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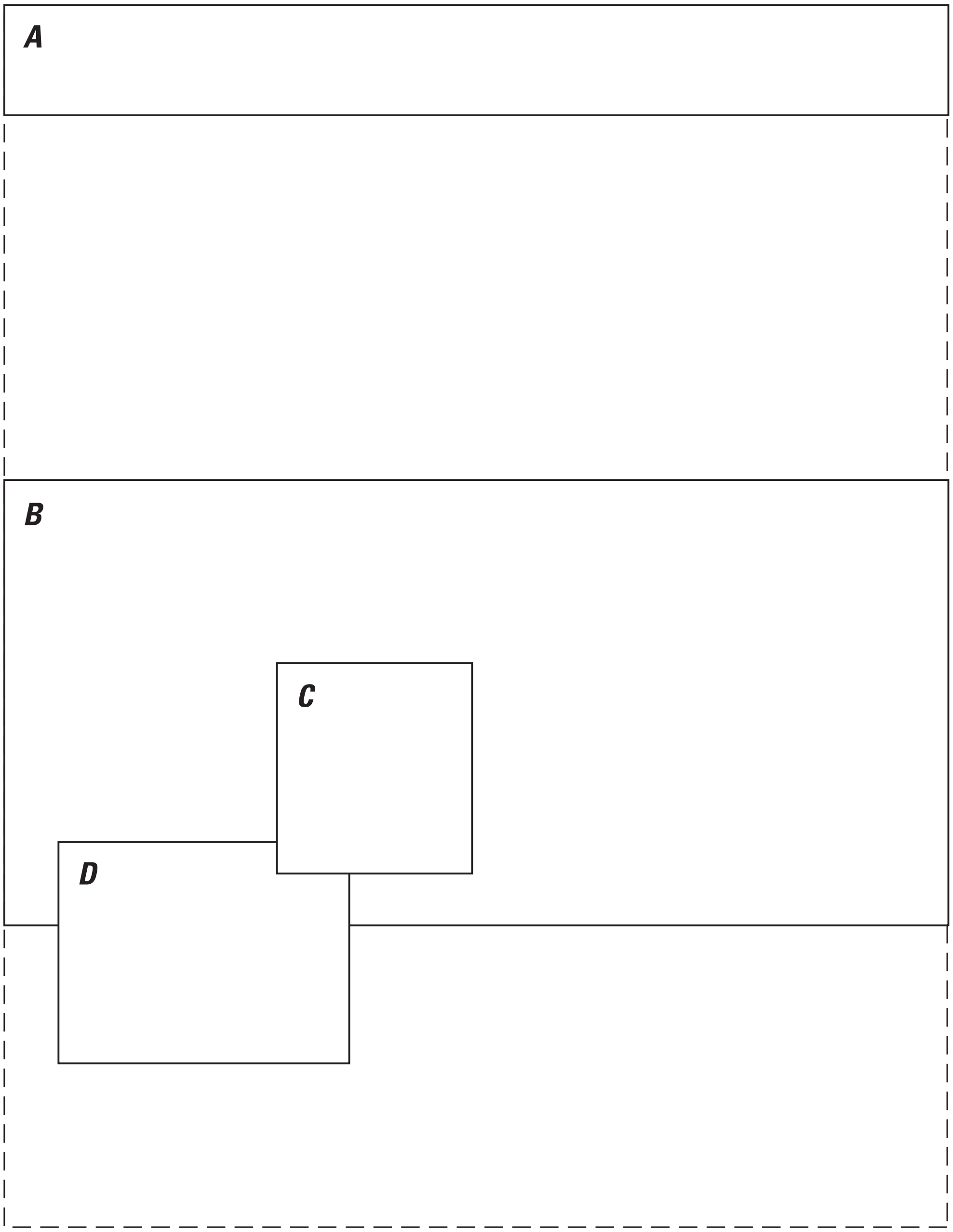
Quality of Shallow Ground Water in Three Areas of Unsewered Low-Density Development in Wyoming and Montana, 2001

Scientific Investigations Report 2008–5012

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



Front cover photographs: ***A***, Low-density development in Red Lodge, Mont., study area.
B, Low-density development in Lander, Wyo., study area.
Flush-mounted monitoring well and global-positioning
system unit in foreground.
C, Monitoring well installed in Sheridan, Wyo., study area.
D, Hydrologist welding chlorofluorocarbon sample vial.

Photographs by Timothy T. Bartos, Laura L. Hallberg, and Peter R. Wright, U.S. Geological Survey.

Quality of Shallow Ground Water in Three Areas of Unsewered Low-Density Development in Wyoming and Montana, 2001

By Timothy T. Bartos, Thomas L. Quinn, Laura L. Hallberg, and
Cheryl A. Eddy-Miller

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U.S. Department of the Interior
DIRK KEMPTHORNE, 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 Datums

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
ounce, fluid (fl. oz)	0.02957	liter (L)
ounce, fluid (fl. oz)	29.57	milliliter (mL)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Pressure	
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

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

$$°F=(1.8\times°C)+32$$

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

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83).

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

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness $[(ft^3/d)/ft^2]ft$. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

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

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

Abbreviations and Acronyms

Abbreviated water-quality units used in this report:

mg/L	milligram per liter
µg/L	microgram per liter
µS/cm	microsiemens per centimeter at 25 degrees Celsius
pCi/L	picocuries per liter
col/100mL	colonies per 100 milliliters

Abbreviations and acronyms used in this report:

AL	Action Level
AMCL	alternate Maximum Contaminant Level
C	carbon
$CaCO_3$	calcium carbonate
CFCs	chlorofluorocarbons
CO_2	carbon dioxide
CH_4	methane
$\delta^{18}O$	oxygen-18/oxygen-16 isotopic ratio
$\delta^{2}H$	deuterium/hydrogen isotopic ratio
$\delta^{15}N$	nitrogen-15/nitrogen-14 isotopic ratio
DO	dissolved oxygen
DOC	dissolved organic carbon
E. coli	*Escherichia coli*
GC/MS	gas chromatography/mass spectrometry
GIS	geographic information system
GMWL	Global Meteoric Water Line
GWSI	Ground-Water Site Inventory
^{3}H	tritium

HAL	Health Advisory Level
HCO_3	bicarbonate
LRL	laboratory reporting level
LT-MDL	long-term method detection level
MBAS	methylene blue active substances
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MRL	minimum reporting level
N_2	nitrogen
NAWQA	National Water-Quality Assessment
NIST	National Institute for Standards and Technology
NTU	nephelometric turbidity unit
NWIS	National Water Information System
NWQL	National Water Quality Laboratory of U.S. Geological Survey
O_2	oxygen
PVC	polyvinyl chloride
QC	quality control
RPD	relative percent difference
RSD	Risk-Specific Dose
RSD4	Risk-Specific Dose at 10^{-4} Cancer Risk
RSIL	Reston Stable Isotope Laboratory of U.S. Geological Survey
SMCL	Secondary Maximum Contaminant Level
SSMDC	sample-specific minimum detectable concentration
THMs	trihalomethanes
TIC	tentatively identified compound
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	volatile organic compound
YRB	Yellowstone River Basin

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By Timothy T. Bartos, Thomas L. Quinn, Laura L. Hallberg, and Cheryl A. Eddy-Miller

Abstract

The quality of shallow ground water underlying unsewered low-density development outside of Sheridan and Lander, Wyo., and Red Lodge, Mont., was evaluated. In 2001, 29 wells (10 each in Sheridan and Lander and 9 in Red Lodge) were installed at or near the water table and sampled for a wide variety of constituents to identify potential effects of human activities on shallow ground-water quality resulting from development on the land surface. All wells were completed in unconfined aquifers in unconsolidated deposits of Quaternary age with shallow water tables (less than 50 feet below land surface). Land use and land cover was mapped in detail within a 500-meter radius surrounding each well, and potential contaminant sources were inventoried within the radii to identify human activities that may affect shallow ground-water quality. This U.S. Geological Survey National Water-Quality Assessment ground-water study was conducted to examine the effects of unsewered low-density development that often surrounds cities and towns of many different sizes in the western United States—a type of development that often is informally referred to as “exurban” or “rural ranchette” development. This type of development has both urban and rural characteristics. Residents in these developments typically rely on a private ground-water well for domestic water supply and a private septic system for sanitary waste disposal.

Although the quality of shallow ground water generally was suitable for domestic or other uses without treatment, some inorganic constituents were detected infrequently in ground water in the three study areas at concentrations larger than U.S. Environmental Protection Agency drinking-water standards or proposed standards. Natural factors such as geology, aquifer properties, and ground-water recharge rates likely influence most concentrations of these constituents. These inorganic constituents generally occur naturally in the study areas and were more likely to limit suitability of water for drinking or other intended uses rather than any constituents suspected of being introduced as a result of human activities.

Effects of human activities associated with low-density development, such as septic systems; fertilizer and pesticide use on pastures, lawns and gardens; manure from horses, cattle, and pets; and increases in road construction and vehicular traffic, were minimal at the time of sampling (2001) but were apparent in the presence of a few types of constituents in shallow ground water. Concentrations of nitrate generally were less than a national background level (1.1 milligrams per liter) assumed to indicate effects from human activities. Total coliform bacteria were detected infrequently (in samples from three wells), and *Escherichia coli* were not detected in samples from a subset of wells. Trace concentrations of methylene blue active substances (ingredients in laundry detergents) were detected at concentrations slightly greater than laboratory reporting levels in samples from 11 wells, but it is unclear if the detections are indicative of natural sources or possible aquifer contamination from septic-tank effluent. Pesticides were detected in both the Sheridan and Lander, Wyo., study areas. Volatile organic compounds were detected very infrequently in all three study areas. Most pesticides and volatile organic compounds were found in water from a few wells in each study area, and commonly as mixtures. The primary exception to this generalization was the relatively widespread detection of the pesticide prometon at trace levels in the Sheridan and Lander study areas. Concentrations of pesticides and volatile organic compounds generally were small and always were smaller than applicable drinking-water standards. Detections of all constituents indicating possible human effects on shallow ground-water quality were consistent with overlying land use mapped during the study, and potential sources of contamination inventoried during the study.

Chlorofluorocarbon age-dating indicated much of the water sampled in the shallow aquifers had been recharged during the early 1990s or earlier. Chemical constituents in shallow ground water in 2001 may, therefore, not yet reflect unsewered low-density development that has occurred surrounding the Sheridan, Lander, and Red Lodge study areas during the past decade. In contrast, the detection of relatively few chemical constituents indicative of contamination by human activities may indicate that overlying unsewered low-density development that occurred in the past has had minimal effects on underlying ground-water quality. Continued monitoring is needed to determine effects on water quality from increasing development over time.

Introduction

A study was conducted to characterize shallow ground-water quality beneath three selected areas of unsewered low-density urban development (fig. 1). In 2001, wells in Sheridan and Lander, Wyo., and in Red Lodge, Mont., were installed and sampled for a wide variety of constituents to identify potential effects of human activities on shallow ground-water quality. This study was conducted as part of the U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program for the Yellowstone River Basin (YRB). The NAWQA Program is designed to (1) describe the status of, and trends in, water quality of large, representative portions of the Nation's water resources, and (2) provide an understanding of natural and human (anthropogenic) factors affecting the quality of these resources (Gilliom and others, 1995).

Studies of ground-water quality are a major component of the YRB NAWQA. The goal of one of three types of NAWQA ground-water studies (known as a land-use study) is to determine the effects of overlying land use on shallow, recently recharged, ground water. Many land-use studies of shallow ground water underlying agricultural and urban metropolitan areas across the country have been conducted as part of the NAWQA Program (*http://water.usgs.gov/nawqa*). The overall purpose of this study was to examine shallow ground-water quality underlying unsewered low-density development adjacent to and near areas of growth, sometimes characterized as "exurban" or "rural ranchette" development, to determine if any effects from this overlying land use could be documented.

Purpose and Scope

The purpose of this report is to describe the quality of shallow ground water in three areas of the YRB that have, and are still undergoing, unsewered low-density urban development—areas outside of Sheridan and Lander, Wyo., and Red Lodge, Mont., were selected for study. Environmental settings such as overlying land use and hydrogeologic characteristics were examined for each study area to determine any effects on shallow ground-water quality. Information collected from mapping land use and land cover, onsite reconnaissance, installation and sampling of 29 monitoring wells during 2001, and associated data analysis are presented herein. This information is presented in the context of two specific study objectives:

1. Evaluate and characterize the shallow ground-water quality beneath low-density development in three selected areas in the YRB, and

2. Determine if there are cumulative effects of the overlying land use (both point and non-point sources) on the shallow aquifer systems.

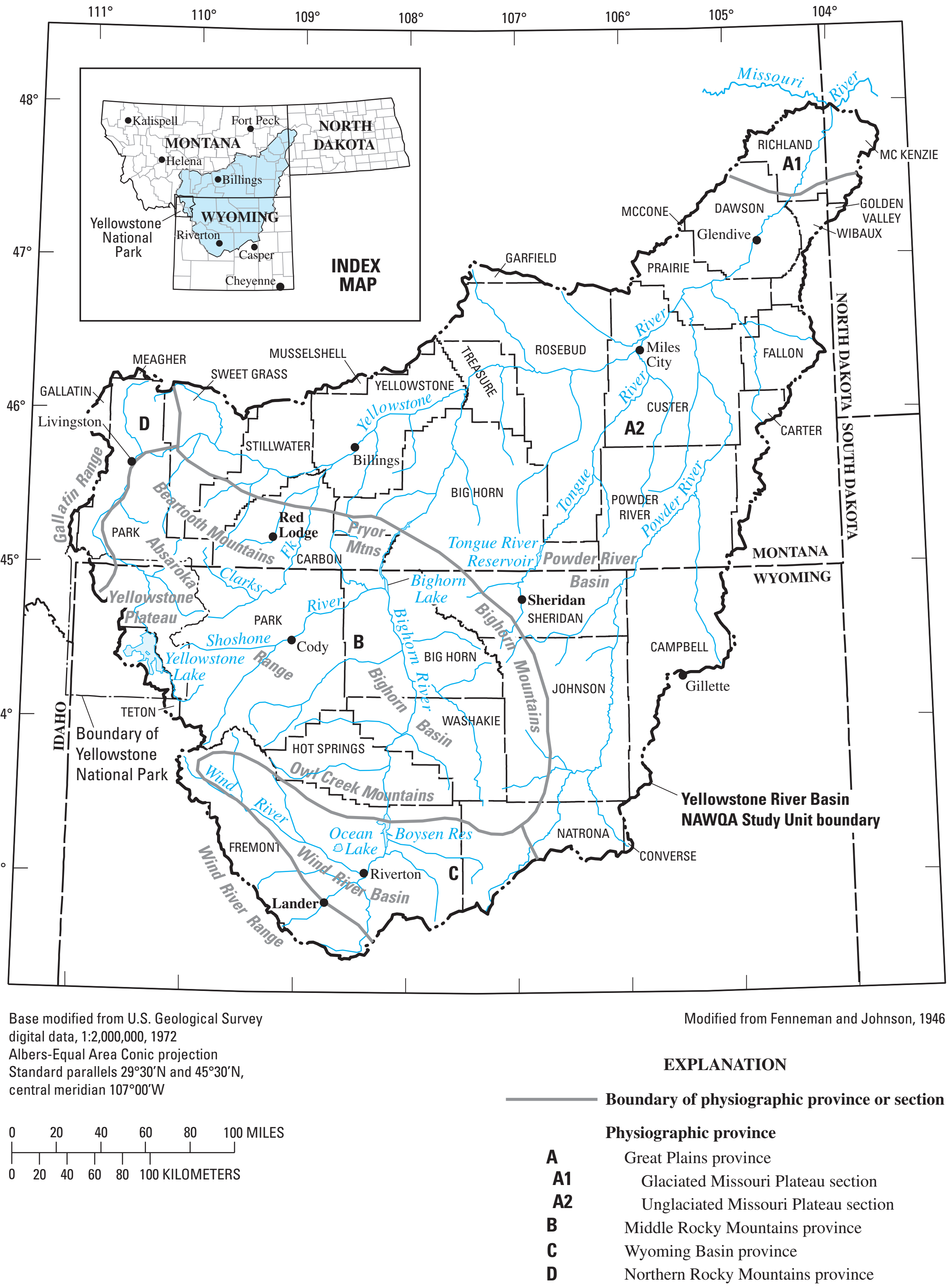
Background

It has been recognized that it is important to understand the potential effects that urban land use can have on environmental resources such as ground water. Urban land use typically contains numerous potential point sources of contamination to ground water, such as underground storage tanks, disposal facilities, and various industrial and commercial facilities. Consequently, programs have been developed at many scales to assess, monitor, and remediate ground-water quality. During the last decade, the USGS NAWQA Program began evaluating water-quality conditions at various scales to include potential non-point sources of chemical contamination to shallow ground water.

Along with population increases, the amount of urban land is increasing rapidly. Seventy million people lived in the Nation's urbanized areas in 1950 with the regions covering about 13,000 square miles (mi^2). By 1990, the urban-suburban population had more than doubled, but the land area occupied by that population almost quintupled to more than 60,000 mi^2 (Mitchell, 2001). In the West, much of this growth is occurring as urban sprawl, including low-density suburban (also known as "exurban" or "rural ranchette") development. One estimate indicates that low-density exurban sprawl will claim 26 million acres of land in the West by 2050 (Theobald, 2001). Of particular interest are areas where low-density suburban/exurban growth is occurring as unsewered developments. Typically, in the western United States, these developments provide an urban lifestyle with similar potential for affecting shallow ground water, in addition to the potential effects from the rural and unsewered nature of many of the areas. A private domestic ground-water well typically is used to supply water to homes in these developments. These wells often are constructed in shallow, unconfined, unconsolidated aquifers, and septic systems often are constructed immediately above the shallow aquifers.

Results of urban land-use studies have shown effects on shallow ground water such as elevated concentrations of nitrate from the application of nitrogen-based fertilizer, leaking sewer pipes, and application of manure; increased salinity from road salt; and detectable levels of pesticides and volatile organic compounds (VOCs) (Miller and Hamilton, 2001). Sources of these compounds in urban land-use settings generally are a combination of both point and non-point sources.

Sewage disposal in unsewered areas is almost always by septic system, with estimates that approximately one-third of all individual households in the Nation and numerous rural commercial establishments utilize septic systems (Hallberg and Keeney, 1993). Numerous studies have documented measurable effects of unsewered subdivision development on shallow ground water (Yates, 1985; Tinker, 1991; Hantzsche and Finnemore, 1992). Much of the literature indicates that environmental characteristics (for example, hydrogeology,



Base modified from U.S. Geological Survey
digital data, 1:2,000,000, 1972
Albers-Equal Area Conic projection
Standard parallels 29°30′N and 45°30′N,
central meridian 107°00′W

Modified from Fenneman and Johnson, 1946

EXPLANATION

Boundary of physiographic province or section

Physiographic province

A	Great Plains province
A1	Glaciated Missouri Plateau section
A2	Unglaciated Missouri Plateau section
B	Middle Rocky Mountains province
C	Wyoming Basin province
D	Northern Rocky Mountains province

Figure 1. Locations of Sheridan, Lander, and Red Lodge within the Yellowstone River Basin NAWQA study unit and relation to physiographic provinces, Montana, North Dakota, and Wyoming.

soils, and climate), in addition to septic or housing unit density, are the controlling factors in whether or not there is a cumulative shallow ground-water effect from unsewered development (Ford and others, 1980; Bauman and Schafer, 1985; Minnesota Pollution Control Agency, 1999, 2000). Several of these studies also have developed methodologies for modeling cumulative nitrogen inputs from unsewered developments, usually through a mass-balance approach. Age of the development also may be an important factor.

Septic effluent can contain many chemicals that can affect shallow ground-water quality. Many studies emphasize characterization of nutrient (nitrogen and phosphorus) inputs from septic discharge into ground water. Some studies have reported elevated levels of inorganic constituents (for example, chloride), VOCs, and bacteriological contamination (Alhajjar and others, 1990, and references therein; Minnesota Pollution Control Agency, 1999, 2000; Mathes, 2000). However, few studies have examined effects from overall low-density suburban/exurban development, including inputs from septic systems and the use of chemicals in the household, lawns, and other landscaping features. One study (Thomas, 2000) evaluated the effects of residential development on shallow ground water in unsewered development areas near Detroit, Mich., using an approach similar to the methods described in this report. The investigator reported elevated concentrations of inorganic constituents (chloride and dissolved solids), nutrients (nitrate), and organic compounds (pesticides and frequent VOC detections). Another study (Minnesota Pollution Control Agency, 2000) reported elevated concentrations of nitrate and bacteriological contamination in ground water were related to septic-system age and housing-lot density. In general, housing density (lot sizes generally less than 1 acre) in the rural subdivisions described in these studies is greater than what is commonly found in the Rocky Mountain Region. One similar study in a more rural area in Colorado reported slightly elevated nitrogen concentrations in ground water and infrequent, low concentrations of total coliform bacteria and methylene blue active substances (MBAS; optical brighteners in laundry detergents) in recently recharged ground water (Apodaca and others, 1999). Moran and others (2002) reported the detection of a wide variety of VOCs in ground water from domestic wells located in rural areas throughout the United States.

Verstraeten and others (2004) conducted a study to determine if septic tank effluent was affecting drinking water from shallow domestic wells near septic fields along the Platte River in eastern Nebraska. The investigators were able to show the effects of septic systems on water from domestic wells using a wide variety of ground-water quality indicators such as dissolved organic carbon, nitrogen species, bacteria, virus indicators, nitrogen and boron isotopes, and organic compounds such as prescription and nonprescription drugs. They also noted that bacteria and nitrate concentrations were not always the best indicators of contamination, and that some of the other indicators were better for identifying effects of septic systems on shallow ground water.

Methods of Investigation

Three areas within the YRB were selected for study (fig. 1). Natural characteristics (physiography, climate, vegetation, surficial geology, hydrology, and hydrogeology) and anthropogenic characteristics (population, land use and land cover, water use, and land-use practices) were examined and used to select the study areas. Areas outside of three small cities (Sheridan and Lander, Wyo., and Red Lodge, Mont.) were selected for study due to low-density suburban/exurban development outside of the city boundaries. These selected study areas are located in three of the major structural basins of the YRB (Powder River Basin, Wind River Basin, and the Bighorn Basin (fig. 1; also see Zelt and others, 1999). These selected study areas have similar land use, and continue to experience population growth and low-density development in areas not served by urban water and sewer systems.

Within the overall environmental setting, Quaternary unconsolidated deposits were delineated in the vicinity of each community. Boundaries for unsewered, low-density suburban/exurban land use in each study area were identified, and sites for monitoring-well installation were selected. Permission was obtained from individual land owners for well installation, wells were installed, and ground-water samples were collected and analyzed for a wide variety of constituents at selected USGS laboratories. Land use and land cover was mapped in detail around each well to document activities that might affect ground-water quality, and to provide a context for possible comparison of mapped land use with land use in other study areas. Ground-water quality-control samples were analyzed as part of an extensive quality-assurance program.

Land-Use and Land-Cover Mapping

Because overlying land use and land cover can influence the presence and distribution of constituents in ground water, land use and land cover were mapped at detail within a 500-meter (m) (1,640-foot (ft)) radius around each installed monitoring well using a combination of aerial photographs and onsite reconnaissance and surveys. Mapping was conducted using standardized NAWQA land-use and land-cover mapping procedures (Koterba, 1998). Onsite surveys within the 500-m radius consisted of locating and inventorying potential sources of contamination such as fuel storage, septic systems, and above-ground storage tanks. Agricultural practices within the radii, such as animal grazing, type/source of irrigation water, pesticide/fertilizer application, crop type, and lawn/garden practices were inventoried. Soils data were obtained from the Natural Resources Conservation Service and included in the surveys.

Many different land-use and land-cover classification categories (Koterba, 1998) were used for mapping purposes (Appendix 1) but these are generalized into eight land-use and land-cover categories when described in the report. Cropland included grass and alfalfa for hay. Agricultural infrastructure included corrals and other animal enclosures; and houses, trailers, garages, barns, parking lots, irrigation ditches, silos, and storage areas in agricultural areas. Livestock pasture included areas used to graze animals (primarily horses and cows). Grasslands were covered entirely with natural grasses, but were not used for animal grazing. Rangeland was primarily open range that may or may not have been used for animal grazing at time of mapping. Wetlands consisted of riparian land cover and included open water (streams) and associated riparian vegetation (wetlands). Urban land use included all commercial businesses, schools, churches, municipal offices, post offices, fire stations, parking lots, public access areas and parks, railroad tracks and associated right of ways, major roads and associated right of ways, and low-density residential housing. The "other" land-use category included barren land or other miscellaneous land uses that comprised a relatively small percentage of total land use within 500 m (1,640 ft) of the wells.

Site Selection

A two-step process was used to delineate the actual study areas (aquifer and land-use boundaries) and is briefly described in this section. A more detailed description of this process, and description of the spatial analysis steps, is available in the metadata for the geographic information system (GIS) data sets constructed for the study (Norris, 2002).

The aquifer boundaries were delineated through identification of Quaternary unconsolidated deposits within 15 kilometers ((km); about 9.3 mi) of the study areas. For the Sheridan and Lander study areas, digital surficial geology maps were used to identify Quaternary unconsolidated deposits. For the Red Lodge study area, geologic mapping by Ritter (1967) was used to identify Quaternary unconsolidated deposits. Boundaries were refined using a combination of onsite reconnaissance, examination of USGS 1:24,000-scale topographic maps, and examination of ground-water levels and geologic logs from well permits at the Wyoming State Engineer's Office *(http://seo.state.wy.us/)* and Montana Ground-Water Information Center (*http://mbmggwic.mtech.edu/)*.

The land-use study-area boundaries were selected so that a network of monitoring wells could be located within the boundaries. Rural-residential (low-density suburban/exurban) land use of interest for this study was defined as having the following characteristics:

1. Any contiguous grouping of 10 or more parcels of land that were occupied by residential dwellings;
2. Outside city boundaries;
3. Having most parcel sizes between 2 and 20 acres;
4. Unsewered, having individual or non-municipal sewage disposal systems, generally septic tank systems;
5. Having shallow ground-water levels (less than 50 ft below land surface);
6. Having Quaternary unconsolidated deposits with unconfined aquifers underlying the area.

