06/2001	1100	Ground water	<.020	<.01	<.010	<.017	<.013
11	06/06/2001	1101	Replicate	<.020	<.01	<.010	<.017	<.013

¹ Compound analyzed for by the gas chromatography/mass spectrometry method.

² Compound analyzed for by the high-performance liquid chromatography method.

Table A-5. Quality-control data for volatile compounds detected in blank water and (or) water sampled from selected public-supply wells in Salt Lake Valley, Utah, 2001

[Number in parentheses is the U.S. Geological Survey National Water Information System parameter code; concentrations reported in micrograms per liter; <, less than; M, presence of compound verified but not quantified; E, estimated value]

Well identifier (fig. 5)	Sample date	Sample time	Sample type	Benzene (34030)	Bromo-dichloro-methane (32101)	Chloroform (32106)	cis-1,2-Dichloro-ethylene (77093)	Dibromo-chloro-methane (32105)	Dichloro-methane (32123)	Tetrachloro-ethylene (34475)
Blanks										
24	05/01/2001	1305	Equipment blank	<0.04	<0.05	<0.02	<0.04	<0.2	M	<0.1
24	05/01/2001	1313	Source-solution blank	<.04	<.05	<.02	<.04	<.2	<.2	<.1
3	05/15/2001	1005	Field blank	<.04	<.05	<.02	<.04	<.2	M	<.1
3	05/15/2001	1013	Source-solution blank	<.04	<.05	<.02	<.04	<.2	<.2	<.1
17	05/29/2001	1005	Field blank	<.04	<.05	<.02	<.04	<.2	<.2	<.1
17	05/29/2001	1013	Source-solution blank	E.02	<.05	<.02	<.04	<.2	<.2	<.1
23	06/26/2001	1105	Field blank	<.04	<.05	<.02	<.04	<.2	<.2	<.1
23	06/26/2001	1113	Source-solution blank	<.04	<.05	<.02	<.04	<.2	<.2	<.1
23	06/26/2001	1108	Trip blank	<.04	<.05	<.02	<.04	<.2	<.2	<.1
Replicates										
10	05/02/2001	1100	Ground water	<.04	E.04	.15	<.04	<.2	<.2	<.1
10	05/02/2001	1101	Replicate	<.04	E.03	.13	<.04	<.2	<.2	<.1
19	05/23/2001	1100	Ground water	<.04	<.05	E.05	<.04	<.2	<.2	<.1
19	05/23/2001	1101	Replicate	<.04	<.05	E.06	<.04	<.2	<.2	<.1
11	06/06/2001	1100	Ground water	<.04	<.05	<.02	<.04	<.2	<.2	<.1
11	06/06/2001	1101	Replicate	<.04	<.05	<.02	<.04	<.2	<.2	<.1
Well identifier (fig. 5)	Sample date	Sample time	Sample type	Tetra-chloro-methane (32102)	Toluene (34010)	1,1,1-Trichloro-ethane (34506)	Trichloro-ethylene (39180)	Trichloro-fluoro-methane (CFC-11) (34488)	1,1,2-Trichloro-trifluor-ethane (CFC-113) (77652)	
Blanks										
24	05/01/2001	1305	Equipment blank	<.06	E.01	<.03	<.04	<.09	<.06	
24	05/01/2001	1313	Source-solution blank	<.06	<.05	<.03	<.04	<.09	<.06	
3	05/15/2001	1005	Field blank	<.06	E.01	<.03	<.04	<.09	<.06	
3	05/15/2001	1013	Source-solution blank	<.06	E.01	<.03	<.04	<.09	<.06	
17	05/29/2001	1005	Field blank	<.06	E.05	<.03	<.04	<.09	<.06	
17	05/29/2001	1013	Source-solution blank	<.06	E.07	<.03	<.04	<.09	<.06	
23	06/26/2001	1105	Field blank	<.06	E.03	<.03	<.04	<.09	<.06	
23	06/26/2001	1113	Source-solution blank	<.06	E.05	<.03	<.04	<.09	<.06	
23	06/26/2001	1108	Trip blank	<.06	<.05	<.03	E.02	<.09	<.06	
Replicates										
10	05/02/2001	1100	Ground water	<.06	<.05	<.03	<.04	<.09	<.06	
10	05/02/2001	1101	Replicate	<.06	<.05	<.03	<.04	<.09	<.06	
19	05/23/2001	1100	Ground water	<.06	E.02	<.03	<.04	<.09	<.06	
19	05/23/2001	1101	Replicate	<.06	E.02	<.03	<.04	<.09	<.06	
11	06/06/2001	1100	Ground water	<.06	E.02	<.03	<.04	<.09	<.06	
11	06/06/2001	1101	Replicate	<.06	<.05	<.03	<.04	<.09	<.06	