Land-use study-area boundaries were determined using a combination of aerial photographs from the USGS National Aerial Photography Program and parcel maps available for the Lander and Sheridan areas. Well logs (lithologic descriptions) and static water-level measurements were examined within these areas of suitable land use to ensure they were within the required hydrogeologic setting (Quaternary unconsolidated deposits with shallow unconfined aquifers). After preliminary land-use study-area boundaries were established, onsite reconnaissance provided additional details to determine the suitability of particular areas for inclusion/exclusion in the land-use delineations.

Land-use boundaries were overlain with aquifer boundaries, and potential monitoring-well locations were selected using a spatially based, stratified-random method (Scott, 1990). The study areas around each city were subdivided into 10 zones, each having an equal areal extent. A single well was to be installed in each zone. Each of the 10 zones was further divided into equal-area grid cells, one of which (grid center point), was randomly selected for well installation. Grid cell sizes were 100 m x 100 m (about 328 ft x 328 ft) for Sheridan, 33 m x 33 m (about 108 ft x 108 ft) for Lander, and 60 m x 60 m (about 197 ft x 197 ft) for Red Lodge. Different cell sizes were selected because study-area sizes differed around the three cities. Permission could not be obtained to install wells at all randomly selected sites, so eight alternate locations were randomly selected for each zone to maintain the random design. Each location was randomly assigned a priority, so that if the first site was not suitable, the second priority site was considered, and this selection process was continued until a suitable location was found. In addition, some well locations were adjusted on the basis of landowner requests.

Well Installation and Construction

Monitoring wells in the Sheridan and Lander study areas were installed with a hollow-stem auger drilling rig using procedures described in Lapham and others (1995). In the Red Lodge study area, monitoring wells were installed with a different type of drill rig because of cobble and boulder size sediments. A specialized air rotary rig with a down-hole eccentric bit was used to drill and drive casing at the same time so that the borehole would be maintained while the well was installed. Boreholes were logged during drilling by geologists employed by the contractors used to install the wells. Wells were constructed and developed using procedures described in Lapham and others (1995). The monitoring wells were constructed with factory cleaned and sealed, 2- or 4-inch (in.) diameter, threaded, flush-jointed, polyvinyl chloride (PVC) casing and perforated, PVC-slotted, non-metallic well screen (0.02-in. slot size). Filter packs composed of 10/20 sand were installed from the bottom of the well to 1 to 3 ft above the screened interval; fine sand was installed above the filter pack to prevent the environmental seal from entering the filter pack. The environmental seal installed above the fine sand consisted of bentonite grout mixed onsite. The top of the well screen was placed approximately 2 to 3 ft below the estimated water-table elevation at the time of drilling. Lockable outer steel protective housings were set in a concrete base to protect the PVC casing protruding above the land surface. In some cases, at the request of the landowner, a flush-mounted steel cap was placed on the well for aesthetic reasons and (or) to allow for driving over the well. Well development consisted of both surging and pumping until the produced water was visibly clear. Detailed information describing well installation and construction was recorded and entered into the USGS National Water Information System (NWIS) Ground-Water Site Inventory (GWSI) database *(http://waterdata.usgs.gov/wy/nwis/gwsi)*.

Ancillary Data

Ancillary data were collected for all wells and included descriptions of the sampling location, the well, the subsurface, and land use/land cover within a 500-m (1,640-ft) radius surrounding the well. Data were collected in a nationally consistent and quantitative manner following NAWQA guidance provided in Koterba (1998). Requirements for ancillary data collection were designed to document activities that might affect shallow ground-water quality.

Sample Collection

Ground-water samples were collected once from each well in Sheridan, Wyo., Lander, Wyo., and Red Lodge, Mont., during June to August 2001. Ground-water samples were collected and processed in a mobile water-quality laboratory using NAWQA ground-water sampling procedures described in Koterba and others (1995) and the USGS National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, 1997 to 2006). Water was pumped into a sampling manifold and flow-through chamber in a mobile field laboratory until at least three well-casing volumes were purged at low rates and measurements of pH, specific conductance, temperature, turbidity, and dissolved oxygen (DO) stabilized. After field measurements stabilized, water was diverted to a sampling chamber consisting of a PVC frame enclosed in a plastic bag to minimize the potential of atmospheric contamination. Samples collected for all analyses except chlorofluorocarbons (CFCs), dissolved gases, and radon-222 (radon) were collected within the sampling chamber. All materials in contact with the water samples after being pumped out of the wells were either stainless steel or Teflon (with the exception of water samples collected for CFCs and dissolved gases).

Samples to determine alkalinity, major-ion, trace-element, and nutrient concentrations were filtered onsite using a 0.45-micrometer pore-size, disposable-capsule filter, and collected in precleaned plastic bottles that were rinsed onsite with filtered ground water. Samples to be analyzed for major cations and trace elements were preserved to a pH of less than 2 standard units using ultrapure nitric acid. Samples for major anions, MBAS, dissolved gases, stable isotopes (hydrogen, oxygen, and nitrate), and tritium (^{3}H) did not require preservation. Radon samples were collected in the mobile field laboratory using a glass syringe to withdraw 10 milliliters (mL) of water from a back-pressure valve; the water sample was then injected below mineral oil into a glass scintillation vial and shipped to a laboratory within 24 hours.

Dissolved organic carbon (DOC) samples were filtered onsite using 0.45-micrometer pore size silver filters contained within a stainless steel filter chamber; the filters impart trace concentrations of silver that prevent biological activity that could affect DOC concentrations. Samples collected for DOC analysis were forced through the silver filters using purified nitrogen gas at a pressure that did not exceed 15 pounds per square inch. DOC samples were collected in cleaned and baked amber-colored glass bottles, were chilled on ice immediately after collection, and shipped to a laboratory within 24 hours.

Water samples analyzed for pesticides were filtered using a methanol-rinsed stainless-steel filter chamber that contained a baked 0.7-micron pore size glass-fiber filter. Samples were collected in precleaned amber-colored glass bottles, chilled on ice immediately after collection, and shipped to a laboratory within 24 hours.

Ground-water samples analyzed for VOCs were not filtered and were collected in three precleaned 40-mL amber-colored glass vials with septa, and the vials were filled without headspace. When filling the three vials, the flow rate was adjusted to about 100 mL per minute to minimize aeration of the samples. VOC samples were preserved to a pH of less than 2 standard units using one to five drops of specially prepared 1:1 hydrochloric acid (certified to be free of VOCs), were chilled on ice immediately after collection, and shipped to a laboratory within 24 hours.

Ground-water samples analyzed for CFCs were collected using procedures described by the USGS Reston Chlorofluorocarbon Laboratory in Reston, Va. (U.S. Geological Survey, 2001). CFC samples were collected through a closed system between the well and sampling equipment. CFCs were collected in borosilicate glass sample bottles that were purged with ultrapure nitrogen gas before and during sample collection. Sample bottles were then welded shut to isolate the water from atmospheric contact. Collection and interpretation of CFCs in ground water is relatively complex, so the reader is referred to other resources describing the collection and interpretation of CFCs in ground water for additional information (Busenberg and Plummer, 1992; Plummer and Friedman, 1999; Plummer and Busenberg, 2000; U.S. Geological Survey, 2001).

Chemical Analyses and Data Reporting

Physical characteristics (water temperature, pH, turbidity, and DO) and bacteria (total coliform and *Escherichia coli*) were measured in the field during collection of ground-water samples using methods described in the USGS National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, 1997 to 2006). Alkalinity was determined onsite by incremental titration of a filtered water sample with sulfuric acid (Rounds and Wilde, 2001).

The USGS National Water Quality Laboratory (NWQL) in Denver, Colo., analyzed ground-water samples for major ions, trace elements, radon, nutrients, DOC, MBAS, pesticides, and VOCs. Major ions and trace elements were analyzed using atomic-absorption spectrometry, colorimetry, ion-exchange chromatography, or inductively-coupled plasma/mass spectrometry (Fishman and Friedman, 1989; Faires, 1993; Fishman, 1993; McLain, 1993; Garbarino, 1999; Jones and Garbarino, 1999). Radon was analyzed using liquid scintillation (American Society for Testing and Materials, 1996). Nutrients were analyzed using colorimetry (Fishman, 1993). DOC was analyzed using ultraviolet light-promoted persulfate oxidation and infrared spectrometry (Brenton and Arnett, 1993). MBAS were analyzed using spectrophotometry (Burkhardt and others, 1995). Ground-water samples were analyzed for 109 different pesticides or pesticide breakdown products (table 1) using either C–18 solid-phase extraction and capillary-column gas chromatography/mass spectrometry (GC/MS) (USGS schedule 2001, table 1) (Zaugg and others, 1995) or graphitized carbon-based solid-phase extraction and high-performance liquid chromatography/mass spectrometry (USGS schedule 2060, table 1) (Furlong and others, 2001). Ground-water samples were analyzed for 85 VOCs (table 2) using a purge and trap capillary GC/MS method (Connor and others, 1998).

The USGS Reston Chlorofluorocarbon Laboratory in Reston, Va., analyzed ground-water samples for dissolved gases (methane, carbon dioxide, nitrogen, oxygen, and argon) and CFCs (CFC–11, CFC–12, and CFC–113). Dissolved gases were analyzed using gas chromatography (Busenberg and Plummer, 1992). CFCs were analyzed using electron-capture gas chromatography (Busenberg and Plummer, 1992). Apparent ground-water ages were assigned by the Reston Chlorofluorocarbon Laboratory using CFC equilibrium partial pressures corrected for recharge temperatures with known historical atmospheric partial pressures (Busenberg and Plummer, 1992; Plummer and Friedman, 1999; Plummer and Busenberg, 2000).

In this report, standard nomenclature is used to describe the analyses of water samples for stable isotopes of oxygen, hydrogen, and nitrogen. The composition of stable isotopes is reported using the delta (δ) notation, which indicates parts per thousand or per mil. The value for δ is calculated using the following equation:

$$\delta\,(\text{in per mil}) = \left[\frac{\text{Rx}}{\text{Rs}} - 1\right] \text{x } 1{,}000.$$

The term Rx is the ratio of the heavy-to-light isotope of the sample, and Rs is the ratio of the heavy-to-light isotope of the applicable reference standard (Clark and Fritz, 1997).

The USGS Reston Stable Isotope Laboratory (RSIL) analyzed ground-water samples for stable isotopes of hydrogen (δ^{2}H or deuterium/hydrogen isotopic ratio) by hydrogen equilibrium (Coplen and others, 1991) and oxygen (δ^{18}O) or oxygen-18/oxygen-16 (^{18}O/^{16}O isotopic ratio) by carbon-dioxide equilibrium (Epstein and Mayeda, 1953). Analyses for nitrogen isotopes (δ^{15} nitrate-nitrogen (N) dissolved in water, or nitrogen-15/nitrogen-14 (^{15}N/^{14}N) isotopic ratio) were conducted through the NWQL with a commercial contract for analysis by mass spectrometry (Bremner, 1965; Bremner and Edwards, 1965; Liu, 1979; Minagawa and others, 1984) at Zymax in San Luis Obispo, Calif. Tritium was analyzed at the USGS Isotope Tracers Project Laboratory in Menlo Park, Calif., using electrolytic enrichment (Ostlund and Dorsey, 1975).

Laboratory analytical results for most constituents were reported relative to laboratory reporting levels (LRLs) or to minimum reporting levels (MRLs). LRLs are set by the NWQL to minimize both false positive and false negative measurement error (Childress and others, 1999). The LRLs are statistically calculated on a continual basis using quality-control data for a given analytical method to determine long-term method detection levels (LT-MDLs) (Childress and others, 1999). The LRLs are defined as twice the annual LT-MDLs. MRLs are the minimum concentrations of a constituent that can be reported reliably using a given analytical method (Timme, 1995). In this report, LRLs typically are reported for VOCs and pesticides, and MRLs typically are reported for all other constituents. MRLs and LRLs can vary for the same constituent because of improvement in analytical methods and (or) possible complications with individual analyses. In tables in this report, the “primary” LRL indicates the LRL for the majority of reported values for a constituent and the “other” LRL indicates the LRLs for the remainder of reported values. In this report, LRLs and MRLs sometimes may be referred to simply as reporting levels or laboratory reporting levels.

The NWQL reports some analytical results as estimated concentrations. Estimated concentrations are smaller than a minimum concentration that can be reliably reported by a given analytical method, but generally larger than the LT-MDL (Childress and others, 1999). Concentrations reported as estimated indicate that the constituent is present in the water

Table 1. Pesticides analyzed, trade names, pesticide actions, classes, laboratory reporting levels, and U.S. Environmental Protection Agency standards.

[Compounds detected during study are in **bold** type; USGS, U.S. Geological Survey; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency; E, value estimated; NC, not calculated; --, not applicable; U, chemical was analyzed for, but not detected; USGS analytical method type: 1 = USGS laboratory schedule 2001, 2 = USGS laboratory schedule 2060]

Pesticide	Trade name	Pesticide action	Pesticide class (or parent compound class)	USGS laboratory parameter code	USGS analytical method (see headnote)	Primary laboratory reporting level (µg/L)	Other laboratory reporting levels (µg/L)	USEPA standard or health advisory (µg/L)
Acetochlor	Guardian, Harness, Relay	Preplant herbicide	Chloroacetamide	49260	1	0.004	--	--
Acifluorfen	Blazer, Tackle 2S, Astic	Herbicide	Miscellaneous	49315	2	.01	--	[1]100
Alachlor	Alanex, Lasso, Shroud	Herbicide	Acetanilide	46342	1	.002	--	[2]2
Aldicarb	Temik	Insecticide, nematicide, acaricide	Carbamate	49312	2	.04	--	[2,3]3
Aldicarb sulfone	Standak, aldoxycarb, aldicarb metabolite	Insecticide	Carbamate	49313	2	.02	--	[2,3]3
Aldicarb sulfoxide	Aldicarb breakdown product	--	Carbamate	49314	2	.01	--	[2,3]4
Atrazine[L]	Aatrex, Atranex	Herbicide	Triazine	39632	1	.007	0.009	[2]3
Azinphos-methyl	Guthion, Crysthyon	Insecticide	Organophosphate	82686	1	.05	--	--
Bendiocarb	Ficam, Garrox, Turcam	Insecticide	Carbamate	50299	2	.025	--	--
Benfluralin	Balan, Benefin	Herbicide	Dinitroaniline	82673	1	.01	--	--
Benomyl	Benlate, Benex	Fungicide	Carbamate	50300	2	.004	--	--
Bensulfuron, methyl	Escuri, Londax	Herbicide	Sulfonylurea	61693	2	.0158	--	--
Bentazon	Basagram, Bentzone	Herbicide	Miscellaneous	38711	2	.01	--	[4]200
Bromacil	Hyvar X	Herbicide	Uracil	04029	2	.03	--	[4]70
Bromoxynil	Buctril, Brominal, Agristar	Herbicide	Miscellaneous	49311	2	.02	--	--
Butylate	Sutan+, Genate Plus	Herbicide	Carbamate	04028	1	.002	--	[4]400

Table 1. Pesticides analyzed, trade names, pesticide actions, classes, laboratory reporting levels, and U.S. Environmental Protection Agency standards.—Continued

[Compounds detected during study are in **bold** type; USGS, U.S. Geological Survey; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency; E, value estimated; NC, not calculated; --, not applicable; U, chemical was analyzed for, but not detected; USGS analytical method type: 1 = USGS laboratory schedule 2001, 2 = USGS laboratory schedule 2060]

Pesticide	Trade name	Pesticide action	Pesticide class (or parent compound class)	USGS laboratory parameter code	USGS analytical method (see headnote)	Primary laboratory reporting level (µg/L)	Other laboratory reporting levels (µg/L)	USEPA standard or health advisory (µg/L)
Carbaryl[L]	Carbatox, Sevin	Insecticide	Carbamate	49310	2	0.03	--	[1]4,000
Carbaryl	Carbatox, Sevin	Insecticide	Carbamate	82680	1	0.041	--	[1]4,000
Carbofuran	Furadan, Futura	Insecticide	Carbamate	49309	2	.01	--	[2]40
Carbofuran	Furadan, Futura	Insecticide	Carbamate	82674	1	.02	--	[2]40
Chloramben, methyl ester	Chloramben	Herbicide	Miscellaneous	61188	2	.02	--	[4]100
Chlorimuron	Classic, Darban, Lory	Herbicide	Sulfonyurea	50306	2	.01	--	--
Chlorothalonil	Bravo	Fungicide	Organochlorine	49306	2	.04	--	[1]150
Chlorpyrifos	Dursban, Lorsban	Insecticide	Organophosphate	38933	1	.005	--	[4]2
Clopyralid	Stinger, Lontrel	Herbicide	Miscellaneous	49305	2	.01	--	--
Cyanazine	Bladex	Selective herbicide	Triazine	04041	1	.018	--	[4]1
Cycloate	Ro-Neet	Selective herbicide	Thiocarbamate	04031	2	.01	--	--
2,4–D	Dacamine, Weed-B-Gon	Herbicide	Chlorophenoxy	39732	2	.02	--	[2]70
2,4–DB	Butoxone, Butyrac	Selective herbicide	Chlorophenoxy	38746	2	.02	--	--
2,4–D methyl ester	--	--	Chlorophenoxy	50470	2	.009	0.02, .03	--
Dacthal monoacid	Dacthal breakdown product	--	Organochlorine	49304	2	.01	--	--
DCPA	Dacthal	Herbicide	Organochlorine	82682	1	.003	--	[4]70
p,p'–DDE	DDT breakdown product	--	Organochlorine	34653	1	.003	--	--
Deethylatrazine	Atrazine breakdown product	--	Triazine	04040	1	.006	.03	--
Deethyl, deisopropyl-atrazine	Atrazine breakdown product	--	Triazine	04039	2	.01	--	--

Table 1. Pesticides analyzed, trade names, pesticide actions, classes, laboratory reporting levels, and U.S. Environmental Protection Agency standards.—Continued

[Compounds detected during study are in **bold** type; USGS, U.S. Geological Survey; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency; E, value estimated; NC, not calculated; --, not applicable; U, chemical was analyzed for, but not detected; USGS analytical method type: 1 = USGS laboratory schedule 2001, 2 = USGS laboratory schedule 2060]

Pesticide	Trade name	Pesticide action	Pesticide class (or parent compound class)	USGS laboratory parameter code	USGS analytical method (see headnote)	Primary laboratory reporting level (µg/L)	Other laboratory reporting levels (µg/L)	USEPA standard or health advisory (µg/L)
Deisopropyl-atrazine	Atrazine/cyanazine/Simazine breakdown product	--	Triazine	04038	2	0.04	--	--
Diazinon	Basudin, Spectracide, Knoxout	Insecticide, nematicide	Organophosphate	39572	1	.005	--	[4]1
Dicamba	Banvel, Banex	Herbicide	Benzoic Acid	38442	2	.01	--	[4]4,000
Dichloroprop	Weedone, Polymone	Herbicide	Chlorophenoxy	49302	2	.01	--	--
Dieldrin	Panoram D-31, Octalox	Insecticide	Organochlorine	39381	1	.005	--	[1].2
2,6-Diethylaniline	Alachlor breakdown product	--	Acetanilide	82660	1	.002	--	--
Dinoseb[L]	Premerge	Herbicide	Nitrophenolic	49301	2	.01	--	[2]7
Diphenamid	Dymid, Enide	Selective herbicide	Amide	04033	2	.03	--	[4]200
Disulfoton	Di-Syston	Insecticide, acaricide	Organophosphate	82677	1	.021	--	[4].7
Diuron	Durashield, Karmex	Herbicide	Urea	49300	2	.01	--	[4]200
EPTC	Eptam, Eradicane	Herbicide	Carbamate	82668	1	.002	--	--
Ethalfluralin	Eptam, Eradicane	Herbicide	Dinitroaniline	82663	1	.009	--	--
Ethoprop	Mocap, Prophos	Insecticide, nematicide	Organophosphate	82672	1	.005	--	--
Fenuron[L]	Fenuron	Herbicide	Urea	49297	2	.03	--	--
Flumetsulam	Broadstrike, Python	Herbicide	Sulfonamide	61694	2	.0110	--	--
Fluometuron	Cotoran	Herbicide	Urea	38811	2	.03	--	[4]90
Fonofos	Dyfonate	Insecticide	Organophosphate	04095	1	.003	--	[4]10

Table 1. Pesticides analyzed, trade names, pesticide actions, classes, laboratory reporting levels, and U.S. Environmental Protection Agency standards.—Continued

[Compounds detected during study are in **bold** type; USGS, U.S. Geological Survey; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency; E, value estimated; NC, not calculated; --, not applicable; U, chemical was analyzed for, but not detected; USGS analytical method type: 1 = USGS laboratory schedule 2001, 2 = USGS laboratory schedule 2060]

Pesticide	Trade name	Pesticide action	Pesticide class (or parent compound class)	USGS laboratory parameter code	USGS analytical method (see headnote)	Primary laboratory reporting level (µg/L)	Other laboratory reporting levels (µg/L)	USEPA standard or health advisory (µg/L)
alpha-HCH		Insecticide	Organochlorine	34253	1	0.005	--	--
gamma-HCH	Lindane, Isotoz	Insecticide	Organochlorine	39341	1	.004	--	[2].2
Hydroxyatrazine	Atrazine breakdown product	--	Triazine	50355	2	.008	--	--
3-Hydroxycarbofuran	Carbofuran breakdown product	--	Carbamate	49308	2	.01	--	--
Imazaquin	Scepter	Herbicide	Imidazolinone	50356	2	.016	--	--
Imazethapyr[S]	New Path, Pursuit	Herbicide	Imidazolinone	50407	2	.017	--	--
Imidacloprid	Admire, Provado	Insecticide	Chloronicotynil	61695	2	.0068	--	--
3-keto Carbofuran	Carbofuran breakdown product	--	Carbamate	50295	2	1.5	--	--
Linuron	Linurex, Lorox	Herbicide	Urea	38478	2	.01	--	--
Linuron	Linurex, Lorox	Herbicide	Urea	82666	2	.035	--	--
Malathion	Cythion, Malaspray	Insecticide	Organophosphate	39532	2	.027	--	[4]100
MCPA	Solve, MCP	Herbicide	Chlorophenoxy	38482	2	.02	--	[4]30
MCPB	Butoxone M40, Thistrol	Herbicide	Chlorophenoxy	38487	2	.01	--	--
Metalaxyl	Apron, Ridamil, Subdue	Fungicide	Miscellaneous	50359	2	.02	--	--
Methiocarb	Mesurol	Insecticide	Carbamate	38501	2	.01	--	--
Methomyl	Lannate, Nudrin	Insecticide	Carbamate	49296	2	.0044	--	[4]200
Methomyloxime	Methomyl breakdown product	--	Carbamate	61696	2	.0110	--	--
Methyl parathion	Penncap-M, Paratox	Insecticide	Organophosphate	82667	1	.006	--	[4]1
Metolachlor	Bicep, Dual	Herbicide	Amide	39415	1	.013	--	[4]700
Metribuzin	Lexone, Sencor	Herbicide	Triazine	82630	1	.006	--	[4]70
Metsulfuron	Ally, Escort	Herbicide	Sulfonylurea	61697	2	.0250	--	--

Table 1. Pesticides analyzed, trade names, pesticide actions, classes, laboratory reporting levels, and U.S. Environmental Protection Agency standards.—Continued

[Compounds detected during study are in **bold** type; USGS, U.S. Geological Survey; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency; E, value estimated; NC, not calculated; --, not applicable; U, chemical was analyzed for, but not detected; USGS analytical method type: 1 = USGS laboratory schedule 2001, 2 = USGS laboratory schedule 2060]

Pesticide	Trade name	Pesticide action	Pesticide class (or parent compound class)	USGS laboratory parameter code	USGS analytical method (see headnote)	Primary laboratory reporting level (µg/L)	Other laboratory reporting levels (µg/L)	USEPA standard or health advisory (µg/L)
Molinate	Hydram, Ordram	Herbicide	Carbamate	82671	1	0.002	--	--
Napropamide	Devrinol	Herbicide	Amide	82684	1	.007	--	--
Neburon	Granurex, Propuron	Herbicide	Urea	49294	2	.01	--	--
Nicosulfuron	Accent, OneHope	Herbicide	Sulfonylurea	50364	2	.013	--	--
Norflurazon	Zorial, Solicam	Herbicide	Miscellaneous	49293	2	.02	--	--
Oryzalin[S]	Surflan	Herbicide	Dinitroaniline	49292	2	.02	--	--
Oxamyl	Vydate	Insecticide, acaricide, nematicide	Carbamate	38866	2	.01	--	[2]200
Oxamyloxime	Oxamyl breakdown product	--	Carbamate	50410	2	.013	--	--
Parathion	Alkron, Bladan, Fighter	Insecticide	Organophosphate	39542	1	.007	--	--
Pebulate	Tillam	Herbicide	Carbamate	82669	1	.002	--	--
Pendimethalin	Prowl, Stomp	Herbicide	Dinitroaniline	82683	1	.010	--	--
cis–Permethrin	Ambush, Pounce	Insecticide	Pyrethroid	82687	1	.006	--	--
Phorate	Thimet, Rampart	Insecticide	Organophosphate	82664	1	.011	--	--
Picloram[L]	Tordon	Herbicide	Amine	49291	2	.02	--	[2]500
Prometon[S,L]	Pramitol, Gesafram	Herbicide	Triazine	04037	1	.015	--	[4]100
Pronamide	Kerb	Herbicide	Amide	82676	1	.004	--	[1]200
Propachlor	Ramrod, Prolex	Herbicide	Amide	04024	1	.010	--	[1]100
Propanil	Stamp	Herbicide	Amide	82679	1	.011	--	--
Propargite	Comite, Omite	Insecticide, acaricide	Miscellaneous	82685	1	.023	--	--
Propham	Chem Hoe	Herbicide	Carbamate	49236	2	.01	--	[4]100
Propiconazole	Banner	Fungicide	Miscellaneous	50471	2	.021	0.03, .07	--

Table 1. Pesticides analyzed, trade names, pesticide actions, classes, laboratory reporting levels, and U.S. Environmental Protection Agency standards.—Continued

[Compounds detected during study are in **bold** type; USGS, U.S. Geological Survey; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency; E, value estimated; NC, not calculated; --, not applicable; U, chemical was analyzed for, but not detected; USGS analytical method type: 1 = USGS laboratory schedule 2001, 2 = USGS laboratory schedule 2060]

Pesticide	Trade name	Pesticide action	Pesticide class (or parent compound class)	USGS laboratory parameter code	USGS analytical method (see headnote)	Primary laboratory reporting level (µg/L)	Other laboratory reporting levels (µg/L)	USEPA standard or health advisory (µg/L)
Propoxur	Baygone, Suncide	Fungicide	Carbamate	38538	2	0.01	--	--
Siduron	Tupersan	Herbicide	Urea	38548	2	.02	--	--
Simazine	Aquazine, Princep	Herbicide	Triazine	04035	1	.011	--	[1]4
Sulfometruron, methyl	Oust	Herbicide	Sulfonylurea	50337	2	.009	--	--
Tebuthiuron[S,L]	Graslan, Spike	Herbicide	Urea	82670	1	.016	0.006	[4]500
Terbacil	Sinbar, Herbicide 732	Herbicide	Uracil	04032	2	.01	--	[4]90
Terbacil	Sinbar, Herbicide 732	Herbicide	Uracil	82665	1	.034	--	[4]90
Terbufos	Counter, Contraven	Insecticide	Organophosphate	82675	1	.017	--	[4].4
Terbuthylazine	Gardoprim	Herbicide	Triazine	04022	1	U	--	--
Thiobencarb	Bolero, Saturn	Herbicide	Carbamate	82681	1	.005	--	--
Triallate	Far-Go, Avadex BW	Herbicide	Carbamate	82678	1	.002	--	--
Tribenuron	Express, Urgent	Herbicide	Sulfonylurea	61159	2	.01	--	--
Triclopyr	Garlon	Herbicide	Chlorophenoxy	49235	2	.02	--	--
Trifluralin	Treflan, Trim	Herbicide	Dinitroaniline	82661	1	.009	--	[4]10
Urea, 3,4-Chlorophenyl, methyl	Diuron breakdown product	--	Urea	61692	2	.0242	--	--

[1] U.S. Environmental Protection Agency Risk-Specific Dose at 10^{-4} Cancer Risk (RSD4) (U.S. Environmental Protection Agency, 2003b, 2006).

[2] U.S. Environmental Protection Agency Maximum Contaminant Level (MCL) (U.S. Environmental Protection Agency, 2006).

[3] The MCL is under administrative stay pending review by U.S. Environmental Protection Agency. The MCL for any combination of 2 or more of these 3 chemicals (aldicarb, aldicarb sulfoxide, and aldicarb sulfone) should not exceed 7 µg/L because of similar mode of action.

[4] U.S. Environmental Protection Agency Lifetime Health Advisory Level (HAL) (U.S. Environmental Protection Agency, 2006).

[S] Detected in ground-water samples collected in Sheridan study area.

[L] Detected in ground-water samples collected in Lander study area.

Table 2. Volatile organic compounds (VOCs) analyzed, laboratory reporting levels, and related U.S. Environmental Protection Agency standards.

[Compounds detected during study are shown in **bold** type. USGS, U.S. Geological Survey; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency; --, not applicable]

Volatile organic compound (VOC)	Common name	USGS laboratory parameter code	Chemical Abstract Service (CAS) number	Primary laboratory reporting level (other laboratory reporting level) (µg/L)	USEPA standard or health advisory (µg/L)
Acetone[R]	**Acetone**	81552	67-64-1	7	--
tert-Amyl methyl ether	TAME	50005	994-05-8	.1	--
Benzene[L]	--	34030	71-43-2	.04	[1]5
Bromobenzene	Phenyl bromide	81555	108-86-1	.04	--
Bromochloromethane	Methylene chlorobromide	77297	74-97-5	.04	[2]90
Bromodichloromethane[R]	**Dichlorobromomethane**	32101	75-27-4	.05	[1,3]80
Bromoethene	Vinyl bromide	50002	593-60-2	.1	--
Bromomethane	Methyl bromide	34413	74-83-9	.3	[2]10
2-Butanone[R]	**Methyl ethyl ketone (MEK)**	81595	78-93-3	2	--
n-Butylbenzene	1-Phenylbutane	77342	104-51-8	.2	--
Carbon disulfide[L]	**Carbon disulfide**	77041	75-15-0	.07	--
Chlorobenzene	Monochlorobenzene	34301	108-90-7	.03	[1]100
Chloroethane	Ethyl chloride	34311	75-00-3	.1	--
Chloroethene	Vinyl chloride	39175	75-01-4	.1	[1]2
Chloromethane	Methyl chloride	34418	74-87-3	.2	[2]30
1-Chloro-2-methylbenzene	*o*-Chlorotoluene	77275	95-49-8	.03	[2]100
1-Chloro-4-methylbenzene	*p*-Chlorotoluene	77277	106-43-4	.06	[2]100
3-Chloro-1-propene	3-Chloropropene	78109	107-05-1	.1	--
Dibromochloromethane	Dibromochloromethane	32105	124-48-1	.2	[1,3]80
1,2-Dibromo-3-chloropropane	DBCP, Nemagon	82625	96-12-8	.2 (.5)	[1].2
1,2-Dibromoethane	Ethylene dibromide (EDB)	77651	106-93-4	.04	[1].05
Dibromomethane	Methylene dibromide	30217	74-95-3	.05	--
1,2-Dichlorobenzene	*o*-Dichlorobenzene	34536	95-50-1	.03	[1]600
1,3-Dichlorobenzene	*m*-Dichlorobenzene	34566	541-73-1	.03	[2]600
1,4-Dichlorobenzene	*p*-Dichlorobenzene	34571	106-46-7	.05	[1]75
trans-1,4-Dichloro-2-butene	(Z)-1,4-Dichloro-2-butene	73547	110-57-6	.7	--
Dichlorodifluoromethane	CFC–12, Freon 12	34668	75-71-8	.3	[2]1,000
1,1-Dichloroethane	Ethylidene dichloride	34496	75-34-3	.04	--
1,2-Dichloroethane	Ethylene dichloride	32103	107-06-2	.1	[1]5
1,1-Dichloroethene	Vinylidene chloride	34501	75-35-4	.04	[1]7
cis-1,2-Dichloroethene	(Z)-1,2-Dichloroethene	77093	156-59-2	.04	[1]70
trans-1,2-Dichloroethene	(E)-1,2-Dichlorothene	34546	156-60-5	.03	[1]100
Dichloromethane	Methylene chloride	34423	75-09-2	.2	[1]5
1,2-Dichloropropane	Propylene dichloride	34541	78-87-5	.03	[1]5

Table 2. Volatile organic compounds (VOCs) analyzed, laboratory reporting levels, and related U.S. Environmental Protection Agency standards.—Continued

[Compounds detected during study are shown in **bold** type. USGS, U.S. Geological Survey; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency; --, not applicable]

Volatile organic compound (VOC)	Common name	USGS laboratory parameter code	Chemical Abstract Service (CAS) number	Primary laboratory reporting level (other laboratory reporting level) (µg/L)	USEPA standard or health advisory (µg/L)
1,3-Dichloropropane	Trimethylene dichloride	77173	142-28-9	0.1	--
2,2-Dichloropropane	--	77170	594-20-7	.05	--
1,1-Dichloropropene	--	77168	563-58-6	.03	--
cis-1,3-Dichloropropene	(Z)-1,3-Dichloropropene	34704	10061-01-5	.09	[4]40
trans-1,3-Dichloropropene	(E)-1,3-Dichloropropene	34699	10061-02-6	.09	[4]40
Diethyl ether	Ethyl ether	81576	60-29-7	.2	--
Diisopropyl ether	Diisopropylether (DIPE)	81577	108-20-3	.1	--
1,2-Dimethylbenzene[L]	***o*-Xylene**	77135	95-47-6	.04	[1,5]10,000
1,3- and 1,4-Dimethylbenzene[L]	***m*- & *p*-Xylene**	85795	*m*-108-38-3 *p*-106-42-3	.06	[1,5]10,000
(1,1-Dimethylethyl)benzene	*tert*-Butylbenzene	77353	98-06-6	.06	--
Ethenylbenzene	Styrene	77128	100-42-5	.04	[1]100
Ethylbenzene[L]	**Phenylethane**	34371	100-41-4	.03	[1]700
Ethyl methacrylate	Ethyl methacrylate	73570	97-63-2	.2	--
Ethyl *tert*-butyl ether	Ethyl-*t*-butyl ether (ETBE)	50004	637-92-3	.05	--
2-Ethyltoluene	*o*-Ethyltoluene	77220	611-14-3	.06	--
1,1,2,3,4,4-Hexachloro-1,3-butadiene	Hexachlorobutadiene	39702	87-68-3	.1	[4]90
1,1,1,2,2,2-Hexachloroethane	Hexachloroethane	34396	67-72-1	.2	[2]1
2-Hexanone	Methyl butyl ketone (MBK)	77103	591-78-6	.7	--
Iodomethane	Methyl iodide	77424	74-88-4	.1	--
1-Isopropyl-4-methylbenzene	*p*-Cymene	77356	99-87-6	.07	--
Methyl acrylonitrile	Methacrylonitrile	81593	126-98-7	.6	--
Methylbenzene[L]	**Toluene**	34010	108-88-3	.05	[1]1,000
(1-Methylethyl)benzene	Cumene	77223	98-82-8	.03	--
Methyl methacrylate	Methyl-2-methacrylate	81597	80-62-6	.3	--
4-Methyl-2-pentanone	Methyl isobutyl ketone (MIK)	78133	108-10-1	.4	--
Methyl-2-propenoate	Methyl acrylate	49991	96-33-3	1	--
(1-Methylpropyl)benzene	*sec*-butylbenzene	77350	135-98-8	.03	--
Methyl *tert*-butyl ether	MTBE	78032	1634-04-4	.2	[6]20–40
Naphthalene	--	34696	91-20-3	.2 (.5)	[2]100
2-Propenenitrile	Acrylonitrile	34215	107-13-1	1	[4]6
n-Propylbenzene	Isocumene	77224	103-65-1	.04	--
1,1,1,2-Tetrachloroethane	--	77562	630-20-6	.03	[4]70
1,1,2,2-Tetrachloroethane	--	34516	79-34-5	.09	[4].3

Table 2. Volatile organic compounds (VOCs) analyzed, laboratory reporting levels, and related U.S. Environmental Protection Agency standards.—Continued

[Compounds detected during study are shown in **bold** type. USGS, U.S. Geological Survey; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency; --, not applicable]

Volatile organic compound (VOC)	Common name	USGS laboratory parameter code	Chemical Abstract Service (CAS) number	Primary laboratory reporting level (other laboratory reporting level) (µg/L)	USEPA standard or health advisory (µg/L)
Tetrachloroethene	Perchloroethene (PCE), tetrachloroethylene	34475	127-18-4	0.1	[1]5
Tetrachloromethane	Carbon tetrachloride	32102	56-23-5	.06	[1]5
Tetrahydrofuran[R]	**Diethylene oxide**	81607	109-99-9	2	--
1,2,3,4-Tetramethylbenzene	Prehitene	49999	488-23-3	.2	--
1,2,3,5-Tetramethylbenzene	Isodurene	50000	527-53-7	.2	--
Tribromomethane	Bromoform	32104	75-25-2	.06	[1,3]80
1,2,3-Trichlorobenzene	--	77613	87-61-6	.3	--
1,2,4-Trichlorobenzene	--	34551	120-82-1	.2	[1]70
1,1,1-Trichloroethane	Methylchloroform	34506	71-55-6	.03	[1]200
1,1,2-Trichloroethane	Vinyl trichloride	34511	79-00-5	.06	[1]5
Trichloroethene	TCE, trichloroethylene	39180	79-01-6	.04	[1]5
Trichlorofluoromethane	CFC–11, Freon 11	34488	75-69-4	.09	[2]2,000
Trichloromethane[S,L,R]	**Chloroform**	32106	67-66-3	.02	[1,3]80
1,2,3-Trichloropropane	Allyl trichloride	77443	96-18-4	.2	[2]40
1,1,2-Trichloro-1,2,2-trifluoroethane	CFC–113, Freon 113	77652	76-13-1	.06	--
1,2,3-Trimethylbenzene	Hemimellitene	77221	526-73-8	.1	--
1,2,4-Trimethylbenzene[L,R]	**Pseudocumene**	77222	95-63-6	.06	--
1,3,5-Trimethylbenzene	Mesitylene	77226	108-67-8	.04	--

[1] U.S. Environmental Protection Agency Maximum Contaminant Level (MCL) (U.S. Environmental Protection Agency, 2006).

[2] U.S. Environmental Protection Agency Lifetime Health Advisory Level (HAL) (U.S. Environmental Protection Agency, 2006).

[3] Total for all trihalomethanes combined cannot exceed 80 µg/L (U.S. Environmental Protection Agency, 2006).

[4] U.S. Environmental Protection Agency Risk-Specific Dose at 10^{-4} Cancer Risk (RSD4) (U.S. Environmental Protection Agency, 2003a, 2003b, 2006).

[5] Total for all xylenes combined cannot exceed 10,000 µg/L (U.S. Environmental Protection Agency, 2006).

[6] The U.S. Environmental Protection Agency Drinking-Water Advisory ranges from 20–40 µg/L (U.S. Environmental Protection Agency, 2006).

[S] Detected in ground-water samples collected in Sheridan study area.

[L] Detected in ground-water samples collected in Lander study area.

[R] Detected in ground-water samples collected in Red Lodge study area.

sample, but there is some type of quantitative analytical uncertainty associated with the reported concentration. In this report, estimated concentrations in text, tables, and appendixes are designated with the placement of the letter “E” preceding the reported laboratory concentration.

Some constituents are reported in this report as “M” values. This designation indicates the constituent was detected but not quantified by the NWQL.

Radon activities are reported in relation to a sample-specific minimum detectable concentration (SSMDC) and an analytical uncertainty value (also known as a precision estimate or counting error). The SSMDC is “the minimum quantity of a specific radionuclide detected by the counting instrument for any sample for a given analysis,” and it is “defined by the requirement that the counted radioactivity must differ from the background count by three times the standard deviation of the background count” (Focazio and others, 2001, p. 24). SSMDCs are determined for each radon analysis on the basis of instrument conditions at the time of measurement and reported by the laboratory for each analysis.

Ground-water samples analyzed for 85 VOCs using a purge and trap capillary GC/MS method (Connor and others, 1998) (table 2) also were analyzed for tentatively identified compounds (TICs). A TIC is a VOC that is identified by a gas chromatography/mass spectrometry library search routine and compared to mass spectra in a reference library, typically the National Institute for Standards and Technology (NIST) library. The VOC is considered “tentatively identified” until a reference standard is obtained and analyzed in the same manner (Donna Rose, U.S. Geological Survey, written commun., 2003). No TICs were identified in ground-water samples collected during this study.

In this report, median constituent concentrations were calculated using two methods. Median concentrations of inorganic constituents were calculated for all data values, including detections and nondetections. Median concentrations of organic constituents (pesticides and VOCs) were calculated only for detections.

Quality Assurance and Quality-Control Samples

In addition to collection of environmental ground-water-quality samples, several types of quality-control (QC) samples were collected as part of the quality-assurance program (Koterba and others, 1995). QC samples included several types of blanks, replicate environmental samples, and field matrix-spike samples. The QC samples were collected, preserved, and analyzed using the same methods and equipment as used for environmental samples. Collection and evaluation of QC samples, in addition to adherence to strict sample collection, processing, and analysis procedures created by the NAWQA Program, composed the quality-assurance program.

Blank Samples

Several types of blank samples were collected to evaluate bias from the potential introduction of contamination to environmental samples during field sample collection, field equipment cleaning, and laboratory analytical procedures. Specially prepared water for all blank samples was provided by the USGS for the NAWQA Program, and was certified to be free of inorganic (inorganic-free blank water) and organic (organic-free blank water) constituents to concentrations less than NWQL LRLs or MRLs. Field-equipment blanks were collected subsequent to collection of environmental samples and cleaning of the sampling equipment. Field-equipment blanks were collected during sampling trips to determine if cleaning procedures removed constituents from sampling equipment between sampling sites and to ensure that field and laboratory methods had not contaminated environmental samples. After cleaning was completed, the field-equipment blank was collected by passing blank water through all sampling equipment and then collecting and preserving the sample using the same procedures as for environmental samples. Trip blanks consisted of vials filled with organic-free blank water and sealed at the USGS NWQL. Trip blanks were used to verify that VOC vials were not contaminated during storage, sampling, or shipment to or from the NWQL. Source-solution blanks were collected by filling sample bottles directly with organic-free blank water instead of passing it through the sampling equipment. Source-solution blanks were collected to ensure that the certified organic-free blank water was free of detectable DOC and VOCs.

Three field-equipment blank samples were collected during sampling and analyzed for major ions, trace elements, nutrients, and DOC. Few constituents were detected in field-equipment blank samples (table 3); concentrations generally were very small and generally much smaller than concentrations measured in environmental samples. Results of field-equipment blank samples indicated that decontamination procedures were adequate, and that field and laboratory contamination of environmental samples by most inorganic constituents was minimal.

Three field-equipment blank samples were collected during sampling and analyzed for MBAS. Although MBAS were detected in only one of three field-equipment blank samples, the measured concentration (0.03 milligram per liter (mg/L)) was similar to most concentrations measured in environmental samples (table 3). Only one environmental MBAS concentration (E0.12 mg/L) was larger than the measured blank concentration; 9 of 10 MBAS detections were less than or equal to 0.03 mg/L. Consequently, reported MBAS detections and concentrations were used cautiously in this study.

Three field-equipment blank samples were collected and analyzed for pesticides during sampling. No pesticide compounds were detected in the three field-equipment blanks, indicating that field and laboratory methods did not result in contamination of samples.

Table 3. Summary of major ions, trace elements, nutrients, dissolved organic carbon, radionuclides, and other constituents detected in field-equipment blank samples and in environmental samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.

[E, estimated concentration; <, less than; mg/L, milligrams per liter; M, constituent detected but not quantified; C, carbon]

Constituent or characteristic	Blank samples		Environmental samples	
	Number of detections/ number of samples	Concentrations	Number of detections/ number of samples	Range of concentrations
Major ions, in milligrams per liter				
Calcium	2/3	<0.01, 0.03, E0.01	29/29	6.27–354
Magnesium	1/3	<0.008, 0.01, <0.008	29/29	1.82–170
Sodium	0/3	<0.1, <0.1, <0.1	29/29	1.3–377
Potassium	0/3	<0.09, <0.09, <0.09	29/29	0.63–10.1
Chloride	1/3	<0.1, E0.1, <0.1	28/29	<0.1–31.8
Sulfate	2/3	0.2, 0.4, <0.1	29/29	2.1–1,780
Fluoride	0/3	<0.2, <0.2, <0.2	29/29	E0.1–1.1
Silica	0/3	<0.1, <0.1, <0.1	29/29	5.9–24.6
Trace elements, in micrograms per liter unless otherwise noted				
Aluminum	1/3	2, <1, <1	16/29	<1–3
Antimony	1/3	<0.05, <0.05, E0.04	25/29	E0.03–0.12
Arsenic	0/3	<0.2, <0.2, <0.2	24/29	E0.1–0.8
Barium	0/3	<1, <1, <1	29/29	5.6–123
Beryllium	0/3	<0.06, <0.06, <0.06	1/29	E0.04–<0.1
Boron	0/3	<7, <7, <7	26/29	E4–722
Bromide (mg/L)	0/3	<0.01, <0.01, <0.01	18/29	<0.01–0.11
Cadmium	0/3	<0.04, <0.04, <0.04	9/29	E0.02–0.07
Chromium	0/3	<0.8, <0.8, <0.8	13/29	E0.5–2.2
Cobalt	2/3	<0.02, 10, 0.02	29/29	0.03–17.6
Copper	2/3	<0.2, 16, 0.2	28/29	<0.2–72.2
Iron	1/3	<10, M, <10	7/29	<10–650
Lead	1/3	<0.08, 0.11, <0.08	6/29	E0.07–<0.2
Lithium	0/3	<0.3, <0.3, <0.3	29/29	0.4–356
Manganese	1/3	<0.1, 0.4, <0.1	29/29	0.1–1,550
Molybdenum	0/3	<0.2, <0.2, <0.2	27/29	E0.1–8.3
Nickel	2/3	<0.06, 0.21, 0.15	22/29	<0.06–3.07
Selenium	0/3	<0.3, <0.3, <0.3	12/29	E0.2–6.7
Silver	0/3	<1, <1, <1	0/29	<1–<2
Strontium	1/3	<0.08, 0.22, <0.08	29/29	24.7–3,550
Thallium	0/3	<0.04, <0.04, <0.04	5/29	E0.02–0.11
Vanadium	0/3	<0.2, <0.2, <0.2	28/29	E0.1–3.6
Zinc	1/3	<1, 2, <1	18/29	<1–7

Table 3. Summary of major ions, trace elements, nutrients, dissolved organic carbon, radionuclides, and other constituents detected in field-equipment blank samples and in environmental samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[E, estimated concentration; <, less than; mg/L, milligrams per liter; M, constituent detected but not quantified; C, carbon]

Constituent or characteristic	Blank samples		Environmental samples	
	Number of detections/ number of samples	Concentrations	Number of detections/ number of samples	Range of concentrations
Nutrients and dissolved organic carbon, in milligrams per liter				
Nitrite, as nitrogen	0/3	<0.006, <0.006, <0.006	14/29	E0.003–0.015
Nitrite + nitrate, as nitrogen	0/3	<0.05, <0.05, <0.05	26/29	E0.026–1.38
Ammonia, as nitrogen	0/3	<0.04, <0.04, <0.04	7/29	E0.023–0.048
Ammonia + organic nitrogen, as nitrogen	0/3	<0.1, <0.1, <0.1	18/29	E0.07–0.34
Phosphorus, as phosphorus	0/3	<0.006, <0.006, <0.006	23/29	E0.003–0.028
Orthophosphate, as phosphorus	0/3	<0.02, <0.02, <0.02	7/29	E0.009–0.025
Dissolved organic carbon (mg/L as C)	1/3	E0.16, <0.3, <0.3	27/27	E0.32–4.6
Radionuclides, in micrograms per liter, dissolved				
Uranium	0/3	<0.02, <0.02, <0.02	29/29	0.02–40.5
Other constituents				
Caffeine (µg/L)	1/3	<0.010, <0.010, E0.008	2/29	E0.006–E0.023
Methylene blue active substances (detergents) (mg/L)	1/3	0.03, <0.02, <0.02	26/26	E0.01–E0.12

Caffeine was detected in one of three field-equipment blank samples (table 3). The caffeine concentration measured in the field-equipment blank sample was small and estimated (0.008 microgram per liter (µg/L)). Caffeine was detected in 2 of 29 environmental samples collected during the study at similar small estimated concentrations (0.006 and 0.023 µg/L). In addition, caffeine was detected frequently in other NAWQA field-blank samples from around the country at similar concentrations. Therefore, both detections of caffeine in environmental samples are considered to be due to some type of sample contamination and were not considered as detections for this study.

Three field-equipment blank samples were collected and analyzed for VOCs during sampling. No VOCs were detected in the three field-equipment blanks, indicating that field and laboratory methods did not result in contamination of samples.

Toluene (methylbenzene), a common component of gasoline, was detected in one of three source-solution blank samples. Toluene is one of four VOCs (benzene, toluene, ethylbenzene, and xylenes, commonly known as BTEX compounds) that are commonly found together in ground water contaminated by gasoline. The toluene concentration measured in the source-solution blank was small and estimated (0.01 µg/L). Because toluene was not detected in the associated field-equipment blank sample, the measured concentration was so small, and relatively large volumes of ground water were purged subsequent to cleaning and prior to sampling, cross-contamination from the VOC was not likely to have contaminated any sample equipment and probably did not account for any environmental detections.

One trip blank was collected during the study. No VOCs were detected in the trip blank sample.

Replicate Samples

A replicate sample (also known as a duplicate sample) is a sample collected immediately after the primary ground-water sample (environmental sample); both are analyzed for the same constituents to assess combined effects of field and laboratory procedures on measurement variability (precision). The relative percent difference (RPD) was calculated to compare constituent concentrations measured in both samples using the following equation:

$$\text{RPD} = \text{absolute value}\left(\frac{sample1 - sample2}{\left(\frac{sample1 + sample2}{2}\right)}\right) \times 100 \; .$$

Three pairs of replicate samples were collected and analyzed for major ions, trace elements, nutrients, DOC, radon, tritium, uranium, and MBAS (Appendix 2). RPDs were not calculated for inorganic sample pairs where one value was reported as less than the MRL and the other value was reported as greater than the MRL or was estimated. RPDs for most constituents were less than or equal to 10 percent, and indicated very good precision (reproducibility) for most inorganic constituents. Thirteen constituents had RPDs greater than 10 percent in at least one of three replicate samples; however, RPDs greater than 10 percent were attributable to small concentration differences that resulted in relatively large RPDs because both environmental and replicate sample concentrations were very small.

RPDs were not calculated for all three MBAS sample pairs because one value was reported as less than the MRL and the other value was reported as greater than the MRL (Appendix 2). MBAS were detected in two of three environmental samples (0.02 and 0.03 mg/L) at or slightly larger than the reporting level (0.02 mg/L), but MBAS were not detected in the corresponding replicate samples. This indicated that reported MBAS detections and concentrations should be used with caution.

Field and Laboratory Matrix-Spike Samples

Field-matrix spike samples for pesticides and VOCs were analyzed to evaluate bias and variability from ground-water matrix interference or potential degradation of constituent concentrations during sample processing, storage, and analysis. Field-matrix spike samples were collected during the field-matrix spiking process by injecting known concentrations of selected pesticides and VOCs into replicate environmental samples. Laboratory-spiked samples also were analyzed for pesticides and VOCs according to laboratory protocols. Recoveries varied for both field and laboratory-spiked pesticide and VOC samples, but no detections were qualified or deleted on the basis of poor recoveries.

Major-Ion Balances

Major-ion data were quality assured by calculating ion balances. The ion balance was calculated (in milliequivalents per liter) as the total dissolved-cation equivalence minus the total dissolved-anion equivalence divided by the total equivalence of ions dissolved in solution. Calculated balances for all ground-water samples were less than 5 percent, which was considered acceptable for the study.

Water-Quality Criteria

Natural processes and human activities can affect ground-water quality. The primary natural factors that can affect the type and quantities of dissolved constituents in ground water include the source and chemical composition of recharge water, the lithologic and hydrologic properties of the geologic unit, the various chemical processes occurring within the geologic unit, the amount of time the water has remained in contact with the geologic unit (residence time), and the mixing of waters from different geologic units. Many different human activities can affect ground-water quality, and the effects are often negative and some can impair the quality of water in relation to some uses. Potential sources of ground-water contamination in the aquifers studied included both point sources, such as leachate from individual septic systems and leaks and spills from above-ground fuel and chemical storage, and nonpoint sources, such as infiltration and return flow from irrigated cropland, pasture, or gardens, nonagricultural application of pesticides and fertilizers, and infiltration of runoff from roads.