Table A-6. Percent recovery for pesticide surrogates in blank water and water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001

[Number in parentheses is the U.S. Geological Survey National Water Information System parameter code; all surrogate recoveries are in percent; E, estimated value; —, no data]

Well identifier (fig. 5)	Sample date	Sample time	Sample type	alpha-HCH-d6 (91065)	Barban (90640)	Caffeine-C13 (99959)	Diazinon-d10 (91063)	2,4,5-T (99958)
24	05/01/2001	1305	Equipment blank	65	94	100	105	86
3	05/15/2001	1005	Field blank	69	88	112	114	95
17	05/29/2001	1005	Field blank	E95	87	134	93	75
23	06/26/2001	1105	Field blank	64	E70	104	95	87
1	05/15/2001	1400	Ground water	76	92	117	95	84
2	05/10/2001	1000	Ground water	66	84	115	114	101
3	05/15/2001	1000	Ground water	80	97	132	114	96
4	05/09/2001	1100	Ground water	79	91	129	123	98
5	05/30/2001	1100	Ground water	E91	89	130	89	83
6	06/05/2001	1500	Ground water	60	99	127	102	85
7	05/08/2001	1100	Ground water	64	101	77	101	98
8	06/25/2001	1500	Ground water	78	103	104	82	88
9	05/16/2001	1400	Ground water	76	63	93	99	74
10	05/02/2001	1100	Ground water	70	108	86	113	90
11	06/06/2001	1100	Ground water	55	72	98	100	85
12	05/14/2001	1000	Ground water	77	96	126	108	92
13	06/12/2001	1300	Ground water	76	94	93	97	85
14	05/03/2001	1100	Ground water	60	80	69	95	83
15	06/13/2001	1100	Ground water	76	100	39	—	—
15	06/26/2001	1500	Ground water	—	—	—	92	94
16	06/25/2001	1100	Ground water	75	99	100	94	92
17	05/29/2001	1000	Ground water	E98	95	116	89	86
18	05/24/2001	1100	Ground water	81	100	163	101	89
19	05/23/2001	1100	Ground water	85	104	E204	103	99
20	05/14/2001	1400	Ground water	80	97	106	113	94
21	06/07/2001	1000	Ground water	72	90	157	84	89
22	05/22/2001	1100	Ground water	79	115	92	115	78
23	06/26/2001	1100	Ground water	70	E76	112	87	92
24	05/01/2001	1400	Ground water	69	103	101	105	91
25	05/21/2001	1100	Ground water	87	85	129	112	106
26	05/23/2001	1500	Ground water	85	98	191	112	103
27	06/11/2001	0900	Ground water	80	97	168	86	85
28	05/16/2001	1000	Ground water	79	70	89	117	89
29	05/07/2001	1200	Ground water	65	92	112	114	92
30	06/05/2001	1000	Ground water	57	75	104	96	89
31	06/12/2001	0900	Ground water	80	94	112	96	93

Table A-7. Percent recovery for volatile organic compound surrogates in blank water and water sampled from 31 public-supply wells in Salt Lake Valley, Utah, 2001

[Number in parentheses is the U.S. Geological Survey National Water Information System parameter code; all surrogate recoveries are in percent]