Ground-water quality data presented in this report are compared with several U.S. Environmental Protection Agency (USEPA) drinking-water standards for finished (treated) water established in the Safe Drinking Water Act. The USEPA has established standards for physical properties and chemical constituents in drinking water that may have adverse effects on human health or that may cause cosmetic effects (for example, skin or tooth discoloration) or aesthetic effects (for example, color, taste, or odor). The Maximum Contaminant Level (MCL) is legally enforceable and health-based and is the maximum permissible level for a constituent in drinking water that is delivered to a user of a public-water system (U.S. Environmental Protection Agency, 2006). The Health Advisory Level (HAL) is a nonenforceable standard that establishes acceptable constituent concentrations for different exposure periods (1 day, 10 day, long-term, and lifetime). A lifetime HAL is the concentration of a chemical that would not result in any known or anticipated adverse noncarcinogenic health effects over a lifetime of exposure (70 years) (U.S. Environmental Protection Agency, 2006). The Risk-Specific Dose (RSD) is a concentration of a chemical with a specific risk level under certain exposure conditions over a lifetime (70 years) (U.S. Environmental Protection Agency, 2006). An action level (AL) is a concentration of a chemical, which, if exceeded, requires treatment by the public water supplier (U.S. Environmental Protection Agency, 2003a, 2003b, 2006). Secondary drinking-water regulations (U.S. Environmental Protection Agency, 2006), such as Secondary Maximum Contaminant Levels (SMCLs), are nonenforceable standards related to the cosmetic or aesthetic effects of drinking water and are the maximum recommended level for a constituent in drinking water. Although these USEPA standards only apply to drinking water supplied by public-water systems, not individual well owners, the concentrations are useful for comparison to evaluate the suitability of water collected from wells for drinking.

Quality of Shallow Ground Water

The quality of shallow ground water in three areas of unsewered low-density development in Wyoming and Montana is described in this section. Land use and land cover and the hydrogeologic setting within each of the three study areas are described first to provide background information for each study area. Effects of human activities on ground-water quality are described and summarized.

Sheridan, Wyo., Study Area

Sheridan is located in north-central Wyoming in Sheridan County and has a population of 15,804 (U.S. Census Bureau, 2007). Ground-water-quality samples were collected in June 2001 from 10 monitoring wells installed in the Sheridan area.

Land Use and Land Cover

Land use and land cover from the National Land Cover Database (U.S. Geological Survey, 2000) is shown for the Sheridan study area and surrounding areas in figure 2. Adjacent to streams and drainages, land use and land cover primarily consists of wetlands, pasture/hay, and occasional row crops. Between streams and drainages, land use and land cover is predominantly rangeland (defined as shrubland or grassland in fig. 2), although minor amounts of other land use or land cover are present.

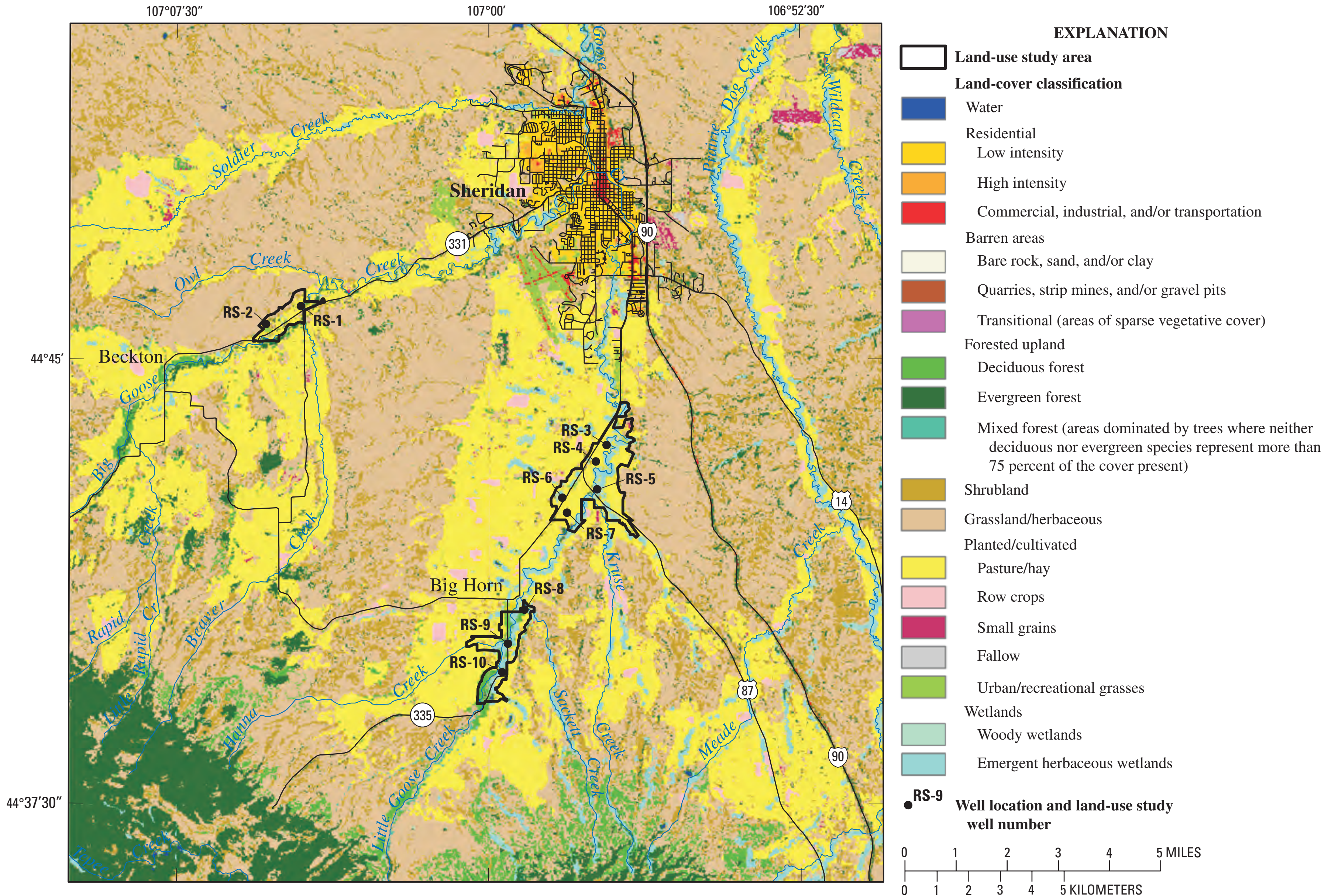
During the study, land use and land cover (“land use”) was mapped onsite at detail within a 500-m (1,640-ft) radius surrounding all 10 wells installed and sampled in the Sheridan study area (table 4; Appendix 1). Livestock pasture was the most abundant land use and was mapped within the radii of all 10 sampled wells, ranging from about 12 to 50 percent with an average of about 30 percent. Urban, which includes low-density residential land use was the second most abundant land use and was mapped within the radii of all 10 wells, ranging from about 7 to 32 percent with an average of about 21 percent. Riparian land (defined as “wetlands” in fig. 2, table 4; Appendix 1) was mapped within the radii of 9 of 10 wells and where present, ranged from about 5 to 28 percent, with an average of about 18 percent. Cropland was mapped within the radii of 8 of 10 wells and where present, ranged from about 8 to 37 percent, with an average of about 18 percent. Almost all cropland was grass or alfalfa grown for hay (Appendix 1). Remaining land uses (agricultural infrastructure, rangeland, and other categories) generally comprised small percentages or were mapped infrequently within 500 m of wells (table 4; Appendix 1).

Hydrogeologic Setting and Apparent Ground-Water Age

Unconfined alluvial aquifers sampled in the Sheridan area consist of unconsolidated Quaternary deposits of alluvium in and adjacent to streams in the area. The alluvium overlies bedrock composed of sedimentary siliciclastic rocks of the lower Tertiary Wasatch and (or) Fort Union Formations. Two wells were installed in the alluvium along Big Goose Creek, whereas the remaining eight wells were installed in alluvium along Little Goose Creek (fig. 3). Both streams originate in steep canyons cut into Paleozoic and Mesozoic sedimentary rocks composing the Bighorn Mountains and then flow across relatively flat Tertiary sedimentary rocks near the city of Sheridan; these rocks are the sources of sediment composing the aquifers. On the basis of cores obtained during drilling and geophysical methods, Odum and Miller (1988, fig. 11; plate 1) estimated the thickness of alluvium along Little and Big Goose Creeks in the Sheridan area (fig. 3) generally to be less than 30 ft thick. The investigators reported the unconsolidated deposits were composed of silt, sand, and gravel. Similar lithologies were noted during drilling and installation of 10 monitoring wells for this study. Depths of the 10 monitoring wells installed for this study ranged from about 13 to 29 ft below land surface (table 5). The full thickness of alluvium was penetrated at well RS–7 (fig. 3), as bedrock was encountered at about 15 ft below land surface. Some hydraulic connection between the alluvial aquifers and aquifers in the underlying lower Tertiary formations is likely in the Sheridan study area (fig. 3).

Water-quality samples were collected from monitoring wells installed for this study (fig. 3; table 5). All but one monitoring well was completed only in unconsolidated deposits; monitoring well RS–2 was completed not only in the Quaternary unconsolidated deposits, but also 2.5 ft into the underlying lower Tertiary-age Fort Union Formation. In contrast, a review of well records for the Sheridan study area indicated that domestic wells generally are installed to greater depths than monitoring wells installed for this study and indicated that domestic wells are completed in the Quaternary unconsolidated deposits, lower Tertiary bedrock underlying the unconsolidated deposits, or are completed in both.

Water levels measured in the 10 monitoring wells installed in the Sheridan area for this study indicated the water table was 4.94 and 25.08 ft below land surface in the two wells



Base modified from Redistricting Census 2000 TIGER/Line Files, U.S. Census Bureau, 2001
Hydrography modified from U.S. Geological Survey National Hydrography Database digital data, 1997
Albers Equal-Area Conic projection, Standard parallels 40°00′N and 45°00′N, central meridian 107°30′W

Modified from U.S. Geological Survey, EROS Data Center National Land Cover Data–30-meter resolution data for Yellowstone River Basin, 2000

Figure 2. Distribution of land use and land cover in the Sheridan study area, Wyoming.

Table 4. Percent land use and land cover mapped within 500-meter radius of sampled wells.

[USGS, U.S. Geological Survey; --, not present within area; NC, not calculated because land use was not present within radii of more than one-half the wells]

Well number	USGS site-identification number	Date of land-use assessment (month/day/year)	Cropland (percent)	Agricultural infrastructure (percent)	Livestock pasture (percent)	Grassland (percent)	Rangeland (percent)	Wetland (percent)	Urban (percent)	Other (percent)	Total (percent)
Sheridan, Wyo., study area monitoring wells											
RS–1	444554107043101	07/25/00	8.7	--	28.0	--	7.4	19.5	32.2	4.2	100.0
RS–2	444536107052201	07/25/00	--	--	47.4	--	15.9	4.6	27.7	4.5	100.0
RS–3	444333106571001	07/26/00	26.1	--	31.2	--	--	21.2	20.5	1.0	100.0
RS–4	444317106572601	04/16/01	10.5	--	33.0	--	--	19.4	29.8	7.3	100.0
RS–5	444249106572301	07/27/00	27.3	2.4	23.0	--	--	26.0	21.4	--	100.0
RS–6	444240106581401	07/26/00	32.6	--	39.0	--	--	--	20.4	8.0	100.0
RS–7	444225106580701	07/25/00	--	--	50.5	--	--	20.4	18.7	10.5	100.0
RS–8	444047106590901	04/16/01	8.3	--	14.7	11.7	14.9	26.7	20.7	3.2	100.0
RS–9	444012106593201	08/09/00	27.0	--	16.0	--	12.0	28.1	12.6	4.4	100.0
RS–10	443943106594001	08/09/00	36.6	9.7	12.1	--	13.7	17.8	7.4	2.7	100.0
Average			[1]17.7	NC	29.5	NC	[1]6.4	[1]18.4	21.1	[1]4.6	
Lander, Wyo., study area monitoring wells											
RL–1	425313108440701	04/19/01	16.1	--	17.2	--	32.6	25.3	6.4	2.3	100.0
RL–2	425253108434501	04/19/01	10.7	--	45.1	--	17.5	11.3	14.0	1.4	100.0
RL–3	425158108433801	04/19/01	22.5	--	52.6	--	--	--	19.3	5.6	100.0
RL–4	425140108430901	04/19/01	--	--	54.6	--	13.6	18.2	8.0	5.5	100.0
RL–5	425129108432401	04/19/01	9.2	--	63.7	--	--	--	23.3	3.8	100.0
RL–6	425116108430101	04/20/01	--	--	52.3	--	--	31.2	12.4	4.1	100.0
RL–7	425111108430501	04/19/01	--	--	45.5	--	--	35.9	9.6	9.0	100.0
RL–8	424830108450101	04/19/01	--	--	44.4	--	8.4	25.7	11.0	10.6	100.0
RL–9	424808108453101	04/19/01	--	--	16.1	--	28.5	34.6	17.2	3.5	100.0
RL–10	424751108455901	04/19/01	14.7	--	23.5	--	24.3	23.4	14.1	--	100.0
Average			NC	NC	41.5	NC	[1]12.5	[1]20.6	13.5	[1]4.6	
Red Lodge, Mont., study area monitoring wells											
RR–1	451510109134801	04/17/01	22.2	--	16.0	12.6	--	26.6	18.3	4.3	100.0
RR–3	450949109164601	04/17/01	--	--	17.9	19.4	--	21.3	39.2	2.3	100.0
RR–4	450958109162801	04/17/01	--	--	15.1	28.9	--	6.4	46.7	2.8	100.0
RR–5	450952109162901	04/17/01	--	--	3.2	26.3	--	17.3	53.1	--	100.0

Table 4. Percent land use and land cover mapped within 500-meter radius of sampled wells.—Continued

[USGS, U.S. Geological Survey; --, not present within area; NC, not calculated because land use was not present within radii of more than one-half the wells]

Well number	USGS site-identification number	Date of land-use assessment (month/day/year)	Cropland (percent)	Agricultural infrastructure (percent)	Livestock pasture (percent)	Grassland (percent)	Rangeland (percent)	Wetland (percent)	Urban (percent)	Other (percent)	Total (percent)
Red Lodge, Mont., study area monitoring wells—Continued											
RR–6	450949109172301	04/17/01	--	--	11.8	61.3	--	10.1	16.6	.3	100.0
RR–7	450943109161701	04/17/01	--	--	--	20.8	--	33.7	43.2	2.3	100.0
RR–8	450935109161701	04/17/01	--	--	--	15.1	16.8	41.5	26.3	.4	100.0
RR–9	450925109180001	04/17/01	--	--	--	14.0	39.3	27.8	10.5	8.5	100.0
RR–10	450845109163701	04/17/01	--	--	--	--	46.3	18.5	27.0	8.2	100.0
Average			NC	NC	[1]7.1	[1]22	NC	[1]22.6	31.2	[1]3.2	

[1] Average calculated for all values, assuming a value of 0 when land use was not present within 500-meter radius of well.

Table 5. Well construction and related ancillary information for monitoring wells installed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.

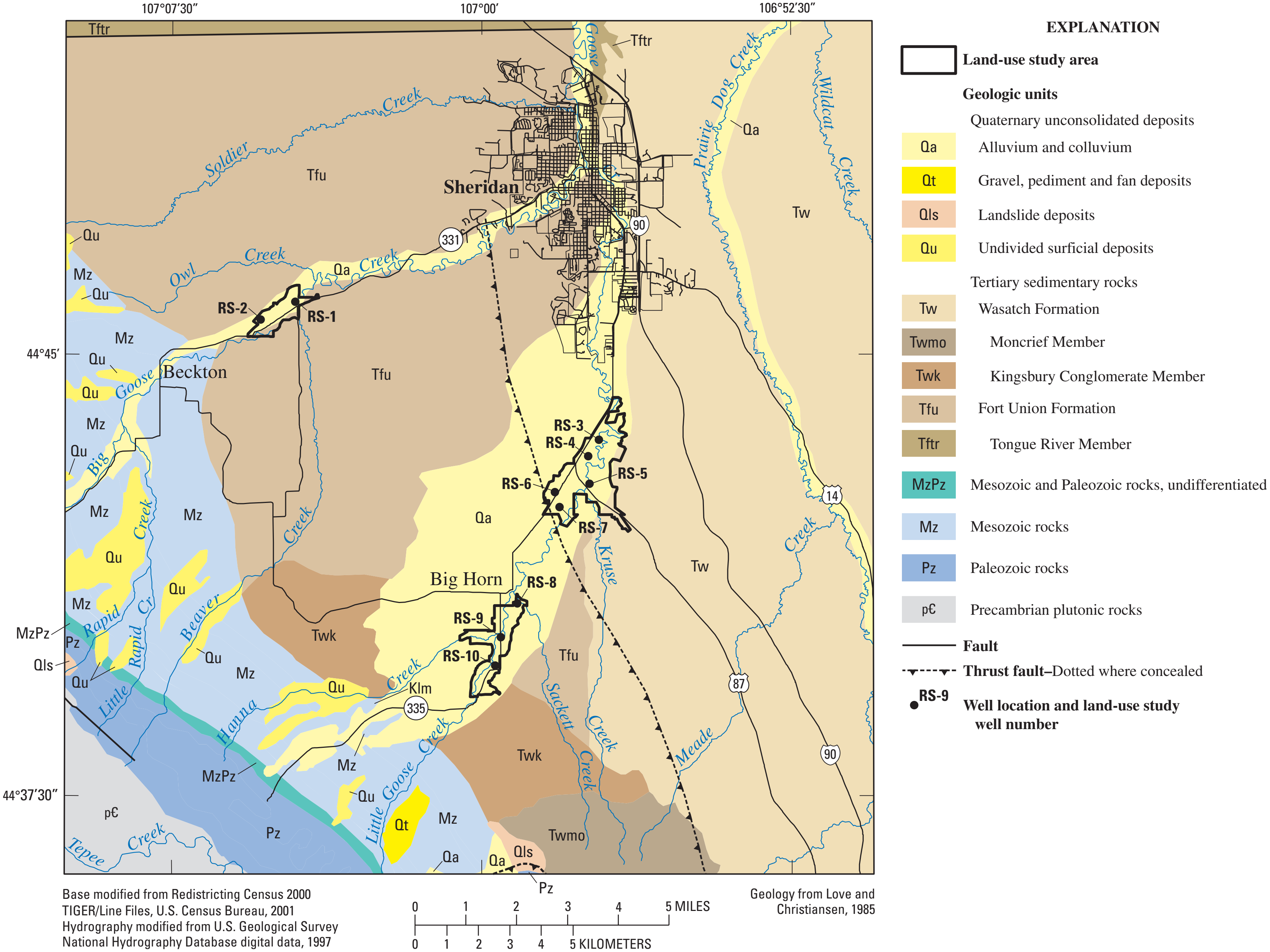
[DMS, degrees, minutes, seconds; NAVD 88, North American Vertical Datum of 1988; P, polyvinyl chloride (PVC)]

Well number	U.S. Geological Survey site-identification number	North latitude (DMS)	West longitude (DMS)	Date of well construction (month/day/year)	Land surface elevation (feet above NAVD 88)	Depth of well (feet below land surface)	Water level (feet below land surface)	Date of water-level measurement	Screened or open interval (feet below land surface)	Casing material	Diameter of casing (inches)
Sheridan, Wyo., study area monitoring wells											
RS–1	444554107043101	44 45 54.18	107 04 31.29	11/01/00	3,940	14	4.94	06/17/01	4–14	P	2
RS–2	444536107052201	44 45 35.82	107 05 21.52	11/01/00	4,000	29	25.08	06/27/01	19–29	P	2
RS–3	444333106571001	44 43 33.39	106 57 09.90	11/02/00	3,895	19	6.12	06/18/01	9–19	P	2
RS–4	444317106572601	44 43 16.90	106 57 25.74	05/21/01	3,910	15	7.05	06/19/01	5–15	P	4
RS–5	444249106572301	44 42 48.55	106 57 23.05	11/02/00	3,920	24	14.69	06/24/01	14–24	P	2
RS–6	444240106581401	44 42 39.86	106 58 13.75	11/03/00	3,950	15.5	2.34	06/20/01	2–12	P	2
RS–7	444225106580701	44 42 24.74	106 58 06.99	05/22/01	3,950	15	8.48	06/21/01	5–15	P	2
RS–8	444047106590901	44 40 46.74	106 59 08.72	05/22/01	4,075	13	4.28	06/25/01	3–13	P	2
RS–9	444012106593201	44 40 12.48	106 59 32.40	11/07/00	4,110	16.5	5.91	06/25/01	4.5–14.5	P	2
RS–10	443943106594001	44 39 43.16	106 59 40.25	05/22/01	4,140	23.5	13.92	06/26/01	13.5–23.5	P	2
Lander, Wyo., study area monitoring wells											
RL–1	425313108440701	42 53 13.07	108 44 06.54	03/20/01	5,365	14.7	3.73	07/08/01	4.7–14.7	P	2
RL–2	425253108434501	42 52 52.63	108 43 45.11	04/25/01	5,345	13.1	6.17	07/12/01	3.1–13.1	P	2
RL–3	425158108433801	42 51 58.21	108 43 37.65	03/20/01	5,320	18.8	5.31	07/17/01	8.8–18.8	P	2
RL–4	425140108430901	42 51 39.75	108 43 09.28	04/26/01	5,290	13.4	4.63	07/09/01	3.4–13.4	P	2
RL–5	425129108432401	42 51 28.91	108 43 23.50	12/14/00	5,295	13.6	.93	07/15/01	3.6–13.6	P	2
RL–6	425116108430101	42 51 15.71	108 43 01.47	04/27/01	5,285	19.7	6.95	08/06/01	9.7–19.7	P	4
RL–7	425111108430501	42 51 11.14	108 43 04.83	03/21/01	5,285	14.3	5.66	07/18/01	4.3–14.3	P	2
RL–8	424830108450101	42 48 29.78	108 45 01.01	04/25/01	5,495	14.5	1.84	07/10/01	4.5–14.5	P	2
RL–9	424808108453101	42 48 07.79	108 45 30.61	04/20/01	5,570	13.3	4.24	07/11/01	3.3–13.3	P	2
RL–10	424751108455901	42 47 51.41	108 45 58.98	04/19/01	5,590	12.8	2.18	07/16/01	2.8–12.8	P	2

Table 5. Well construction and related ancillary information for monitoring wells installed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[DMS, degrees, minutes, seconds; NAVD 88, North American Vertical Datum of 1988; P, polyvinyl chloride (PVC)]

Well number	U.S. Geological Survey site-identification number	North latitude (DMS)	West longitude (DMS)	Date of well construction (month/day/year)	Land surface elevation (feet above NAVD 88)	Depth of well (feet below land surface)	Water level (feet below land surface)	Date of water-level measurement	Screened or open interval (feet below land surface)	Casing material	Diameter of casing (inches)
Red Lodge, Mont., study area monitoring wells											
RR–1	451510109134801	45 15 09.76	109 13 48.09	07/24/01	5,165	15.5	7.98	08/08/01	11.5–15.5	P	2
RR–3	450949109164601	45 09 48.72	109 16 45.50	09/10/01	5,965	41.5	38.06	09/19/01	36.5–41.5	P	4
RR–4	450958109162801	45 09 58.32	109 16 27.71	09/10/01	5,915	45	34.23	09/18/01	40–45	P	4
RR–5	450952109162901	45 09 51.94	109 16 29.04	09/04/01	5,935	58	48.2	09/17/01	53–58	P	4
RR–6	450949109172301	45 09 48.71	109 17 23.02	08/21/01	6,050	39.5	35.57	09/16/01	34.5–39.5	P	2
RR–7	450943109161701	45 09 42.99	109 16 17.02	07/25/01	5,825	14.67	9.19	08/09/01	9.67–14.67	P	2
RR–8	450935109161701	45 09 35.22	109 16 16.54	07/25/01	5,815	14	6.83	09/17/01	9–14	P	2
RR–9	450925109180001	45 09 24.72	109 18 00.01	08/10/01	6,020	15	4.24	09/18/01	10–15	P	2
RR–10	450845109163701	45 08 44.75	109 16 36.70	09/11/01	5,900	41.5	33.05	08/07/01	36.5–41.5	P	2



Base modified from Redistricting Census 2000
TIGER/Line Files, U.S. Census Bureau, 2001
Hydrography modified from U.S. Geological Survey
National Hydrography Database digital data, 1997
Albers Equal-Area Conic projection
Standard parallels 40°00'N and 45°00'N, central meridian 107°30'W

Geology from Love and
Christiansen, 1985

Figure 3. Geologic map of the Sheridan study area, Wyoming.

installed along Big Goose Creek, and ranged from 2.34 to 14.69 ft below land surface in the eight wells installed along Little Goose Creek (table 5; fig. 3). Odum and Miller (1988, fig. 11) reported that three water levels measured in wells near Little Goose Creek ranged from about 10 to 25 ft below land surface and that two water levels measured in wells near Big Goose Creek were about 4 and 8.5 ft below land surface. Recharge to the unconfined alluvial aquifers likely is not only from areal infiltration and percolation of precipitation, but also from infiltration of diverted surface water from unlined irrigation canals and ditches, water applied to hayfields and gardens, and water from domestic septic systems. The direction of ground-water flow in the area has not been mapped, but is likely towards Little and Big Goose Creeks and in the direction of streamflow.

Paired $\delta^{18}O$ and $\delta^{2}H$ values in water samples grouped closely together and plotted slightly below the Global Meteoric Water Line (GMWL) (Craig, 1961) (fig. 4). This indicates that sampled waters were likely subject to similar recharge and (or) evolutional paths, and the differences in the $\delta^{18}O$ and $\delta^{2}H$ values were minimal.

Apparent ground-water ages were estimated for water samples from all 10 wells using CFCs supplemented with dissolved-gas analyses (table 6). The apparent age for water from 7 of 10 wells sampled were similar and ranged from the mid-1980s to early 1990s. Water from one well sampled (RS–3) was estimated to have recharged between the early to middle 1970s, and water from two wells (RS–5 and RS–6) was estimated to have recharged between the late 1960s to early 1970s. Apparent ages estimated for water samples from these three wells were older than expected and may be attributable to CFC degradation. CFCs can undergo microbial degradation in reducing (anoxic or anaerobic) waters (Plummer and Busenberg, 2000). Measurement of ground-water samples with degraded CFC concentrations would result in erroneous older recharge dates. Although Plummer and Busenberg (2000) reported that CFCs degrade in reducing conditions, the investigators noted that degradation was usually not detected in ground water until sulfate-reducing conditions were present. DO concentrations measured in the field during collection of water samples from wells RS–3 and RS–6 were small and indicative of reducing conditions (less than 1 mg/L). In addition, methane was measured in the dissolved-gas sample from well RS–6 (Appendix 3), indicating that water from this well was past sulfate reduction in terms of terminal-electron accepting processes (Chapelle and others, 1993; Chapelle, 2001). Although not as small as measured in wells RS–3 and RS–6, the DO concentration measured in the field in the water sample from well RS–5 also was small (0.8 mg/L).

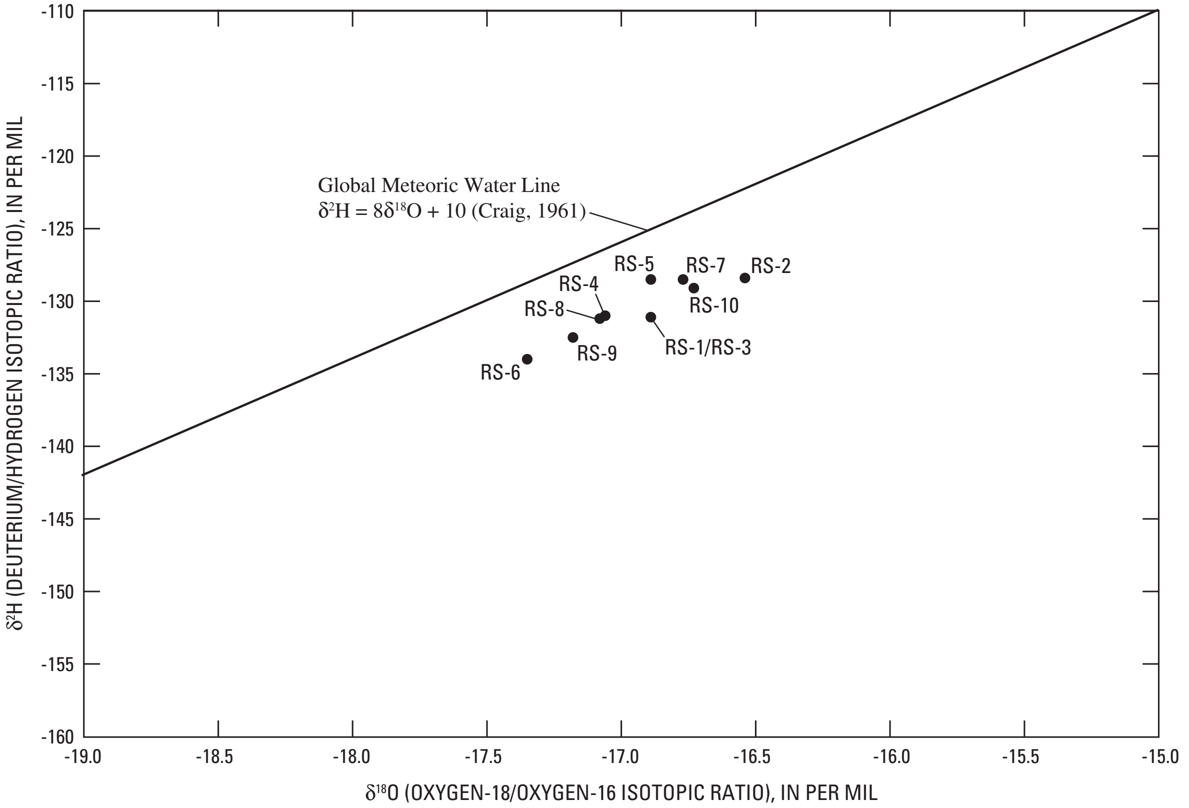


Figure 4. Relation between $\delta^{18}O$ and $\delta^{2}H$ for ground-water samples collected from Quaternary unconsolidated deposits, Sheridan study area, Wyoming, 2001.

Table 6. Apparent ground-water age estimated from chlorofluorocarbons, Sheridan study area, Wyoming, 2001.

Well number	Sample date (month/day/year)	Apparent ground-water age
RS–1	06/17/01	Late 1980s to early 1990s.
RS–2	06/27/01	Late 1980s to early 1990s.
RS–3	06/18/01	Early to mid-1970s.
RS–4	06/19/01	Mid-1980s.
RS–5	06/24/01	Late 1960s to early 1970s.
RS–6	06/20/01	Late 1960s to early 1970s.
RS–7	06/21/01	Mid-1980s.
RS–8	06/25/01	Early 1990s.
RS–9	06/25/01	Mid- to late 1980s.
RS–10	06/26/01	Mid-1980s.

Atmospheric tritium concentrations have varied considerably, both spatially and temporally (Michel, 1989), so tritium often is used to qualitatively age-date ground waters. Tritium concentrations herein are expressed in picocuries per liter (pCi/L). In general, tritium concentrations in ground water recharged prior to nuclear device testing (referred to as "old" water in this report) would be less than about 2.6 pCi/L in 2001; greater concentrations would indicate that some component of the ground water has been recharged after the early 1950s when atmospheric thermonuclear device testing began (referred to as "modern" water in this report) or ground water that is a mixture of old and modern waters (Plummer and others, 1993; Clark and Fritz, 1997).

Ground-water samples from two wells (RS–1 and RS–3) also were analyzed for tritium. Tritium concentrations in water from both wells sampled (Appendix 4) were very similar (about 50 pCi/L) and corroborated the "modern" CFC-based apparent age interpretation for waters from these two wells.

Physical Characteristics

Physical characteristics measured in the field during collection of water samples from 10 wells in the Sheridan area included water temperature, pH, turbidity, and DO (table 7; Appendix 5). Water temperatures ranged from 9.0 to 13.5 degrees Celsius (°C), with a median of 11.0°C. Field pH measurements were alkaline (pH greater than 7.0) and were very similar, ranging from 7.2 to 7.5, with a median of 7.4. Turbidity ranged from 0.4 to 12 nephelometric turbidity units (NTU), with a median of 2.8 NTU. DO concentrations ranged from 0.2 to 5.8 mg/L, with a median of 3.3 mg/L. Although sampled waters in most wells generally were well oxygenated (oxic), DO concentrations indicative of reducing (anoxic or anaerobic) conditions (generally less than 1 mg/L) were measured in 3 of 10 wells sampled (RS–3, RS–5, and RS–6, fig. 3).

Major Ions and Related Water-Quality Characteristics

Major ions comprise most of the dissolved constituents in ground water and generally occur naturally as a result of recharge composition and interactions between water and soil or rock. Water samples were analyzed for the major ions calcium, magnesium, sodium, potassium, chloride, sulfate, and fluoride. Silica, an uncharged species, is described with the major ions for convenience. Alkalinity as calcium carbonate ($CaCO_3$), a measure of the acid-buffering capacity of a filtered water sample, was determined onsite and in the laboratory. Bicarbonate and carbonate concentrations were calculated from alkalinity values measured onsite (Hem, 1985).

One major ion and one related water-quality characteristic were measured at concentrations larger than USEPA standards (table 7) in water from 10 wells sampled in the Sheridan area. Sulfate concentrations in water from 3 of 10 wells sampled (RS–1, RS–2, and RS–5; Appendix 6) were greater than the SMCL of 250 mg/L. Dissolved-solids concentrations in water from 6 of 10 wells (RS–1, RS–2, RS–3, RS–4, RS–5, and RS–6) sampled were greater than the SMCL of 500 mg/L.

Dissolved-solids concentrations ranged from 320 to 1,100 mg/L, with a median of 568 mg/L (table 7; Appendix 6). Compared to the USGS salinity classification (Heath, 1983, p. 65, table 2), water from 8 of 10 wells sampled was classified as fresh (dissolved-solids concentrations less than 1,000 mg/L). Dissolved-solids concentrations in water from two wells sampled (RS–2, 1,100 mg/L; and RS–5, 1,100 mg/L) were classified as slightly saline (dissolved-solids concentrations between 1,000 and 3,000 mg/L).

Calculated hardness ranged from 280 to 810 mg/L as $CaCO_3$, with a median of 460 mg/L as $CaCO_3$ (table 7; Appendix 6). Compared to the hardness scale of Durfor and Becker (1964), water from all 10 wells sampled was classified as very hard (greater than 180 mg/L as $CaCO_3$).

The major-ion chemistry of ground water sampled from 10 wells in the Sheridan area was classified using trilinear and stiff diagrams (figs. 5 and 6). Calcium, magnesium, and bicarbonate were the predominant ions in water from 7 of 10 wells sampled (fig. 5, wells RS–3, RS–4, RS–6, RS–7, RS–8, RS–9, and RS–10); water sampled from these seven wells clustered together on the trilinear diagram, indicating similar ionic composition. Water from three wells with larger dissolved-solids concentrations (RS–1, RS–2, and RS–5) clustered together in a group offset from the other seven wells (fig. 5). The percentage of sulfate relative to bicarbonate was much larger in water sampled from these three wells, indicating that ground water in the area may evolve towards water with larger concentrations of sulfate as dissolved-solids concentrations increase (figs. 5 and 6). Dissolved-solids concentrations in ground water generally increased downstream along Little Goose Creek (fig. 6).

Table 7. Summary of inorganic ground-water-quality samples collected from wells completed in the Sheridan study area, Wyoming, 2001.

[USGS, U.S. Geological Survey; NWIS, National Water Information System; MRL, minimum reporting level, USEPA, U.S. Environmental Protection Agency; °C, degrees Celsius; --, not applicable; SMCL, Secondary Maximum Contaminant Level; NTU, nephelometric turbidity units; mg/L, milligrams per liter; HCO_3, bicarbonate; $CaCO_3$, calcium carbonate; µS/cm, microsiemens per centimeter at 25 degrees Celsius; E, estimated concentration; MCL, Maximum Contaminant Level; HAL, Health Advisory Level; AL, Action Level; C, carbon; µg/L, micrograms per liter; PMCL, proposed Maximum Contaminant Level; AMCL, alternate Maximum Contaminant Level; mL, milliliter; MCLG, Maximum Contaminant Level Goal; *E. coli*, *Escherichia coli*]

Constituent or characteristic	Number of detections/ number of samples	USGS NWIS parameter code	MRL	Minimum concen-tration or value	Median concen-tration or value	Maximum concen-tration or value	USEPA drinking-water standards or health advisories
Physical characteristics							
Water temperature (°C)	10/10	00010	--	9.0	11.0	13.5	--
pH, field (standard units)	10/10	00400	--	7.2	7.4	7.5	6.5–8.5 (SMCL)
Turbidity (NTU)	10/10	61028	--	.4	2.8	12	5 (SMCL)
Dissolved oxygen (mg/L)	10/10	00300	--	.2	3.3	5.8	--
Major ions and related water-quality characteristics, in milligrams per liter unless otherwise noted, dissolved (sample filtered through 0.45-micrometer filter)							
Calcium	10/10	00915	--	54.9	83.4	120	--
Magnesium	10/10	00925	--	25.6	61.5	127	--
Sodium	10/10	00930	--	8.6	32.7	89.2	--
Potassium	10/10	00935	--	1.25	1.9	3.29	--
Bicarbonate (mg/L as HCO_3)	10/10	00453	--	320	460	626	--
Chloride	9/10	00940	0.1	<.1	3.2	9.4	250 (SMCL)
Sulfate	10/10	00945	--	20.2	75.8	464	250 (SMCL)
Fluoride	10/10	00950	--	.3	.3	.6	2 (SMCL) 4 (MCL)
Silica	10/10	00955	--	10.7	12.4	14.7	--
Dissolved solids	10/10	70300	--	320	568	1,100	500 (SMCL)
Alkalinity, field (mg/L as $CaCO_3$)	10/10	39086	--	263	378	514	--
Hardness, total (mg/L as $CaCO_3$)	10/10	00900	calculated	280	460	810	--
Specific conductance (µS/cm)	10/10	00095	--	557	936	1,730	--
Sodium-adsorption ratio (SAR)	10/10	00931	calculated	.2	.7	2	--
Trace elements, in micrograms per liter unless otherwise noted, dissolved (sample filtered through 0.45-micrometer filter)							
Aluminum	3/10	01106	1	<1	1.4	2	50–200 (SMCL)
Antimony	10/10	01095	--	E.04	.06	.09	--
Arsenic	10/10	01000	--	E.1	.2	.7	10 (MCL)
Barium	10/10	01005	--	16.1	75.4	116	2,000 (MCL)
Beryllium	0/10	01010	.06	<.06	<.06	<.06	4 (MCL)
Boron	10/10	01020	--	24	107	249	600 (Draft HAL)
Bromide (mg/L)	8/10	71870	.01	<.01	.03	.07	--
Cadmium	4/10	01025	.04	E.02	[1].03	.07	5 (MCL)
Chromium	6/10	01030	.8	E.6	1.8	2	100 (MCL)
Cobalt	10/10	01035	--	.12	.23	.53	--
Copper	10/10	01040	--	.7	1.2	4.5	1,300 (AL) 1,000 (SMCL)
Iron	2/10	01046	10	<10	<10	120	300 (SMCL)
Lead	4/10	01049	.08	E.07	[1].07	.12	15 (AL)

Table 7. Summary of inorganic ground-water-quality samples collected from wells completed in the Sheridan study area, Wyoming, 2001.—Continued

[USGS, U.S. Geological Survey; NWIS, National Water Information System; MRL, minimum reporting level, USEPA, U.S. Environmental Protection Agency; °C, degrees Celsius; --, not applicable; SMCL, Secondary Maximum Contaminant Level; NTU, nephelometric turbidity units; mg/L, milligrams per liter; HCO_3, bicarbonate; $CaCO_3$, calcium carbonate; µS/cm, microsiemens per centimeter at 25 degrees Celsius; E, estimated concentration; MCL, Maximum Contaminant Level; HAL, Health Advisory Level; AL, Action Level; C, carbon; µg/L, micrograms per liter; PMCL, proposed Maximum Contaminant Level; AMCL, alternate Maximum Contaminant Level; mL, milliliter; MCLG, Maximum Contaminant Level Goal; *E. coli*, *Escherichia coli*]

Constituent or characteristic	Number of detections/ number of samples	USGS NWIS parameter code	MRL	Minimum concen- tration or value	Median concen- tration or value	Maximum concen- tration or value	USEPA drinking-water standards or health advisories
Trace elements, in micrograms per liter unless otherwise noted, dissolved (sample filtered through 0.45-micrometer filter)—Continued							
Lithium	10/10	01130	--	5	18.6	55.9	--
Manganese	10/10	01056	--	E.1	4.17	150	50 (SMCL)
Molybdenum	10/10	01060	--	.3	.95	3.6	40 (HAL)
Nickel	10/10	01065	--	.2	.758	3.07	100 (HAL)
Selenium	7/10	01145	0.3	<.3	.54	6.7	50 (MCL)
Silver	0/10	01075	1	<1	<1	<1	100 (HAL/ SMCL)
Strontium	10/10	01080	--	271	471	1,150	17,000 (HAL)
Thallium	1/10	01057	.04	<.04	<.04	.11	2 (MCL)
Vanadium	9/10	01085	.2	E.1	.41	3.6	--
Zinc	5/10	01090	1	<1	[1]1	2	2,000 (HAL) 5,000 (SMCL)
Nutrients, in milligrams per liter, dissolved (sample filtered through 0.45-micrometer filter), and dissolved organic carbon							
Nitrite, as nitrogen	5/10	00613	0.006	E0.003	[1]0.005	E0.005	1 (MCL)
Nitrite + nitrate, as nitrogen	8/10	00631	.05	E.037	.232	1.38	10 (MCL)
Ammonia, as nitrogen	4/10	00608	.04	E.023	[1].025	.048	30 (HAL)
Ammonia + organic nitrogen, as nitrogen	8/10	00623	.1	E.08	.13	.19	--
Phosphorus, as phosphorus	8/10	00666	.006	E.004	.008	.015	--
Orthophosphate, as phosphorus	4/10	00671	.02	E.009	[1].011	E.015	--
Dissolved organic carbon (mg/L as C)	8/8	00681	--	1.2	2.1	3.6	--
Radionuclides, in picocuries per liter unless otherwise noted							
Tritium (unfiltered)	2/2	07000	--	48.6	50.7	52.8	--
Uranium (µg/L) (filtered)	10/10	22703	--	2.12	8.77	40.5	30 (MCL)
Radon-222 (unfiltered)	10/10	82303	--	505	1,080	1,440	300 (PMCL) 4,000 (AMCL)
Other constituents, in milligrams per liter unless otherwise noted							
Total coliform, colonies/100 mL	2/9	31501	1	<1	<1	E19	1 (MCLG)
E. coli, colonies/100 mL	[2]0/2	31633	1	<1	<1	<1	--
Methylene blue active substances (detergents)	5/8	38260	.02	E.01	.014	E.12	[3].5 (SMCL)

[1] Median value was less than highest minimum reporting level and was estimated using log-probability regression (Helsel and Cohn, 1988).

[2] Samples analyzed for *E. coli* if total coliform detected.

[3] Foaming agents.

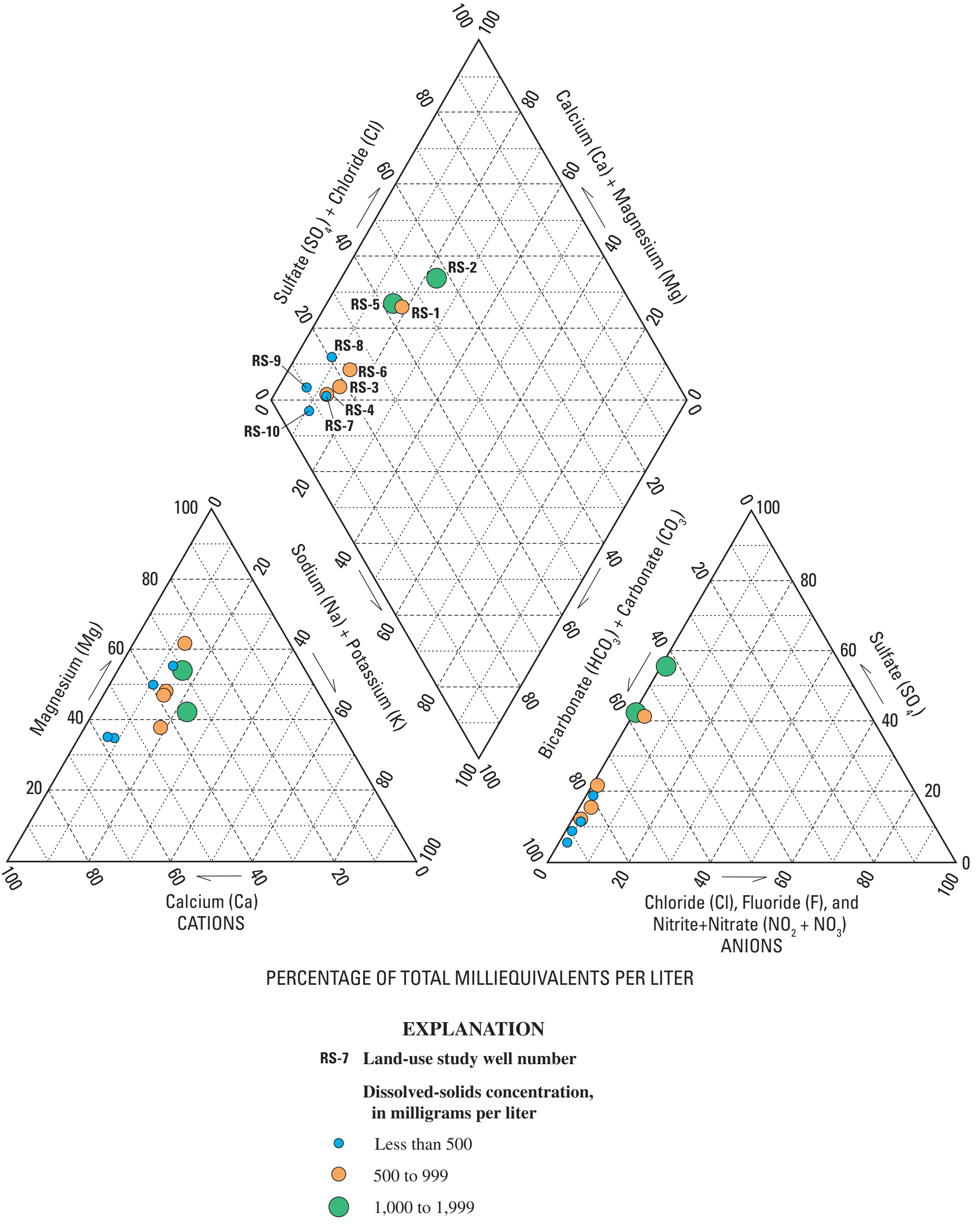
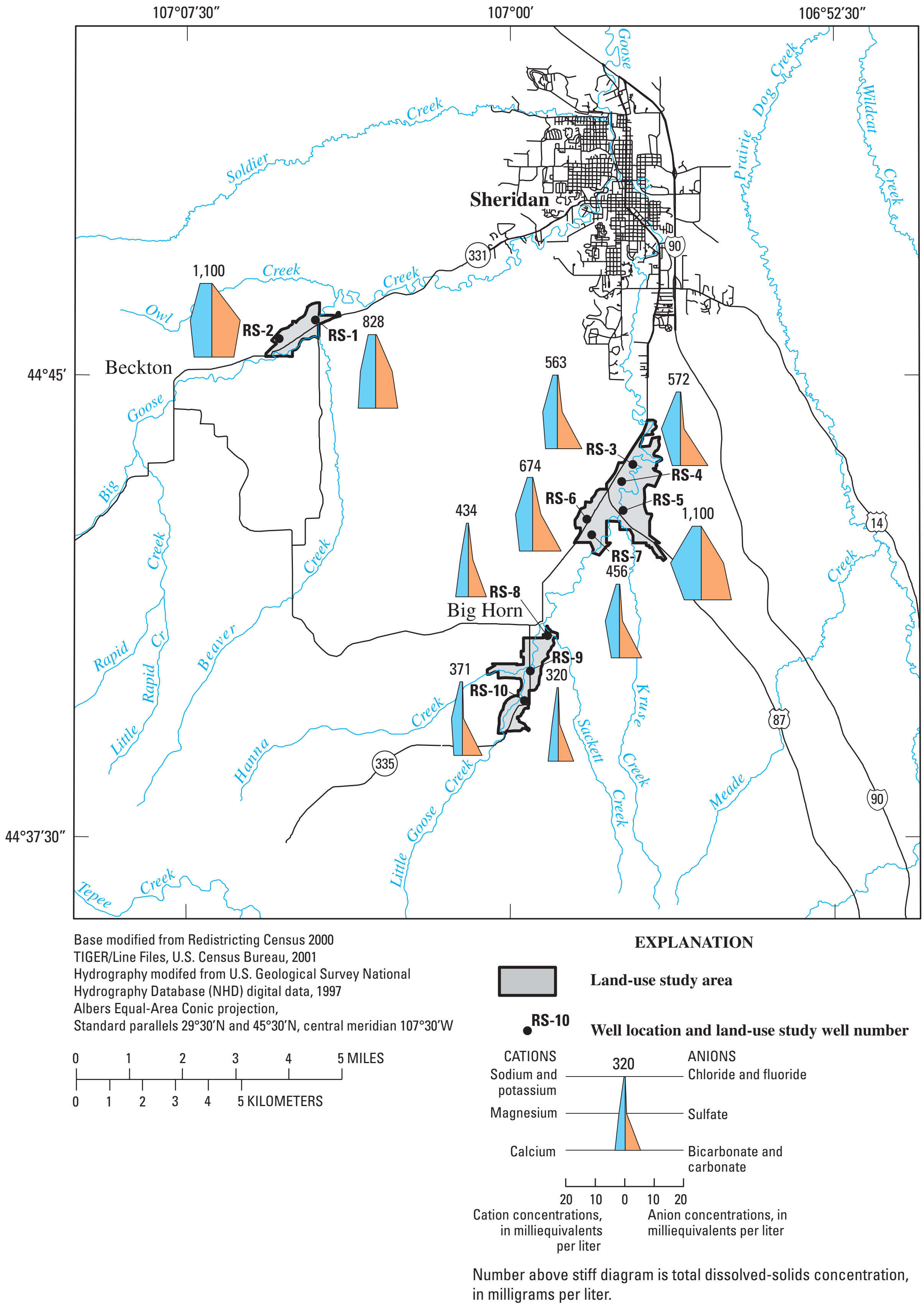


Figure 5. Trilinear diagram showing major-ion composition and dissolved-solids concentrations for ground-water samples collected from Quaternary unconsolidated deposits in the Sheridan study area, Wyoming, 2001.



Base modified from Redistricting Census 2000
TIGER/Line Files, U.S. Census Bureau, 2001
Hydrography modifed from U.S. Geological Survey National
Hydrography Database (NHD) digital data, 1997
Albers Equal-Area Conic projection,
Standard parallels 29°30′N and 45°30′N, central meridian 107°30′W

Number above stiff diagram is total dissolved-solids concentration, in milligrams per liter.

Figure 6. Stiff diagrams showing areal distribution of major-ion composition and dissolved-solids concentrations for ground-water samples collected from Quaternary unconsolidated deposits in the Sheridan study area, Wyoming, 2001.

Trace Elements and Radon

Trace elements are a diverse group of constituents that generally occur naturally at small concentrations (less than 1 mg/L) in ground water. Some trace elements (for example, iron and manganese) can be present at concentrations greater than the other trace elements, and are sometimes included with major ions. Trace elements often are collectively referred to as metals even though some trace elements, such as antimony, arsenic, and selenium, are semimetallic elements. Uranium, a trace element, is listed and grouped in tables and appendixes with radionuclides for convenience. Geochemical conditions often control measured concentrations of trace elements in ground water rather than the element's abundance in the rocks and minerals composing the aquifer (Hem, 1985). Health-based regulatory standards (MCLs) have been established by the USEPA for many trace elements because of toxicity to the human body. In addition, some trace elements, such as iron and manganese, can stain plumbing and laundry, so the USEPA has established secondary standards (SMCLs) for some trace elements for these and other aesthetic reasons.