Well identifier (fig. 5)	Sample date	Sample time	Sample type	1,2-Dichloro-ethane-d4 (99832)	1,4-Bromofluoro-benzene (99834)	Toluene-d8 (99833)
24	05/01/2001	1305	Equipment blank	73	104	95
24	05/01/2001	1313	Source-solution blank	78	105	98
3	05/15/2001	1005	Field blank	77	120	98
3	05/15/2001	1013	Source-solution blank	79	116	98
17	05/29/2001	1005	Field blank	97	103	100
17	05/29/2001	1013	Source-solution blank	98	100	98
23	06/26/2001	1105	Field blank	80	109	99
23	06/26/2001	1113	Source-solution blank	76	110	91
23	06/26/2001	1108	Trip blank	78	107	93
1	05/15/2001	1400	Ground water	70	128	97
2	05/10/2001	1000	Ground water	110	116	104
3	05/15/2001	1000	Ground water	74	134	100
4	05/09/2001	1100	Ground water	74	121	99
5	05/30/2001	1100	Ground water	92	108	99
6	06/05/2001	1500	Ground water	74	117	97
7	05/08/2001	1100	Ground water	110	113	103
8	06/25/2001	1500	Ground water	70	111	96
9	05/16/2001	1400	Ground water	112	119	104
10	05/02/2001	1100	Ground water	71	107	97
11	06/06/2001	1100	Ground water	74	116	97
12	05/14/2001	1000	Ground water	70	127	99
13	06/12/2001	1300	Ground water	87	107	101
14	05/03/2001	1100	Ground water	106	104	102
15	06/13/2001	1100	Ground water	69	128	97
16	06/25/2001	1100	Ground water	70	112	96
17	05/29/2001	1000	Ground water	87	104	97
18	05/24/2001	1100	Ground water	112	121	110
19	05/23/2001	1100	Ground water	105	121	104
20	05/14/2001	1400	Ground water	72	129	100
21	06/07/2001	1000	Ground water	77	106	100
22	05/22/2001	1100	Ground water	121	117	110
23	06/26/2001	1100	Ground water	72	110	96
24	05/01/2001	1400	Ground water	70	110	98
25	05/21/2001	1100	Ground water	103	120	104
26	05/23/2001	1500	Ground water	106	119	109
27	06/11/2001	0900	Ground water	87	102	104
28	05/16/2001	1000	Ground water	113	123	104
29	05/07/2001	1200	Ground water	109	116	104
30	06/05/2001	1000	Ground water	72	117	95
31	06/12/2001	0900	Ground water	88	107	101

Table A-8. Percent recovery for matrix spikes of pesticides in water sampled from selected public-supply wells in Salt Lake Valley, Utah, 2001
 [Well location is shown on figure 5; parameter code is used in U.S. Geological Survey National Water Information System database; —, no data; <, less than]

Parameter code	Compound	Recovery, in percent					
		Well 2 05/10/2001		Well 25 05/21/2001		Well 15 06/13/2001	
		Matrix spike	Matrix-spike replicate	Matrix spike	Matrix-spike replicate	Matrix spike	Matrix-spike replicate
Gas Chromatography/Mass Spectrometry analytical method (samples were spiked in the field)							
82660	2,6-Diethylaniline	79	90	92	94	73	85
49260	Acetochlor	116	120	100	105	95	108
46342	Alachlor	105	109	100	102	94	110
34253	alpha-HCH	88	103	85	90	79	86
39632	Atrazine	—	—	95	—	—	<119
82686	Azinphos-methyl	53	52	105	106	65	77
82673	Benfluralin	74	77	74	74	72	75
04028	Butylate	105	106	90	90	80	93
82680	Carbaryl	93	109	322	367	102	136
82674	Carbofuran	104	115	239	253	80	95
38933	Chlorpyrifos	82	84	91	99	80	90
82687	cis-Permethrin	54	57	65	59	51	66
04041	Cyanazine	105	107	112	116	92	105
82682	Dacthal	94	98	101	106	99	113
04040	Deethylatrazine	—	—	50	—	—	68
39572	Diazinon	117	113	92	93	83	101
39381	Dieldrin	96	96	91	94	86	91
82677	Disulfoton	104	106	79	71	72	71
82668	EPTC	85	92	89	91	73	79
82663	Ethalfuralin	80	86	79	87	74	82
82672	Ethoprophos	83	87	91	96	76	94
04095	Fonofos	109	113	91	95	56	86
39341	Lindane	103	106	99	102	77	86
82666	Linuron	121	121	121	126	124	162
39532	Malathion	66	78	89	97	61	70
39415	Metolachlor	112	115	100	107	95	108
82630	Metribuzin	91	92	89	88	89	101
82671	Molinate	89	91	90	90	85	114
82684	Napropamide	98	104	102	108	83	100
34653	p,p'-DDE	69	75	75	76	68	81
39542	Parathion	84	88	93	98	72	83
82667	Parathion-methyl	93	98	90	94	65	80
82669	Pebulate	93	94	92	94	90	110
82683	Pendimethalin	81	85	78	82	62	75
82664	Phorate	102	107	77	79	67	71
04037	Prometon	92	96	102	108	80	94
04024	Propachlor	108	107	97	102	85	146
82679	Propanil	105	106	109	118	88	104
82685	Propargite	69	78	70	72	52	57
82676	Propyzamide	95	94	95	99	82	98
04035	Simazine	93	96	102	105	86	104
82670	Tebuthiuron	—	—	109	—	—	<136