Most trace elements detected in water from 10 wells sampled in the Sheridan study area had small concentrations less than USEPA standards (table 7; Appendix 7). Beryllium and silver were not detected in any well samples. Five trace elements were detected in less than one-half of the well samples: aluminum (three detections), cadmium (four detections), iron (two detections), lead (four detections), and thallium (one detection); no concentrations of these five trace elements were larger than USEPA standards. Five trace elements (bromide, chromium, selenium, vanadium, and zinc) were detected more frequently, but no concentrations were larger than USEPA standards. Eleven trace elements (antimony, arsenic, barium, boron, cobalt, copper, lithium, manganese, molybdenum, nickel, and strontium) were detected in water from all 10 wells sampled, but no concentrations except for manganese, were larger than USEPA standards where applicable (antimony, cobalt, and lithium do not have standards).

Manganese was detected in water from all 10 wells sampled at concentrations ranging from 0.1 (estimated concentration) to 150 µg/L, with a median of 4.17 µg/L (table 7; Appendix 7). Concentrations of manganese in water from 2 of 10 wells sampled (RS–3, 150 µg/L; and RS–6, 146 µg/L) were larger than the USEPA SMCL (50 µg/L). Manganese is an undesirable trace element at concentrations greater than the SMCL because of a tendency to deposit black manganese dioxide stains. The occurrence of manganese in ground water in the study area is likely from natural sources. DO concentrations in water from both wells RS–3 and RS–6 were small (less than 0.5 mg/L; Appendix 5) and indicative of reducing conditions. Concentrations of manganese dissolved in ground water (solubility) often are related to the redox potential of ground water. Manganese concentrations in ground water generally increase under reducing conditions because of dissolution from organic and manganese complexes or from manganese oxides (Hem, 1985).

The concentration of uranium in water from one well (RS–2, 40.5 µg/L) was larger than the USEPA MCL of 30 µg/L (table 7; Appendix 4). Although uranium was detected in water from all 10 wells sampled, the concentration in water from well RS–2 was more than twice the next highest measured concentration in the Sheridan area. Well RS–2 was completed to a greater depth (about 29 ft below land surface) than all other wells. The well was completed not only in the Quaternary unconsolidated deposits, but also 2.5 ft into the bedrock of the underlying Fort Union Formation. It is possible that the large uranium concentration in water from well RS–2 may be attributable to the well being partially completed into the Fort Union Formation.

Radon-222 (radon) is a naturally occurring radioactive gas that is the decay product of radium-226. The source of radon gas in ground water is naturally occurring uranium in rock and sediments. Ingestion of large concentrations of radon in drinking water can cause stomach cancer, but ingestion is not the primary health risk. The primary health risk is inhalation. Radon also can enter homes by the use of water from wells—radon can degas from water into household air during activities such as taking a shower. Radon is second only to cigarette smoking in causing lung cancer in the United States and is estimated to cause between 5,000 and 20,000 lung-cancer fatalities annually (Cothern and Smith, 1987). Because of health concerns, the USEPA has proposed two drinking-water standards (U.S. Environmental Protection Agency, 1999)—an MCL of 300 pCi/L and an alternate MCL (AMCL) of 4,000 pCi/L for communities with indoor air multimedia mitigation programs.

Radon was detected in water from all 10 wells sampled at activities ranging from 505 ± 26 pCi/L to 1,440 ± 39 pCi/L, with a median of 1,080 pCi/L (table 7; Appendix 4). All measured activities were larger than the USEPA proposed MCL (300 pCi/L) but smaller than the USEPA proposed AMCL (4,000 pCi/L).

Nutrients and Dissolved Organic Carbon

Ground-water samples were analyzed for different species of nitrogen and phosphorus. Small concentrations of both nutrients occur naturally in ground water, but elevated concentrations commonly are associated with human (anthropogenic) activities. The most common anthropogenic sources of nitrogen and phosphorus in shallow ground water are from leaching of fertilizers from agricultural lands, animal manure, or septic system effluent (Alley, 1993, and references therein).

Nitrate (an oxidized species of nitrogen in water) and phosphorus in water are of environmental and health concern. Nitrate and phosphorus discharged to surface waters can contribute to eutrophication. Large concentrations of nitrate in drinking water have been associated with several potential adverse health effects including low levels of oxygen in the blood of infants (“blue baby” syndrome, also known as methemoglobinemia) (Fan and Steinberg, 1996), miscarriage (Centers for Disease Control and Prevention, 1996), and increased risk of non-Hodgkins lymphoma (Ward and others, 1996).

As noted by Hem (1985, p. 124), “nitrogen occurs in water as nitrite or nitrate anions, in cationic form as ammonium, and at intermediate oxidation states as a part of organic solutes.” Consequently, ground-water samples were analyzed for several species of nitrogen, including both oxidized and reduced forms. Biogeochemical processes often control the species of nitrogen measured in ground water (Hem, 1985). All nitrogen species concentrations described in this report are reported as equivalent concentrations of nitrogen. Ground-water samples were analyzed for total ammonia as nitrogen (referred to as “ammonia” in this report) that included ammonium ion and un-ionized ammonia. At the pHs measured in ground-water samples collected during this study, un-ionized ammonia was likely a small component of total ammonia (Hem, 1985).

Nutrient concentrations were small in water from most wells sampled in the Sheridan area, and all concentrations were much smaller than applicable USEPA standards (table 7; Appendix 8). Nitrite as nitrogen (nitrite) was detected in water from one-half the wells sampled; all detections were estimated concentrations (concentration less than minimum reporting level) and were much smaller than the USEPA MCL (1 mg/L). Because nitrite was detected infrequently at very small concentrations and composed very little of the nitrite plus nitrate as nitrogen concentrations (Appendix 8), nitrite plus nitrate concentrations as nitrogen are referred to as “nitrate” herein.

Nitrate was the form of nitrogen detected most frequently and generally at the largest concentrations in water from most wells sampled (table 7; Appendix 8). Nitrate was detected in water from 8 of 10 wells at concentrations ranging from an estimated 0.037 to 1.38 mg/L, with a median of 0.232 mg/L. Ammonia as nitrogen (ammonia) was detected in water from 4 of 10 wells at small concentrations ranging from an estimated 0.023 to 0.048 mg/L, with a median of 0.025 mg/L. Ammonia plus organic nitrogen as nitrogen was detected in water from 8 of 10 wells at concentrations ranging from an estimated 0.08 to 0.19 mg/L, with a median of 0.13 mg/L. A comparison of the ranges of concentrations for ammonia with ammonia plus organic nitrogen (Appendix 8) indicates that organic nitrogen was present and composed most of the ammonia plus organic nitrogen.

The frequent detection of nitrate compared with most other species of nitrogen was expected because DO concentrations in water from 7 of 10 wells sampled were indicative of oxic conditions (defined herein as DO concentrations larger than 1 mg/L); nitrate is the most common form of nitrogen in oxic ground water and is stable over a wide range of geochemical conditions (Hem, 1985). All measured nitrate concentrations were much smaller than the USEPA MCL (10 mg/L) (table 7). Nitrate was not detected in water from two wells with DO concentrations indicative of reducing conditions (RS–3 and RS-6). In general, concentrations of nitrate are small in uncontaminated ground water. Concentrations of nitrate in ground water in the conterminous United States greater than 3 mg/L (Madison and Brunett, 1985), 2 mg/L (Mueller and Helsel, 1996), or 1.1 mg/L (Nolan and Hitt, 2003) have been suggested to be the result of human (anthropogenic) activities. Nitrate concentrations in water samples from 2 of 10 wells (RS–1, 1.38 mg/L; and RS–2, 1.29 mg/L) were slightly greater than the lowest estimate (1.1 mg/L) of concentrations that would be expected when influenced by human activities.

Ground-water samples from 7 of 10 wells had enough nitrate for analysis of $\delta^{15}N$ (Appendix 8). Even though nitrate concentrations were small, $\delta^{15}N$ values in water samples from seven wells with detectable nitrate were relatively enriched, and ranged from +6.5 to +14.1 per mil. Water samples from 4 of 7 wells (RS–2, RS–4, RS–7, and RS–10) had $\delta^{15}N$ values between +6.5 to +8.1 per mil, within the +4 to +9 per mil range expected for nitrate derived from soil organic nitrogen (Gormly and Spalding, 1979; Heaton, 1986; Hubner, 1986). Measured $\delta^{15}N$ values in this range also could result from the mixing of atmospheric or fertilizer-derived nitrate with waste-derived nitrate. Water from 3 of 7 wells sampled (RS–1, RS–5, and RS–8) had $\delta^{15}N$ values between +10.8 to +14.1 per mil, within the range of +9 to +23 per mil attributable to nitrate derived exclusively from animal (livestock) or human waste (from septic system effluent) (Kreitler, 1975; Gormly and Spalding, 1979; Lindau and Spalding, 1984; Heaton, 1986). The largest DOC concentration in the Sheridan study area was measured in well RS–5 (3.6 mg/L), and the DO concentration was relatively small (0.8 mg/L) and indicative of reducing conditions. Under reducing conditions, denitrification in ground water can cause smaller $\delta^{15}N$ values to become larger, resulting in an erroneous interpretation that the higher $\delta^{15}N$ value was attributable to waste when, in fact, the high value was due to fractionation of $\delta^{15}N$. Additional work would be needed to determine if this was the case, but it is beyond the scope of this study and is not likely necessary because all nitrogen species in water from well RS–5 were measured at small concentrations.

Dissolved phosphorus (total as phosphorus) was detected in water from 8 of 10 wells sampled, but concentrations were small, ranging from an estimated 0.004 to 0.015 mg/L, with a median of 0.008 mg/L (table 7; Appendix 8). Dissolved orthophosphate (as phosphorus) was detected in water from 4 of 10 wells sampled, but concentrations were small and all were estimated, ranging from 0.009 to less than 0.02 mg/L with a median of 0.011 mg/L (table 7; Appendix 8). Phosphorus concentrations in ground water usually are small because of low solubility and a tendency to adsorb to organic matter or metallic oxides in the subsurface (Hem, 1985). The USEPA has not established water-quality standards for phosphorus in ground water; however, to reduce the possibility of eutrophication and resulting effects on aquatic life, USEPA recommends that total phosphorus concentrations in surface water should not be greater than 0.1 mg/L (as phosphorus) for flowing water not directly discharging into a lake or reservoir. Larger phosphorus concentrations in ground water can be a concern when ground water discharges to surface water, as may occur in the Sheridan study area. No total phosphorus concentrations in ground water sampled from the 10 monitoring wells were greater than 0.1 mg/L.

DOC occurs naturally in ground water, but elevated concentrations can indicate ground-water contamination from human sources (typically from septic system effluent). Most natural DOC in ground water is from humic and fulvic acids generated by biogeochemical degradation of organic material in the soil profile above the aquifer or by degradation of organic matter within the aquifer deposits. Percolating waters (ground-water recharge) transport DOC in the soil zone to the water table. DOC concentrations in ground water can affect trace-element solubility (through formation of complexes) and the redox state of ground water (DOC is a common electron donor) (Hem, 1985).

Concentrations of DOC for 8 samples ranged from 1.2 to 3.6 mg/L, with a median of 2.1 mg/L (table 7; Appendix 8). These concentrations are within or near the range of 0 to about 3 mg/L reported for natural (uncontaminated) ground water (Drever, 1997, fig. 6–1, p. 108).

Bacteria

Ground water from 9 of 10 wells sampled in the Sheridan study area was analyzed for coliform bacteria (table 7; Appendix 9). Coliform bacteria, including total coliform and *E. coli*, are commonly used to assess the sanitary quality of water because their presence can indicate contamination by fecal material from warm-blooded animals. Total coliform bacteria were detected in water samples from wells RS–6 (estimated 2 colonies/100 milliliters (col/100 mL)) and RS–10 (estimated 19 col/100 mL). Both counts were larger than the USEPA Maximum Contaminant Level Goal (MCLG) for drinking water (1 col/100 mL). Samples in which total coliform bacteria were detected also were analyzed for *E. coli*, which is a better indicator of contamination from warm-blooded animals. *E. coli* was not detected in either sample, indicating the bacteria detected in wells RS–6 and RS–10 probably are from soils, not warm-blooded animals.

Methylene Blue Active Substances

MBAS are natural or synthetic anionic sulfate- and sulfonate-based surfactants. They are commonly used as optical brighteners in many laundry detergents (Burkhardt and others, 1995). Detergents in drinking water can cause foaming and unpleasant taste. MBAS are water soluble and may be transported from septic-system effluent into ground water (Thurman and others, 1986). The USEPA has established an SMCL of 0.5 mg/L for foaming agents. No analytical methods exist to measure foaming agents, so this property is determined indirectly by measuring anionic surfactant concentrations in water using MBAS analysis. Although many substances other than detergents will cause foaming, their presence will be detected through analysis for MBAS. Consequently, MBAS concentrations can be compared directly to the USEPA SMCL.

Ground water from 8 of 10 wells sampled in the Sheridan study area were analyzed for MBAS (table 7; Appendix 9). MBAS was detected at estimated concentrations in water from 3 of 8 wells sampled (RS–5, RS–8, and RS–10) and equal to or slightly greater than the reporting level in two wells sampled (RS–6 and RS–7). All measured concentrations were smaller than the USEPA SMCL (0.5 mg/L). However, as noted previously in the report (“Quality Assurance and Quality-Control Samples” section), interpretation of QC samples makes it difficult to determine if most of these trace-level MBAS detections are actually in water from the aquifers (environmental detections) or if they are due to sample contamination during sampling or laboratory analysis.

Pesticides and Volatile Organic Compounds

Four pesticides and one VOC were detected in ground-water samples from the Sheridan study area, but at small concentrations much lower than USEPA standards (table 8; Appendixes 10 and 11). All four of the detected pesticides (imazethapyr, oryzalin, prometon, and tebuthiuron) are herbicides, and at least one pesticide was detected in water from every well sampled except well RS–7.

Prometon was the only pesticide detected frequently (8 of 10 wells sampled), but 6 of 8 concentrations were estimated. Prometon is a general-use herbicide not registered for agricultural use. The pesticide is used in agricultural areas for nonagricultural purposes (non-cropland areas including rangeland, hay, and forage) and in urban areas for many purposes (asphalt, rights-of way, fence rows, industrial sites, recreational areas, and residential areas) (Barbash and others, 2001, and references therein; Meister, 2002; Gilliom and others, 2006). Land use and land cover consistent with many of these likely types of use were observed or mapped during this study (table 4; Appendix 1). Eddy-Miller and Norris (2001) sampled shallow ground water in Sheridan County considered vulnerable to pesticide contamination, including some of the same aquifers sampled during this study. The investigators noted that prometon was the most frequently detected pesticide in the county and that this was different “from the other counties (in Wyoming) where baseline monitoring has been completed” (Eddy-Miller and Norris, 2001, p. 4). Barbash and others (1999; 2001, and references therein) and Gilliom and others (2006) noted close associations between urban land use and prometon in ground water. The investigators also noted frequent detection of prometon in USGS studies of shallow ground water beneath agricultural areas, but noted that the occurrence was likely due to non-cropland applications of the herbicide.

Table 8. Summary of organic chemical detections, Sheridan study area, Wyoming, 2001.

[USGS, U.S. Geological Survey; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency; E, estimated concentration; NC, not calculated; --, not applicable]

Chemical name/trade or common name	USGS laboratory parameter code	Number of detections	Number of analyses	Well(s) where chemical was detected	Primary laboratory reporting level (µg/L)	Minimum concentration of detections (µg/L)	Median concentration of detections (µg/L)	Maximum concentration of detections (µg/L)	USEPA standard or health advisory (µg/L)
Pesticides									
Imazethapyr/New Path	50407	2	10	RS–2, RS–10	0.02	E0.011	0.03	E0.055	--
Oryzalin/Surflan	49292	1	10	RS–2	.02	.02	NC	.02	--
Prometon/Pramitol	04037	8	10	RS–1, RS–3, RS–4, RS–5, RS–6, RS–8, RS–9, RS–10	.015	E.003	.006	.033	[1]100
Tebuthiuron/Spike	82670	1	10	RS–1	.016	E.004	NC	E.004	[1]500
Volatile organic compounds									
Trichloromethane/chloroform	32106	2	10	RS–2, RS–7	0.02	E0.01	0.03	E0.04	[2,3]80

[1] U.S. Environmental Protection Agency Lifetime Health Advisory Level (HAL) (U.S. Environmental Protection Agency, 2006).

[2] U.S. Environmental Protection Agency Maximum Contaminant Level (MCL) (U.S. Environmental Protection Agency, 2006).

[3] Total for all trihalomethanes combined cannot exceed 80 µg/L (U.S. Environmental Protection Agency, 2006).

The remaining three pesticides were detected much less frequently. Imazethapyr was detected in water from two wells sampled (RS–2 and RS–10), and the herbicide commonly is associated with agricultural use (Meister, 2002). In a survey of pesticide use in Wyoming for 1990, Legg and others (1992) reported that imazethapyr was used on alfalfa. Oryzalin was detected in water from one well sampled (RS–2), and the herbicide is associated with agricultural or nonagricultural (bermudagrass turf) use (Meister, 2002). Tebuthiuron was detected in water from one well sampled (RS–1), and the herbicide commonly is associated with non-cropland use (non-cropland areas, rangelands, rights-of-way, and industrial sites) (Meister, 2002). Eddy-Miller and Norris (2001) noted infrequent detection of tebuthiuron in Sheridan County, as the pesticide was detected in water from only 1 of 15 wells sampled. Bartos and others (2005) noted that prometon and tebuthiuron, both herbicides commonly associated with nonagricultural (noncrop) use, were two of the most frequently detected pesticides in Quaternary unconsolidated deposit aquifers of the Bighorn Basin of the YRB in Wyoming and Montana. Many of the aquifers sampled in that study have hydrogeologic characteristics and overlying land use the same as or similar to those sampled during this study.

VOCs are generally manmade chemicals in many commonly used products, such as plastics, paints, refrigerants, gasoline, fuel oils, lubricants, solvents, fumigants, pesticides, personal hygiene products, and disinfection byproducts. Many VOCs are highly soluble, mobile, and persistent in ground water. In addition, many VOCs are suspected carcinogens or have some type of health risk associated with exposure (Zogorski and others, 2006, and references therein). Therefore, USEPA regulatory standards have been established for many VOCs in drinking water.

One VOC, trichloromethane (chloroform), was detected at small (estimated) concentrations in two wells sampled (RS–2 and RS–7). Chloroform belongs to a class of VOCs known as trihalomethanes (THMs). In USGS studies of rural domestic wells across the United States, Moran and others (2002) noted that THMs were among the most frequently detected VOCs. Although THMs have some natural sources (Moran and others, 2002, and references therein), THMs in water commonly are the by-products of chlorine disinfection. Shock chlorination, a type of chlorine disinfection, is a process whereby a solution of bleach (typically sodium hypochlorite) and water is added to a well to kill bacteria. The addition of this solution to the well adds free chlorine that can react with naturally occurring organic matter in the water to create THMs (Trussell and Umphres, 1978; Alawi and others, 1994). Septic-system effluent can be a potential source of THMs. Moran and others (2002, p. 42) noted that some THMs "might form through the same reactions during the use of household bleach in washing machines," and that "wastewater discharged from the washing machine to a septic system may enter shallow ground water near the domestic well."

Summary of Extent of Possible Water-Quality Effects from Human Activities in the Sheridan, Wyo., Study Area

As described previously, effects of human activities on shallow ground-water quality were indicated in the Sheridan study area; however, the results of the study indicate that the shallow ground water is suitable for most uses without treatment and that effects from human activities generally were minimal and limited in areal extent at the time of sampling (2001). Several inorganic constituents were detected at concentrations greater than USEPA drinking-water standards (dissolved solids, sulfate, uranium, and manganese) or proposed standards (radon). Natural factors such as geology, aquifer properties, and ground-water recharge rates likely influence concentrations of these constituents. Detected anthropogenic constituents were consistent with overlying land uses mapped during the study. Constituents indicative of contamination by human activities generally were measured at small (trace level) concentrations that were much less than drinking-water standards.

Ground water from 3 of 10 wells sampled (RS–1, RS–2, and RS–10, fig. 3) had mixtures of two or more constituents indicative of human activities. Both monitoring wells installed along Big Goose Creek (RS–1 and RS–2) had mixtures of two or more constituents indicative of human activities. Two pesticides were detected in water from well RS–1. More than one pesticide is commonly found in ground-water samples containing pesticides (Gilliom, 2001; Gilliom and others, 2006). In ground water, pesticides also are found frequently in samples containing other contaminants such as nitrate and VOCs (Squillace and others, 2002). Nitrate was detected in water from well RS–1 at a concentration slightly greater than estimated background concentrations; the corresponding $\delta^{15}N$ value was enriched and indicative of possible contamination by either animal (livestock) or human waste. Two pesticides and one VOC were detected in water from well RS–2. In addition, nitrate was detected in water from well RS–2 at a similar concentration to water from well RS–1, and also was slightly greater than estimated background concentrations. Water from one well sampled along Little Goose Creek (RS–10) had a mixture of two or more constituents indicative of contamination by human activities (MBAS and the pesticides imazethapyr and prometon).

Only two constituents were detected frequently enough (in water from more than one-half of monitoring wells) to indicate any widespread effects of human activities on ground water in aquifers underlying low-density development in the Sheridan study area. The pesticide prometon was detected at trace concentrations in 8 of 10 wells sampled, indicating low-concentration ground-water contamination from non-cropland pesticide application. Trace concentrations of MBAS (optical brighteners in laundry detergents) were detected in 5 of 8 wells sampled, indicating possible ground-water contamination from septic system effluent; however, as described previously, QC procedures indicate these detections are questionable, and evidence of widespread trace-level contamination by MBAS is inconclusive.

CFC age-dating (see "Hydrogeologic Setting and Apparent Ground-Water Age" section of report) indicated that much of the water sampled had recharged the shallow aquifers in the Sheridan study area during the early 1990s or earlier. Chemical constituents in shallow ground water in 2001 may, therefore, not yet reflect low-density (rural ranchette) development surrounding the Sheridan area during the past decade. Although low-density development is continuing in and near the Sheridan study area, land use appears relatively stable, and most observed changes in the study area were small and localized. Consequently, the detection of relatively few chemical constituents indicative of contamination by human activities may indicate that overlying unsewered low-density development that occurred in the past has had minimal effects on underlying ground-water quality. Continued monitoring likely would be necessary to determine effects on water quality from increasing low-density development over time.

Lander, Wyo., Study Area

Lander is located in central Wyoming in Fremont County and has a population of 6,867 (U.S. Census Bureau, 2007). Ground-water quality samples were collected in July and August 2001 from 10 monitoring wells installed in the Lander area.

Land Use and Land Cover

Land use and land cover from the National Land Cover Database (U.S. Geological Survey, 2000) is shown for the Lander study area and surrounding areas in figure 7. Adjacent to the North Popo Agie River part of the Lander study area (areas near wells RL–1 to RL–7), land use and land cover primarily consists of wetlands, pasture/hay, and occasional row crops. In the southern part of the Lander study area near the Middle Popo Agie River (areas near wells RL–8 to RL–10), land use and land cover primarily consists of shrubland/grassland, forested land, wetlands, pasture/hay, and occasional crops.

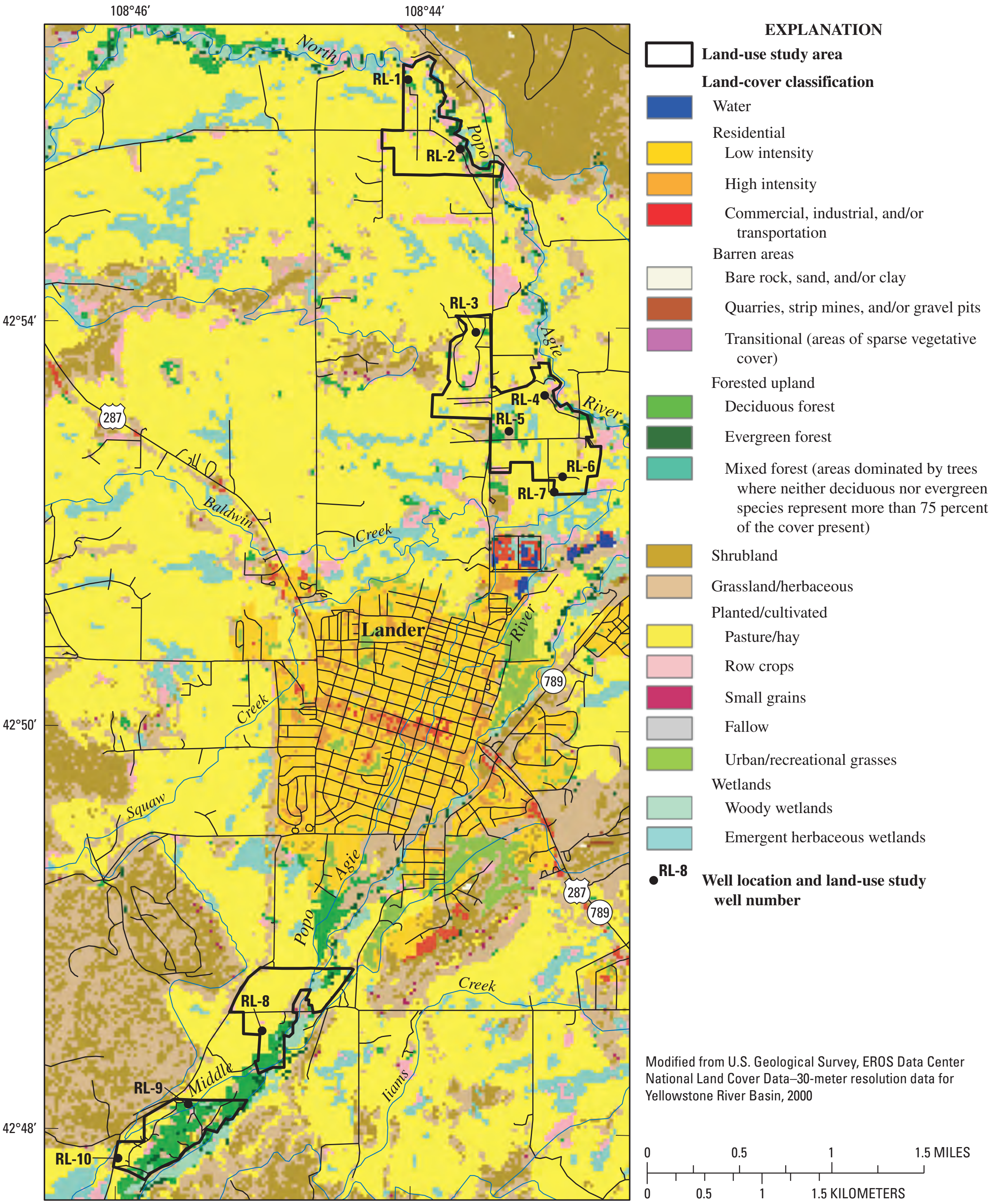
During the study, land use and land cover ("land use") was mapped onsite at greater detail within a 500-m (1,640-ft) radius surrounding all 10 wells installed and sampled in the Lander study area (table 4; Appendix 1). Livestock pasture was the most abundant land use and was mapped within the radii of all 10 sampled wells, ranging from about 16 to 64 percent with an average of about 42 percent. Riparian land (defined as "wetlands" in fig. 7, table 4; Appendix 1) was the second most abundant land use and was mapped within the radii of 8 of 10 wells, ranging from about 11 to 36 percent with an average of about 21 percent. Urban land, which includes low-density residential land use, was mapped within the radii of all 10 wells and ranged from about 6 to 23 percent, with an average of about 14 percent. Cropland was mapped within the radii of 5 of 10 wells and ranged from about 9 to 22 percent. Rangeland was mapped within the radii of 6 of 10 wells and ranged from about 8 to 33 percent, with an average of about 12 percent. Remaining land uses (agricultural infrastructure, grassland, and other categories) generally comprised small percentages or were not mapped within 500 m of more than one-half the wells (table 4; Appendix 1).

Hydrogeologic Setting and Apparent Ground-Water Age

Unconfined alluvial aquifers sampled in the Lander area consist of unconsolidated Quaternary deposits of alluvium in and adjacent to streams in the area (fig. 8). The streams originate in canyons cut into rocks composing the Wind River Range (fig. 1). Drilling and installation of the 10 monitoring wells for this study indicated that the unconsolidated deposits in the Lander area were composed of clay, silt, sand, and gravel. Sediments composing the unconsolidated deposits in the Lander study area were relatively fine grained and consequently, well yields of the monitoring wells were small. Overall, the unconsolidated deposits were finer grained in the Lander study area than in either the Sheridan or Red Lodge study areas. The unconsolidated deposits overlie various Cretaceous-age geologic formations (fig. 8) composed of siliciclastic sedimentary rocks. Depths of the 10 wells installed for this study ranged from about 13 to 20 ft below land surface (table 5).

Water-quality samples were collected from monitoring wells installed for this study (fig. 8; table 5). A review of well records for the Lander study area indicated that domestic wells generally are installed to greater depths than monitoring wells installed for this study and indicated that domestic wells are completed in the Quaternary unconsolidated deposits, Cretaceous bedrock underlying the unconsolidated deposits, or are completed in both.

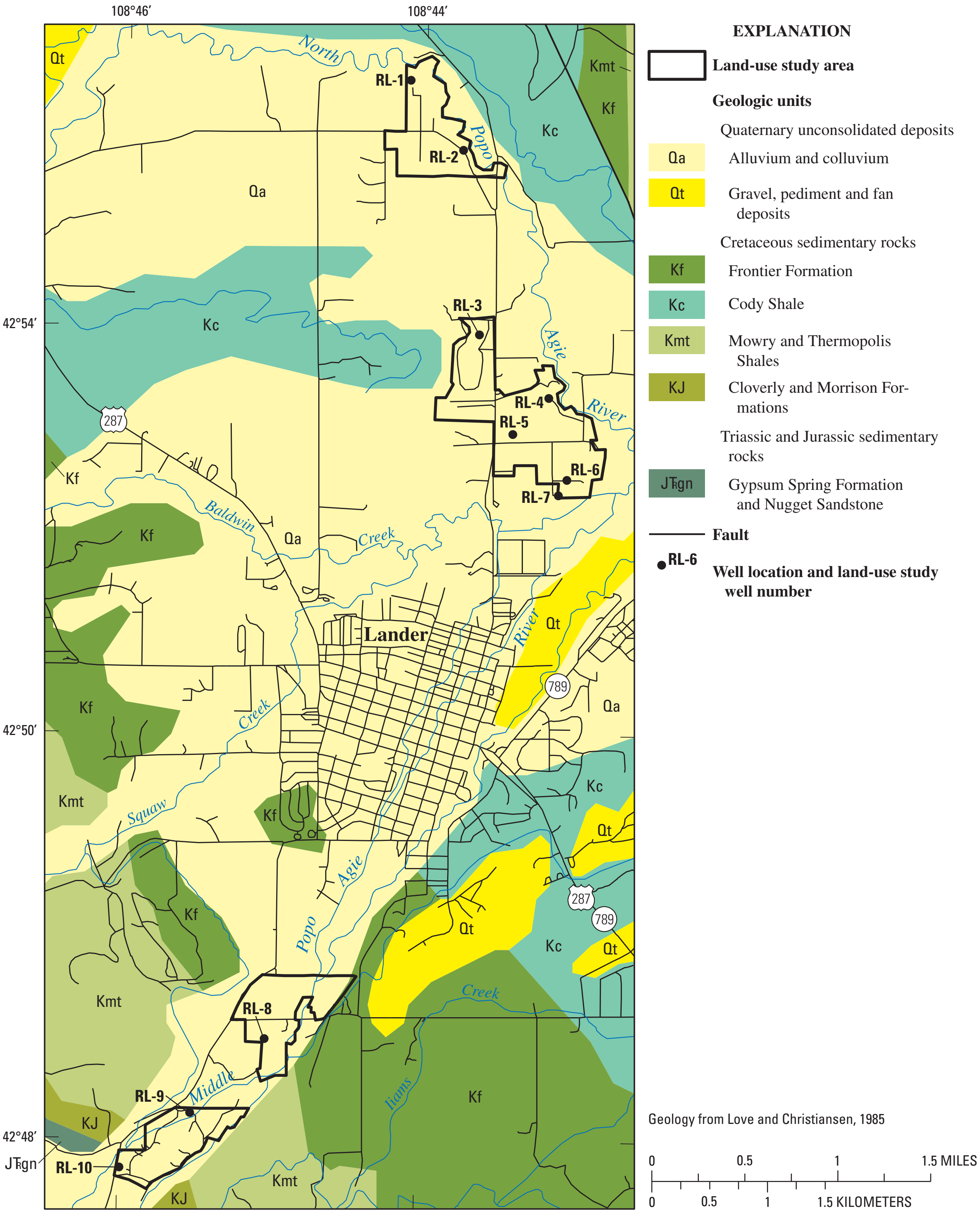
Water levels measured in the three wells installed south of Lander (wells RL–8, RL–9, and RL–10, fig. 8) for this study indicated the water table was very shallow and ranged from 1.84 ft below land surface at well RL–8 to 4.24 ft below land surface at well RL–9 (table 5). Water levels measured in the five wells installed immediately north of Lander (wells RL–3 to RL–7; fig. 8) indicated the water table ranged from 0.93 ft below land surface at well RL–5 to 6.95 ft below land surface at well RL–6 (table 5). Water levels measured in the wells installed farthest north of Lander indicated the water table was 3.73 ft below land surface at well RL–1 and 6.17 ft below land surface at well RL–2 (table 5). Recharge to the unconfined alluvial aquifers likely is not only from areal infiltration and percolation of precipitation, but also from infiltration of diverted surface water from unlined irrigation canals and ditches, water applied to cropland, hayfields and gardens, and water from domestic septic systems. The direction of



Modified from U.S. Geological Survey, EROS Data Center National Land Cover Data–30-meter resolution data for Yellowstone River Basin, 2000

Base modified from Redistricting Census 2000 TIGER/Line Files, U.S. Census Bureau, 2001
Hydrography modified from U.S. Geological Survey National Hydrography Database digital data, 1997
Albers Equal-Area Conic projection, Standard parallels 40°00′N and 45°00′N, central meridian 107°30′W

Figure 7. Distribution of land use and land cover in the Lander study area, Wyoming.



Base modified from Redistricting Census 2000 TIGER/Line Files, U.S. Census Bureau, 2001
Hydrography modified from U.S. Geological Survey National Hydrography Database digital data, 1997
Albers Equal-Area Conic projection, Standard parallels 40°00′N and 45°00′N, central meridian 107°30′W

Figure 8. Geologic map of the Lander study area, Wyoming.

ground-water flow in the area has not been mapped, but likely is towards the streams and in the direction of streamflow.

Paired δ^{18}O and δ^{2}H values in water samples grouped closely together and plotted slightly below the GMWL (Craig, 1961) (fig. 9). This indicates that sampled waters were likely subject to similar recharge and (or) evolutional paths, so that the net differences in the δ^{18}O and δ^{2}H values were minimal.

Apparent ground-water ages were estimated for water samples from 9 of 10 wells using CFCs supplemented with dissolved-gas analyses (table 9; Appendix 3). CFCs were not measured in the ground-water sample collected from well RL–6 because of leaks in the ampoules received by the laboratory. The apparent ages for water samples from six wells were similar and ranged from the mid-1980s to early 1990s.

A water sample from one well (RL–9) was estimated to have been recharged in the early 1970s, and water samples from two wells (RL–5 and RL–10) were estimated to have been recharged in the middle 1970s. Apparent ages estimated for water samples from these three wells were older than expected, and the older apparent ages in water from two of the

Table 9. Apparent ground-water age estimated from chlorofluorocarbons, Lander study area, Wyoming, 2001.

Well number	Sample date (month/day/ year)	Apparent ground-water age
RL–1	07/08/01	Late 1980s to early 1990s.
RL–2	07/12/01	Mid- to late 1980s.
RL–3	07/17/01	Late 1980s to early 1990s.
RL–4	07/09/01	Mid-1980s.
RL–4 (replicate sample)	07/09/01	Mid-1980s.
RL–5	07/15/01	Mid-1970s.
RL–7	07/18/01	Mid-1980s.
RL–8	07/10/01	Late 1980s to early 1990s.
RL–9	07/11/01	Early 1970s.
RL–10	07/16/01	Mid-1970s.

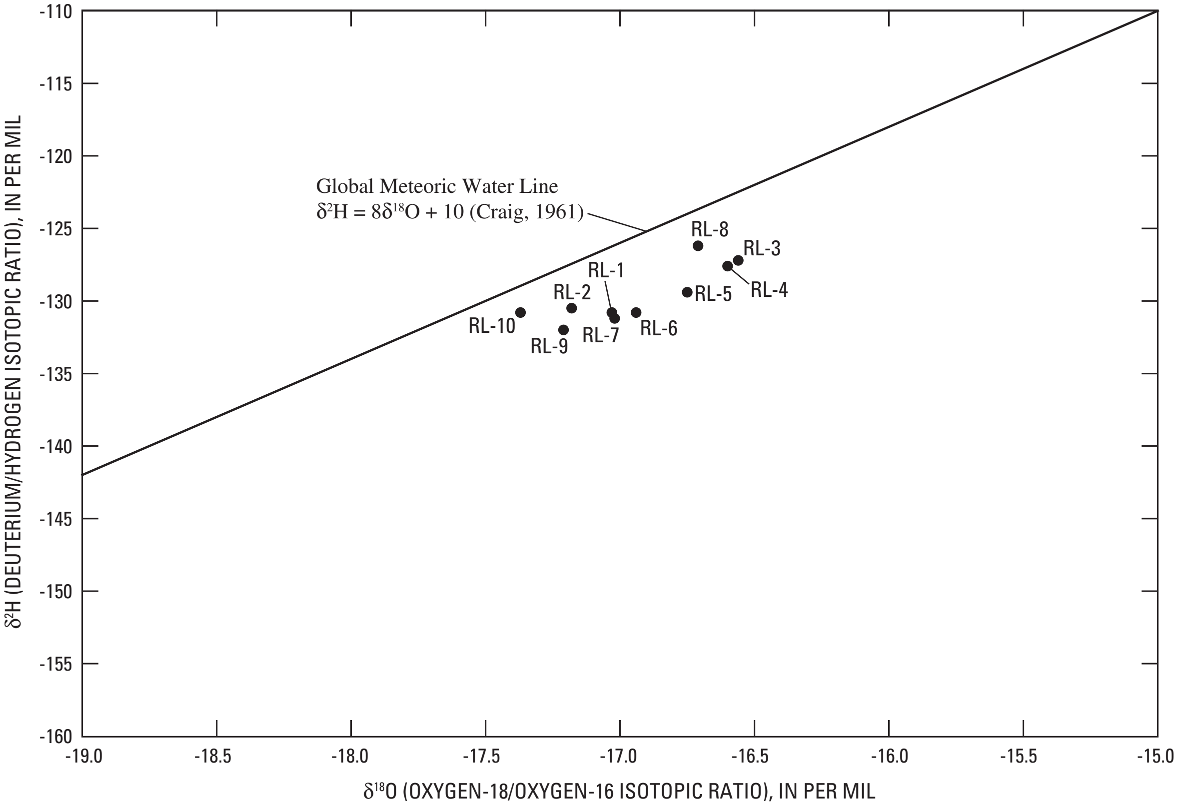


Figure 9. Relation between δ^{18}O and δ^{2}H for ground-water samples collected from Quaternary unconsolidated deposits, Lander study area, Wyoming, 2001.

wells (RL–5 and RL–9) may be attributable to CFC degradation for reasons described previously (see “Hydrogeologic Setting and Apparent Ground-Water Age”, in Sheridan, Wyo., Study Area section). DO concentrations measured in the field in water samples from wells RL–5 and RL–9 were small (less than 0.5 mg/L) (Appendix 5) and indicative of reducing conditions. The DO concentration measured in water sampled from well RL–10 was not as small (1.0 mg/L) and may be indicative of oxidizing conditions, so the reason for the older recharge estimate is unknown.

Ground-water samples from two wells (RL–4 and RL–8) also were analyzed for tritium. Tritium concentrations in water from both wells sampled (Appendix 4) were very similar (about 40 pCi/L) and corroborated the “modern” CFC-based apparent age interpretation for waters from these two wells.

Physical Characteristics

Physical characteristics measured in the field during collection of water samples from 10 wells in the Lander area included water temperature, pH, turbidity, and DO (table 10; Appendix 5). Water temperatures ranged from 10.5 to 18.0°C, with a median of 13.0°C. Field pH measurements were alkaline (pH greater than 7.0) and were very similar, ranging from 7.0 to 7.6 with a median of 7.3. Turbidity ranged from 1.2 to 81 NTU, with a median of 2.3 NTU. DO concentrations ranged from 0.2 to 3.2 mg/L, with a median of 1.3 mg/L. Although sampled waters generally were oxic, DO concentrations indicative of reducing (anoxic or anaerobic) conditions (less than 1 mg/L) were measured in water from 2 of 10 wells sampled (RL–5 and RL–9).

Major Ions and Related Water-Quality Characteristics

One major ion and one related water-quality characteristic had concentrations larger than USEPA standards (table 10) in water sampled in the Lander area. Sulfate concentrations in water from 5 of 10 wells sampled (RL–3, RL–5, RL–6, RL–7, and RL–10) were greater than the SMCL of 250 mg/L. Dissolved-solids concentrations in 6 of 10 wells sampled (RL–3, RL–5, RL–6, RL–7, RL–9, and RL–10) were greater than the SMCL of 500 mg/L.

Dissolved-solids concentrations ranged from 227 to 3,180 mg/L, with a median of 648 mg/L (table 10; Appendix 6). Compared to the USGS salinity classification (Heath, 1983, p. 65, table 2), water from 7 of 10 wells sampled was classified as fresh (dissolved-solids concentrations less than 1,000 mg/L). Dissolved-solids concentrations in water from two wells sampled (RL–3, 1,210 mg/L; and RL–5, 2,850 mg/L) were classified as slightly saline (dissolved-solids concentrations between 1,000 and 3,000 mg/L). The dissolved-solids concentration in water from one well sampled (RL–6, 3,180 mg/L) was classified as moderately saline (dissolved-solids concentrations between 3,000 and 10,000 mg/L).

Calculated hardness ranged from 170 to 1,600 mg/L as $CaCO_3$, with a median of 460 mg/L as $CaCO_3$ (table 10; Appendix 6). Compared to the hardness scale of Durfor and Becker (1964), water from all but one well (RL-8, 170 mg/L) sampled was classified as very hard (greater than 180 mg/L as $CaCO_3$).

The major-ion chemistry of ground water sampled from the 10 monitoring wells in the Lander study area was classified using trilinear and stiff diagrams (figs. 10 and 11). Calcium, bicarbonate, and sulfate were the predominant ions in water from most wells sampled in the Lander area. Calcium was the predominant cation in water from all but three wells sampled; water samples from these three wells (RL–4, RL–5, and RL–6) had mixed cation composition. Bicarbonate was the predominant anion in water from one-half the wells sampled, whereas sulfate was the predominant anion in the remaining one-half the wells sampled. The percentage of sulfate relative to bicarbonate increased with increasing dissolved-solids concentrations.

Dissolved-solids concentrations in water samples closest to perennial streams tended to have the smallest dissolved-solids concentrations (fig. 11). Similar to the trilinear diagrams, the stiff diagrams indicated that increases in dissolved-solids concentrations were related to increases in the percentage of sulfate relative to bicarbonate.

The chloride concentration measured in water sampled from well RL–6 was large (31.8 mg/L) compared to the median chloride concentration (3.0 mg/L, table 10) for 10 wells in the Lander study area. Elevated chloride concentrations in shallow ground water can be from septic systems (Alhajjar and others, 1990); septic system effluent can contain elevated chloride concentrations due to human consumption and disposal of salt (sodium chloride). In addition, runoff and subsequent infiltration of salt applied to de-ice roads also can contaminate shallow ground water.

Trace Elements and Radon

Most trace elements detected in water from 10 wells sampled in the Lander study area had small concentrations less than USEPA standards (table 10; Appendix 7). Beryllium, lead, and silver were not detected in any well samples. Five trace elements were detected in water from one-half or fewer of the wells sampled—cadmium (five detections); iron (four detections); nickel (five detections); selenium (five detections); and thallium (two detections). Aluminum, bromide, chromium, and zinc were detected more frequently, but no concentrations were larger than USEPA standards where applicable (bromide does not have a standard). Eleven trace elements (antimony, arsenic, barium, boron, cobalt, copper, lithium, manganese, molybdenum, strontium, and vanadium) were detected in water from all 10 wells sampled,

Table 10. Summary of inorganic ground-water-quality samples collected from wells completed in the Lander study area, Wyoming, 2001.

[USGS, U.S. Geological Survey; NWIS, National Water Information System; MRL, minimum reporting level, USEPA, U.S. Environmental Protection Agency; °C, degrees Celsius; --, not applicable; SMCL, Secondary Maximum Contaminant Level; NTU, nephelometric turbidity units; mg/L, milligrams per liter; HCO_3, bicarbonate; $CaCO_3$, calcium carbonate; µS/cm, microsiemens per centimeter at 25 degrees Celsius; E, estimated concentration; MCL, Maximum Contaminant Level; HAL, Health Advisory Level; AL, Action Level; C, carbon; µg/L, micrograms per liter; PMCL, proposed Maximum Contaminant Level; AMCL, alternate Maximum Contaminant Level; mL, milliliter; MCLG, Maximum Contaminant Level Goal; *E. coli*, *Escherichia coli*]

Constituent or characteristic	Number of detections/ number of samples	USGS NWIS parameter code	Highest MRL	Lowest MRL	Minimum concentration or value	Median concentration or value	Maximum concentration or value	USEPA drinking-water standards or health advisories
Physical characteristics								
Water temperature (°C)	10/10	00010	--	--	10.5	13.0	18.0	--
pH, field (standard units)	10/10	00400	--	--	7.0	7.3	7.6	6.5–8.5 (SMCL)
Turbidity (NTU)	10/10	61028	--	--	1.2	2.3	81	5 (SMCL)
Dissolved oxygen (mg/L)	10/10	00300	--	--	.2	1.3	3.2	--
Major ions and related water-quality characteristics, in milligrams per liter unless otherwise noted, dissolved (sample filtered through 0.45-micrometer filter)								
Calcium	10/10	00915	--	--	44.1	127	354	--
Magnesium	10/10	00925	--	--	15.6	34.3	170	--
Sodium	10/10	00930	--	--	6.9	32.7	377	--
Potassium	10/10	00935	--	--	1.91	3.64	10.1	--
Bicarbonate (mg/L as HCO_3)	10/10	00453	--	--	157	297	467	--
Chloride	10/10	00940	--	--	1.8	3.0	31.8	250 (SMCL)
Sulfate	10/10	00945	--	--	46.7	267	1,780	250 (SMCL)
Fluoride	10/10	00950	--	--	.3	.5	1.1	4 (MCL) 2 (SMCL)
Silica	10/10	00955	--	--	11.2	15.3	24.6	--
Dissolved solids	10/10	70300	--	--	227	648	3,180	500 (SMCL)
Alkalinity, field (mg/L as $CaCO_3$)	10/10	39086	--	--	129	244	384	--
Hardness, total (mg/L as $CaCO_3$)	10/10	00900	calculated	calculated	170	460	1,600	--
Specific conductance (µS/cm)	10/10	00095	--	--	367	889	3,370	--
Sodium-adsorption ratio (SAR)	10/10	00931	calculated	calculated	.1	.6	5	--
Trace elements, in micrograms per liter unless otherwise noted, dissolved (sample filtered through 0.45-micrometer filter)								
Aluminum	7/10	01106	2	1	<1	1	3	50–200 (SMCL)
Antimony	10/10	01095	--	--	E.03	.08	.12	--
Arsenic	10/10	01000	--	--	E.1	.6	.8	10 (MCL)
Barium	10/10	01005	--	--	8.7	37.8	123	2,000 (MCL)
Beryllium	0/10	01010	.1	.06	<.06	<.06	<.1	4 (MCL)

Table 10. Summary of inorganic ground-water-quality samples collected from wells completed in the Lander study area, Wyoming, 2001.—Continued

[USGS, U.S. Geological Survey; NWIS, National Water Information System; MRL, minimum reporting level, USEPA, U.S. Environmental Protection Agency; °C, degrees Celsius; --, not applicable; SMCL, Secondary Maximum Contaminant Level; NTU, nephelometric turbidity units; mg/L, milligrams per liter; HCO_3, bicarbonate; $CaCO_3$, calcium carbonate; µS/cm, microsiemens per centimeter at 25 degrees Celsius; E, estimated concentration; MCL, Maximum Contaminant Level; HAL, Health Advisory Level; AL, Action Level; C, carbon; µg/L, micrograms per liter; PMCL, proposed Maximum Contaminant Level; AMCL, alternate Maximum Contaminant Level; mL, milliliter; MCLG, Maximum Contaminant Level Goal; *E. coli*, *Escherichia coli*]

Constituent or characteristic	Number of detections/ number of samples	USGS NWIS parameter code	Highest MRL	Lowest MRL	Minimum concentration or value	Median concentration or value	Maximum concentration or value	USEPA drinking-water standards or health advisories
Trace elements, in micrograms per liter unless otherwise noted, dissolved (sample filtered through 0.45-micrometer filter)—Continued								
Boron	10/10	01020	--	--	23	100	722	600 (Draft HAL)
Bromide (mg/L)	7/10	71870	0.01	0.01	<.01	.02	.11	--
Cadmium	5/10	01025	.04	.04	E.02	[1].03	.07	5 (MCL)
Chromium	6/10	01030	.8	.8	E.5	1.6	2.2	100 (MCL)
Cobalt	10/10	01035	--	--	.3	1.04	17.6	--
Copper	10/10	01040	--	--	.9	3.48	72.2	1,300 (AL) 1,000 (SMCL)
Iron	4/10	01046	30	10	<10	12.5	650	300 (SMCL)
Lead	0/10	01049	.2	.08	<.08	<.08	<.2	15 (AL)
Lithium	10/10	01130	--	--	3.8	24	356	--
Manganese	10/10	01056	1	1	E.1	47.4	1,550	50 (SMCL)
Molybdenum	10/10	01060	--	--	1.2	1.9	8.3	40 (HAL)
Nickel	5/10	01065	.3	.06	<.06	1.68	2.38	100 (HAL)
Selenium	5/10	01145	.3	.3	E.2	1.32	4.5	50 (MCL)
Silver	0/10	01075	2	1	<1	<1	<2	100 (HAL/SMCL)
Strontium	10/10	01080	--	--	421	1,280	3,550	17,000 (HAL)
Thallium	2/10	01057	.08	.04	<.08	<.04	E.03	2 (MCL)
Vanadium	10/10	01085	--	--	E.1	1.2	2.2	--
Zinc	7/10	01090	1	1	<1	2	7	2,000 (HAL) 5,000 (SMCL)
Nutrients, in milligrams per liter, dissolved (sample filtered through 0.45-micrometer filter), and dissolved organic carbon								
Nitrite, as nitrogen	7/10	00613	0.006	0.006	E0.004	0.008	0.015	1 (MCL)
Nitrite + nitrate, as nitrogen	9/10	00631	.05	.05	E.026	.082	.202	10 (MCL)
Ammonia, as nitrogen	1/10	00608	.04	.04	E.038	<.04	E.038	30 (HAL)
Ammonia + organic nitrogen, as nitrogen	9/10	00623	.1	.1	E.07	.11	.34	--
Phosphorus, as phosphorus	10/10	00666	--	--	E.004	.008	.028	--
Orthophosphate, as phosphorus	2/10	00671	.02	.02	<.02	<.02	.025	--
Dissolved organic carbon (mg/L as C)	10/10	00681	--	--	1.3	2.1	4.6	--

Table 10. Summary of inorganic ground-water-quality samples collected from wells completed in the Lander study area, Wyoming, 2001.—Continued

[USGS, U.S. Geological Survey; NWIS, National Water Information System; MRL, minimum reporting level, USEPA, U.S. Environmental Protection Agency; °C, degrees Celsius; --, not applicable; SMCL, Secondary Maximum Contaminant Level; NTU, nephelometric turbidity units; mg/L, milligrams per liter; HCO_3, bicarbonate; $CaCO_3$, calcium carbonate; µS/cm, microsiemens per centimeter at 25 degrees Celsius; E, estimated concentration; MCL, Maximum Contaminant Level; HAL, Health Advisory Level; AL, Action Level; C, carbon; µg/L, micrograms per liter; PMCL, proposed Maximum Contaminant Level; AMCL, alternate Maximum Contaminant Level; mL, milliliter; MCLG, Maximum Contaminant Level Goal; *E. coli*, *Escherichia coli*]

Constituent or characteristic	Number of detections/ number of samples	USGS NWIS parameter code	Highest MRL	Lowest MRL	Minimum concentration or value	Median concen-tration or value	Maximum concentration or value	USEPA drinking-water standards or health advisories
Radionuclides, in picocuries per liter unless otherwise noted								
Tritium (unfiltered)	2/2	07000	--	--	40.6	41.1	41.6	--
Uranium (µg/L) (filtered)	10/10	22703	--	--	1.48	3.68	28.6	30 (MCL)
Radon-222 (unfiltered)	10/10	82303	--	--	774	1,546	4,370	300 (PMCL) 4,000 (AMCL)
Other constituents, in milligrams per liter unless otherwise noted								
Total coliform, colonies/100 mL	1/10	31501	1	1	<1	<1	E3	1 (MCLG)
E. Coli, colonies/100 mL	[2]0/1	31633	1	1	<1	<1	<1	--
Methylene blue active substances (detergents)	4/9	38260	.02	.02	<.02	[1].018	.02	[3].5 (SMCL)

[1] Median value was less than highest minimum reporting level and was estimated using log-probability regression (Helsel and Cohn, 1988).