Table A-8. Percent recovery for matrix spikes of pesticides in water sampled from selected public-supply wells in Salt Lake Valley, Utah, 2001—Continued

Parameter code	Compound	Recovery, in percent					
		Well 2 05/10/2001		Well 25 05/21/2001		Well 15 06/13/2001	
		Matrix spike	Matrix-spike replicate	Matrix spike	Matrix-spike replicate	Matrix spike	Matrix-spike replicate
Gas Chromatography/Mass Spectrometry analytical method (samples were spiked in the field)—Continued							
82665	Terbacil	77	83	95	106	76	88
82675	Terbufos	81	84	82	82	70	82
82681	Thiobencarb	115	117	109	101	95	108
82678	Triallate	115	118	91	94	87	89
82661	Trifluralin	73	77	83	83	56	75
High-Performance Liquid Chromatography analytical method (samples were spiked in the laboratory)							
39732	2,4-D	74	83	108	111	94	<112
50470	2,4-D methyl ester	48	99	101	100	72	<73
38746	2,4-DB	48	54	69	72	45	61
50355	2-Hydroxyatrazine	129	106	108	108	130	129
61692	3(4-Chlorophenyl)-1-methyl urea	109	109	117	108	61	<61
49308	3-Hydroxycarbofuran	70	90	56	83	76	<72
50295	3-Ketocarbofuran	3	51	1	47	49	58
49315	Acifluorfen	92	83	101	104	100	<99
49312	Aldicarb	4	18	24	25	21	7
49313	Aldicarb sulfone	52	65	45	90	66	51
49314	Aldicarb sulfoxide	33	51	31	50	59	34
39632	Atrazine	61	76	—	80	64	—
50299	Bendiocarb	38	76	22	70	71	<71
50300	Benomyl	66	91	82	72	51	<55
61693	Bensulfuron-methyl	128	128	150	143	102	101
38711	Bentazon	—	51	59	50	69	<82
04029	Bromacil	81	83	83	86	62	61
49311	Bromoxynil	70	65	87	79	80	92
50305	Caffeine	106	117	139	136	70	<64
49310	Carbaryl	78	97	80	83	76	<75
49309	Carbofuran	81	87	80	90	69	<72
61188	Chloramben methyl ester	66	87	90	79	55	58
50306	Chlorimuron-ethyl	116	154	189	191	84	<68
49306	Chlorothalonil	4	<14	14	18	83	17
49305	Clopyralid	66	76	80	83	90	<95
04031	Cycloate	59	54	83	75	48	48
49304	Dacthal monoacid	85	72	83	83	97	<106
04040	Deethylatrazine	44	62	—	66	42	—
04039	Deethyldeisopropylatrazine	52	54	62	61	118	112
04038	Deisopropylatrazine	41	54	62	61	38	34
38442	Dicamba	96	90	94	101	107	<112
49302	Dichlorprop	81	87	97	104	76	<89
49301	Dinoseb	89	69	87	86	97	<82
04033	Diphenamid	89	83	83	90	76	<72
49300	Diuron	96	94	97	93	80	<3
49297	Fenuron	81	90	94	90	55	<10

Table A-8. Percent recovery for matrix spikes of pesticides in water sampled from selected public-supply wells in Salt Lake Valley, Utah, 2001—Continued

Parameter code	Compound	Recovery, in percent					
		Well 2 05/10/2001		Well 25 05/21/2001		Well 15 06/13/2001	
		Matrix spike	Matrix-spike replicate	Matrix spike	Matrix-spike replicate	Matrix spike	Matrix-spike replicate
High-Performance Liquid Chromatography analytical method (samples were spiked in the laboratory)—Continued							
61694	Flumetsulam	145	171	191	176	110	114
38811	Fluometuron	100	94	97	93	76	<75
50356	Imazaquin	193	127	145	145	141	150
50407	Imazethapyr	163	99	109	101	103	102
61695	Imidacloprid	118	132	145	145	78	<78
38478	Linuron	85	101	101	97	73	<72
38482	MCPA	63	83	80	86	69	<85
38487	MCPB	52	58	69	72	48	68
50359	Metalaxyl	89	84	89	91	76	<73
38501	Methiocarb	52	94	73	72	69	72
49296	Methomyl	78	90	94	90	76	68
61696	Methomyl oxime	5	7	4	5	<4	<4
61697	Metsulfuron methyl	1	12	35	36	16	4
49294	Neburon	103	94	104	104	83	<78
50364	Nicosulfuron	164	142	169	173	136	122
49293	Norflurazon	103	97	101	101	80	68
49292	Oryzalin	78	90	108	111	55	<55
38866	Oxamyl	59	83	56	90	76	<72
50410	Oxamyl oxime	67	18	53	26	12	9
49291	Picloram	85	79	94	115	94	<102
49236	Propham	81	105	101	97	69	<68
50471	Propiconazole	94	104	117	115	78	<76
38538	Propoxur	74	87	69	75	69	<65
38548	Siduron	106	98	105	104	82	<87
50337	Sulfometuron-methyl	114	118	135	133	97	91
82670	Tebuthiuron	107	99	—	103	91	—
04032	Terbacil	81	90	90	86	69	68
61159	Tribenuron-methyl	—	—	17	25	<3	<3
49235	Triclopyr	85	87	94	101	90	<102

Table A-9. Percent recovery for matrix spikes of volatile organic compounds in water sampled from selected public-supply wells in Salt Lake Valley, Utah, 2001

[Well location is shown on figure 5; parameter code is used in U.S. Geological Survey National Water Information System database]

Parameter code	Compound	Recovery, in percent					
		Well 2 05/10/2001		Well 25 05/21/2001		Well 15 06/13/2001	
		Matrix spike	Matrix-spike replicate	Matrix spike	Matrix-spike replicate	Matrix spike	Matrix-spike replicate
77562	1,1,1,2-Tetrachloroethane	74	91	68	74	102	81
34506	1,1,1-Trichloroethane	74	94	60	74	111	91
34516	1,1,2,2-Tetrachloroethane	70	83	76	69	99	84
34511	1,1,2-Trichloroethane	77	88	77	75	105	88
77652	1,1,2-Trichlorotrifluoroethane	70	91	57	70	98	83
34496	1,1-Dichloroethane	71	89	59	71	112	92
34501	1,1-Dichloroethylene	66	89	51	62	96	87
77168	1,1-Dichloropropene	74	96	55	68	109	98
49999	1,2,3,4-Tetramethylbenzene	79	88	60	56	116	97
50000	1,2,3,5-Tetramethylbenzene	66	75	49	49	97	84
77613	1,2,3-Trichlorobenzene	67	75	63	55	91	83
77443	1,2,3-Trichloropropane	69	81	81	69	113	94
77221	1,2,3-Trimethylbenzene	80	88	62	62	124	106
34551	1,2,4-Trichlorobenzene	67	78	61	50	89	78
77222	1,2,4-Trimethylbenzene	73	86	52	59	120	100
82625	1,2-Dibromo-3-chloropropane	71	81	81	71	96	81
77651	1,2-Dibromoethane	72	87	72	70	91	79
34536	1,2-Dichlorobenzene	77	91	70	70	106	89
32103	1,2-Dichloroethane	82	90	82	82	115	98
34541	1,2-Dichloropropane	68	82	58	62	103	88
77226	1,3,5-Trimethylbenzene	70	87	51	57	117	96
34566	1,3-Dichlorobenzene	72	89	60	66	106	87
77173	1,3-Dichloropropane	80	88	71	71	106	97
34571	1,4-Dichlorobenzene	74	87	62	64	111	89
77170	2,2-Dichloropropane	67	84	51	61	87	80
81595	2-Butanone	84	103	109	84	109	103
77275	2-Chlorotoluene	68	83	51	60	98	79
77103	2-Hexanone	71	82	82	67	96	92
78109	3-Chloropropene	71	82	47	59	94	82
77277	4-Chlorotoluene	68	86	52	59	104	89
77356	4-Isopropyl-1-methylbenzene	70	86	48	57	104	87
78133	4-Methyl-2-pentanone	63	75	69	57	103	98
81552	Acetone	89	103	117	92	110	99
34215	Acrylonitrile	80	89	97	80	106	97
34030	Benzene	68	87	53	66	104	87
81555	Bromobenzene	70	85	62	62	91	77
77297	Bromochloromethane	78	94	77	80	53	46
32101	Bromodichloromethane	81	94	77	81	117	96
32104	Bromoform	76	86	80	76	97	86
34413	Bromomethane	78	99	57	64	92	78
77342	Butylbenzene	67	84	50	56	106	89
77041	Carbon disulfide	71	91	56	71	105	88
34301	Chlorobenzene	70	87	57	64	91	81

Table A-9. Percent recovery for matrix spikes of volatile organic compounds in water sampled from selected public-supply wells in Salt Lake Valley, Utah, 2001—Continued

Parameter code	Compound	Recovery, in percent					
		Well 2 05/10/2001		Well 25 05/21/2001		Well 15 06/13/2001	
		Matrix spike	Matrix-spike replicate	Matrix spike	Matrix-spike replicate	Matrix spike	Matrix-spike replicate
34311	Chloroethane	71	97	62	71	115	97
32106	Chloroform	81	91	66	77	111	91
34418	Chloromethane	71	99	64	71	96	85
32105	Dibromochloromethane	77	95	77	77	107	89
30217	Dibromomethane	77	87	79	77	98	83
34668	Dichlorodifluoromethane	85	124	78	82	53	46
34423	Dichloromethane	83	107	71	83	231	195
81576	Diethyl ether	69	81	63	56	88	81
81577	Diisopropyl ether	64	74	53	64	85	74
73570	Ethyl methacrylate	72	84	72	61	84	76
50004	Ethyl tert-butyl ether	68	83	57	57	87	83
34371	Ethylbenzene	68	87	51	62	98	85
39702	Hexachlorobutadiene	76	91	61	68	98	83
34396	Hexachloroethane	78	89	61	73	212	173
77223	Isopropylbenzene	64	83	43	51	100	87
49991	Methyl acrylate	71	85	85	71	99	92
81593	Methyl acrylonitrile	67	81	83	70	122	107
77424	Methyl iodide	80	106	64	64	48	43
81597	Methyl methacrylate	73	88	76	64	94	94
34696	Naphthalene	60	68	60	47	68	64
77128	Styrene	70	87	55	57	111	94
34475	Tetrachloroethylene	78	87	58	68	107	87
32102	Tetrachloromethane	73	94	58	75	116	94
81607	Tetrahydrofuran	74	85	90	74	96	90
34010	Toluene	72	89	55	70	102	87
39180	Trichloroethylene	70	89	55	66	98	85
34488	Trichlorofluoromethane	76	100	58	79	111	93
50002	Vinyl bromide	74	96	64	74	106	96
39175	Vinyl chloride	78	97	58	78	107	97
77093	cis-1,2-Dichloroethylene	70	94	57	68	94	81
34704	cis-1,3-Dichloropropene	73	94	69	67	86	84
85795	m- and p-Xylene	68	86	51	62	112	95
77224	n-Propylbenzene	68	83	47	55	109	91
77220	o-Ethyl toluene	72	91	54	61	103	86
77135	o-Xylene	66	84	50	55	102	89
77350	sec-Butylbenzene	68	85	45	55	113	96
78032	tert-Butyl methyl ether	69	85	69	64	85	85
77353	tert-Butylbenzene	78	97	54	67	117	98
50005	tert-Pentyl methyl ether	68	78	68	58	87	78
34546	trans-1,2-Dichloroethylene	70	87	53	66	109	91
34699	trans-1,3-Dichloropropene	74	84	69	66	89	78
73547	trans-1,4-Dichloro-2-butene	86	100	99	83	115	99