[2] Samples analyzed for *E. coli* if total coliform detected.

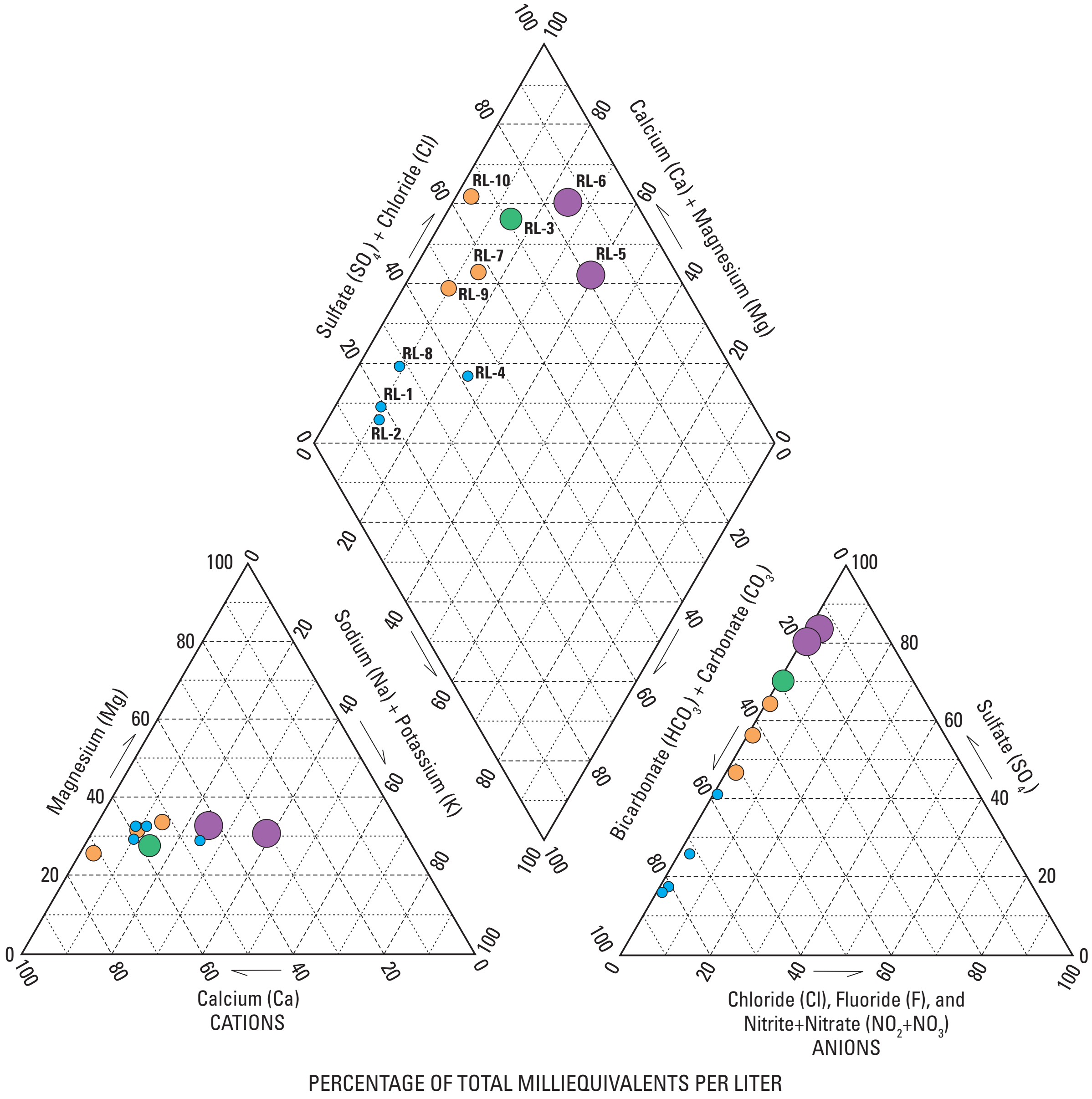
[3] Foaming agents.

but no concentrations, except for manganese, were larger than USEPA standards where applicable (antimony, cobalt, lithium, and vanadium do not have standards).

Three trace elements were detected at concentrations larger than USEPA standards. Boron was measured in water from one well sampled (RL–5, 722 µg/L) at a concentration larger than the USEPA draft HAL (600 µg/L). Iron was measured in water from one well sampled (RL–7, 650 µg/L) at a concentration larger than the USEPA SMCL (300 µg/L). Manganese was detected in all 10 wells sampled at concentrations ranging from 0.1 (estimated concentration) to 1,550 µg/L, with a median of 47.4 µg/L (table 10; Appendix 7). Concentrations of manganese in water from 4 of 10 wells sampled (RL–5, RL–6, RL–7, and RL–9) were larger than the USEPA SMCL (50 µg/L). The occurrence of manganese in ground water in the study area probably is from natural sources. DO concentrations in water sampled from 2 of 4 wells with manganese concentrations larger than the SMCL were very small (RL–5, 0.2 mg/L; and RL–9, 0.3 mg/L; Appendix 5) and indicative of reducing conditions. Under reducing conditions, manganese may be dissolved from organic and manganese complexes or from manganese oxides. Manganese is an undesirable trace element at concentrations greater than the SMCL because of a tendency to deposit black manganese dioxide stains.

Uranium was detected in water from all 10 wells sampled (table 10; Appendix 4). Although all measured concentrations were smaller than the USEPA MCL (30 µg/L), the uranium concentration in water from one well sampled (RL-5, 28.6 µg/L) was much larger than all other measurements and was near the MCL.

Radon was detected in water from all 10 wells sampled at activities ranging from 774 ± 32 pCi/L to 4,370 ± 65 pCi/L, with a median of 1,546 pCi/L (table 10; Appendix 4). All activities were larger than the USEPA proposed MCL (300 pCi/L). Activities measured in water samples from two wells (RL–8, 4,180 pCi/L; and RL–9, 4,370 pCi/L) were larger than the USEPA proposed AMCL (4,000 pCi/L).



EXPLANATION

RL-2 **Land-use study well number**

Dissolved-solids concentration, in milligrams per liter

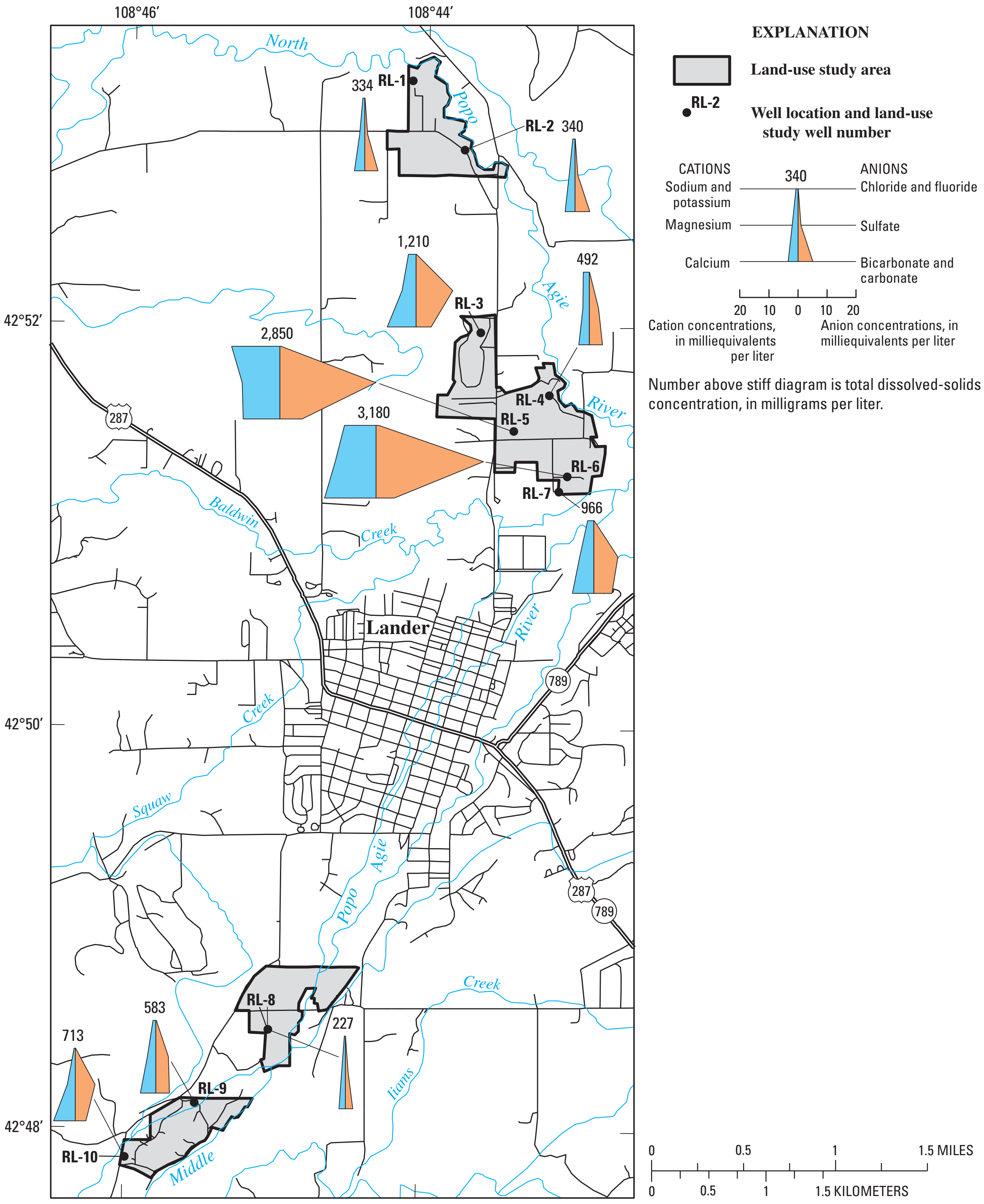
● Less than 500

● 500 to 999

● 1,000 to 1,999

● 2,000 or greater

Figure 10. Trilinear diagram showing major-ion composition and dissolved-solids concentrations for ground-water samples collected from Quaternary unconsolidated deposits in the Lander study area, Wyoming, 2001.



Base modified from Redistricting Census 2000 TIGER/Line Files, U.S. Census Bureau, 2001
Hydrography modified from U.S. Geological Survey National Hydrography Database digital data, 1997
Albers Equal-Area Conic projection, Standard parallels 40°00′N and 45°00′N, central meridian 107°30′W

Figure 11. Stiff diagrams showing areal distribution of major-ion composition and dissolved-solids concentrations for ground-water samples collected from Quaternary unconsolidated deposits in the Lander study area, Wyoming, 2001.

Nutrients and Dissolved Organic Carbon

Nutrient concentrations were small in water from most wells sampled in the Lander study area. All concentrations were much smaller than applicable USEPA standards (table 10; Appendix 8).

On the basis of measured concentrations, much of the nitrogen measured in ground water was either in the form of nitrate or ammonia plus organic nitrogen as nitrogen (Appendix 8). Nitrite as nitrogen (nitrite) was detected in 7 of 10 wells in the Lander study area, but concentrations were small and ranged from an estimated 0.004 to 0.015 mg/L, with a median concentration of 0.008 mg/L; all concentrations were much smaller than the USEPA MCL (1 mg/L). Because nitrite concentrations were so small and composed very little of the nitrite plus nitrate as nitrogen concentrations (Appendix 8), nitrite plus nitrate as nitrogen concentrations are referred to as "nitrate" herein. Nitrate was detected in 9 of 10 wells sampled at small concentrations ranging from an estimated 0.026 to 0.202 mg/L, with a median of 0.082 mg/L. All nitrate concentrations were much smaller than the USEPA MCL (10 mg/L) (table 10). Ammonia as nitrogen (ammonia) was detected in only one well sampled (RL-6) at an estimated concentration of 0.038 mg/L. Ammonia plus organic nitrogen was detected in 9 of 10 wells sampled at small concentrations ranging from an estimated 0.07 to 0.34 mg/L, with a median of 0.11 mg/L. This indicates that organic nitrogen composed most of the ammonia plus organic nitrogen (Appendix 8). Nitrate usually is the most common form of nitrogen in ground-water samples, but ammonia plus organic nitrogen was frequently measured at concentrations similar to or greater than nitrate concentrations; however, concentrations were small (Appendix 8). The detection of nitrate in water samples from most wells was expected because DO concentrations in water samples from 8 of 10 wells indicated oxic conditions (Appendix 5); nitrate is the most common form of nitrogen in oxic ground water and is stable over a wide range of geochemical conditions (Hem, 1985).

Ground-water samples from 2 of 10 wells had enough nitrate for analysis of $\delta^{15}N$. Even though nitrate concentrations were small, $\delta^{15}N$ values in water samples from both wells were enriched (RL–1, +9.7 per mil; and RL–6, +23 per mil). These $\delta^{15}N$ values are near or within the range of +9 to +22 per mil expected for nitrate derived from human or animal waste or septic effluent (Kreitler, 1975; Gormly and Spalding, 1979; Lindau and Spalding, 1984; Heaton, 1986). Land use overlying both wells indicated potential sources of nitrogen to shallow ground water (table 4; Appendix 1), such as substantial amounts of livestock pasture and (or) the presence of septic systems. Land use within 500 m of well RL–6 was composed of a substantial amount of livestock pasture (about 52 percent). In addition, the DOC concentration in the water sample collected from well RL–6 (4.5 mg/L) was the second largest and more than twice the median DOC concentration for water from all 10 wells in the Lander study area. Septic-system effluent can contain large DOC concentrations. Additional work would be needed to determine the cause of the enriched $\delta^{15}N$ values in water from both wells, but it is beyond the scope of this study and is not likely of concern because the nitrate concentrations were so small.

Dissolved phosphorus (total as phosphorus) was detected in water from all 10 wells sampled, but concentrations were small and ranged from an estimated 0.004 to 0.028 mg/L, with a median of 0.008 mg/L (table 10; Appendix 8). Dissolved orthophosphate (as phosphorus) was detected in only 2 of 10 wells sampled at very small concentrations (table 10; Appendix 8). Ground water in the Lander study area likely discharges to surface waters at some locations. No measured phosphorus concentrations were greater than the 0.1 mg/L USEPA recommendation for surface water to prevent eutrophication and resulting effects on aquatic life.

Concentrations of DOC for 10 samples ranged from 1.3 to 4.6 mg/L, with a median of 2.1 mg/L (table 10; Appendix 8). These concentrations are near or slightly greater than the 0 to about 3 mg/L range reported for natural (uncontaminated) ground water (Drever, 1997, fig. 6–1, p. 108).

Bacteria

Ground water from all 10 wells sampled in the Lander study area was analyzed for total coliform bacteria (table 10; Appendix 9). Total coliform bacteria were detected in one water sample from well RL–3 (estimated 3 col/100 mL). The count was larger than the USEPA MCLG for drinking water (1 col/100 mL). *E. coli* was not detected in the sample, indicating the bacteria detected in well RL–3 probably are from soils, not warm-blooded animals.

Methylene Blue Active Substances

Ground water from 9 of 10 wells sampled in the Lander study area were analyzed for MBAS (table 10; Appendix 9). MBAS were detected at an estimated concentration in water sampled from well RL–1 and slightly greater than the reporting level in three wells (RL–4, RL–6, and RL–9). It is difficult to determine if the concentrations detected were from septic-system effluent or other sources because the MBAS concentrations were less than or near the reporting level. However, as noted previously in the report ("Quality Assurance and Quality-Control Samples" section), interpretation of QC samples makes it difficult to determine if these trace-level MBAS detections are actually in water from the aquifers (environmental detections) or if they are due to sample contamination during sampling or laboratory analysis.

Pesticides and Volatile Organic Compounds

At least 1 of 7 pesticides was detected in water from 6 of 10 wells (table 11) sampled in the Lander study area. Six of the detected pesticides were herbicides, whereas one detected pesticide was an insecticide (carbaryl, detected in water from

Table 11. Summary of organic chemical detections, Lander study area, Wyoming, 2001.

[USGS, U.S. Geological Survey; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency; E, estimated concentration; NC, not calculated; --, not applicable]

Chemical name/trade or common name	USGS laboratory parameter code	Number of detections	Number of analyses	Well(s) where chemical was detected	Primary laboratory reporting level (µg/L)	Minimum concentration of detections (µg/L)	Median concentration of detections (µg/L)	Maximum concentration of detections (µg/L)	USEPA standard or health advisory (µg/L)
Pesticides									
Atrazine	39632	1	9	RL–5	0.007	E0.004	NC	E0.004	[1]3
Carbaryl	49310	1	10	RL–6	.03	E.01	NC	E.01	[2]4,000
Dinoseb	49301	1	10	RL–6	.01	E.01	NC	E.01	[1]7
Fenuron	49297	1	10	RL–6	.03	E.01	NC	E.01	--
Picloram	49291	1	10	RL–6	.02	.10	NC	.10	[3]500
Prometon	04037	5	9	RL–2, RL–5, RL–6, RL–9, RL–10	.015	E.002	0.004	.025	[3]100
Tebuthiuron	82670	4	9	RL–2, RL–5, RL–6, RL–7	.016	E.003	.05	E.104	[3]500
Volatile organic compounds									
Benzene	34030	2	10	RL–6, RL–10	0.04	E0.01	0.09	0.17	[1]5
Carbon disulfide	77041	2	10	RL–6, RL–10	.07	E.03	.04	E.05	--
1,2-Dimethylbenzene/*o*-xylene	77135	1	10	RL–6	.04	E.02	NC	E.02	[1,4]10,000
1,3- & 1,4-Dimethylbenzene/ *m*-& *p*-xylene	85795	1	10	RL–6	.06	E.04	NC	E.04	[1,4]10,000
Ethylbenzene/phenylethane	34371	1	10	RL–6	.03	E.03	NC	E.03	[1]700
Methylbenzene/toluene	34010	2	10	RL–4, RL–6	.05	E.01	.07	.13	[1]1,000
Trichloromethane/chloroform	32106	1	10	RL–6	.02	.12	NC	.12	[1,5]80
1,2,4-Trimethylbenzene/ pseudocumene	77222	1	10	RL–6	.06	E.05	NC	E.05	--

[1] U.S. Environmental Protection Agency Maximum Contaminant Level (U.S. Environmental Protection Agency, 2006).

[2] U.S. Environmental Protection Agency Risk-specific dose at 10^{-4} cancer risk (U.S. Environmental Protection Agency, 2006).

[3] U.S. Environmental Protection Agency Lifetime Health Advisory Level (U.S. Environmental Protection Agency, 2006).

[4] Total for all Xylenes combined cannot exceed 10,000 µg/L (U.S. Environmental Protection Agency, 2006).

[5] Total for all trihalomethanes combined cannot exceed 80 µg/L (U.S. Environmental Protection Agency, 2006).

well RL–6). Six of 14 detections (about 43 percent) were in one water sample collected from well RL–6. In fact, of the seven pesticides detected, four (carbaryl, dinoseb, fenuron, and picloram) were detected only in the water sample from well RL–6. All concentrations were much smaller than USEPA standards (table 11).

The two most frequently detected pesticides were prometon and tebuthiuron. Prometon was detected in water from 5 of 9 wells (about 56 percent), and tebuthiuron was detected in water from 4 of 9 wells (about 44 percent). Although measured concentrations were small and much less than USEPA standards, prometon and tebuthiuron were the only pesticides detected in water from more than one well with some measured concentrations that were greater than the reporting level (table 11). Eddy-Miller and Norris (2000) sampled shallow ground water in Fremont County considered vulnerable to pesticide contamination, including some of the same aquifers sampled during this study. Prometon and tebuthiuron were the second and third most frequently detected pesticides in shallow ground water in the county. Legg and others (1992) reported no use of either pesticide for agricultural purposes in the State of Wyoming in 1990. For 1994, Ferrell and others (1996) reported infrequent use of tebuthiuron on improved pasture and rangelands in Wyoming. The relatively high frequency of detection of both herbicides indicates widespread use in the Lander area, although likely not from croplands. However, both pasture and rangeland comprised relatively large percentages of mapped land use/land cover within 500 m (1,640 ft) of sampled wells (table 4; Appendix 1). As noted previously herein, both pesticides are associated with noncrop use, and often are detected in shallow ground water underlying urban areas.

The five other pesticides were detected only once. Atrazine was detected in one water sample from well RL–5; the selective herbicide commonly is used on corn. Eddy-Miller and Norris (2000) reported that atrazine was the most frequently detected pesticide in shallow ground water in Fremont County. Atrazine was reported to be used on corn and wheat in both 1990 and 1994 surveys of agricultural pesticide use in Wyoming, although use on corn decreased between surveys (Legg and others, 1992; Ferrell and others, 1996). Little to no corn or wheat crops were mapped within 500 m (1,640 ft) of the sampled wells (Appendix 1). Carbaryl was detected in a water sample from one well (RL–6) and is a broad spectrum insecticide (Meister, 2002). Dinoseb and fenuron were detected in a water sample from well RL–6, but neither had reported agricultural use in 1990 and 1994 Wyoming pesticide surveys (Legg and others, 1992; Ferrell and others, 1996). Picloram, an herbicide, also was detected in a water sample from well RL–6. Eddy-Miller and Norris (2000) reported that picloram was the fourth most frequently detected pesticide in shallow ground water in Fremont County. Picloram has been one of the most widely used herbicides in Wyoming and has been used on many different crops (Legg and others, 1992; Ferrell and others, 1996). In addition, picloram was reported to be the most used herbicide on alfalfa, grass hay, improved pasture, and rangeland in Wyoming (Legg and others, 1992; Ferrell and others, 1996). These non-cropland land-use categories composed large percentages of mapped land use/land cover within 500 m (1,640 ft) of sampled wells (table 4; Appendix 1).

At least 1 of 8 VOCs were detected in water from three wells sampled in the Lander study area (RL–4; RL–6; and RL–10; table 11). Eight of 11 VOC detections (about 73 percent) were in one water sample from well RL–6, indicating localized contamination (in the immediate vicinity of the sampled well) by trace levels of VOCs. With the exception of carbon disulfide and chloroform, the remaining VOCs detected in the Lander study area (table 11) are constituents commonly associated with gasoline, and almost all were detected in water sampled from well RL–6.

Carbon disulfide was detected in two wells (RL–6 and RL–10) (table 11). Carbon disulfide is used in the manufacture of a wide variety of products and also is used as a solvent (Verschueren, 1983), but no anthropogenic sources are known in the study area. Carbon disulfide does occur naturally at low concentrations in the environment. Carbon disulfide is naturally emitted from many soils, particularly soils with much organic material, and through bacterial interactions with sulfide minerals such as pyrite (Verschueren, 1983; Newhook and others, 2002) and can be present naturally at low concentrations in the environment. Other natural sources of carbon disulfide in the environment are forest and grass fires and volcanoes (Newhook and others, 2002).

Chloroform (trichloromethane) was detected in water from one well (RL–6) at a relatively large concentration (0.12 µg/L) compared to most VOC detections (table 11; Appendix 11). As noted previously, chloroform belongs to a class of VOCs known as THMs that are commonly the by-products of chlorine disinfection.

Summary of Extent of Possible Water-Quality Effects from Human Activities in the Lander, Wyo., Study Area

As described previously, effects of human activities on shallow ground-water quality were indicated in the Lander study area; however, the results of the study indicate that the shallow ground water is suitable for most uses without treatment, and that effects from human activities (ground-water contamination) generally were minimal and limited in areal extent at the time of sampling (2001). Although several inorganic constituents were detected at concentrations greater than USEPA drinking-water standards (dissolved solids, sulfate, and the trace elements boron, iron, and manganese) or proposed standards (radon), natural factors such as geology, aquifer properties, and ground-water recharge rates likely influence concentrations of these constituents. Evidence of possible anthropogenic sources of nitrogen measured in ground water was indicated by enriched nitrogen isotope values, but concentrations of nitrate were very small and much less than the USEPA standard. Evidence of ground-water contamination by human activities primarily is based on detections of organic constituents (pesticides and VOCs). Detected organic constituents generally were consistent with predominant overlying land uses mapped during the study and were measured at very small (trace level) concentrations that were much less than drinking-water standards.

Ground water from 3 of 10 wells sampled (RL–5, RL–6, and RL–10) had mixtures of two or more constituents indicative of contamination by human activities. Wells RL–5 and RL–6 are located in the same general area along the North Popo Agie River, whereas well RL–10 is located south of Lander along the Middle Popo Agie River. Most constituents detected and indicative of contamination by human activities in these wells were organic compounds (pesticides and VOCs). Most organic compounds were not widely detected throughout the Lander study area—20 of 25 (80 percent) organic detections were in water sampled from only three wells (RL–5, RL–6, and RL–10). At least three pesticides were detected in water from both wells RL–5 and RL–6. More than one pesticide commonly is found in ground-water samples containing pesticides (Gilliom, 2001; Gilliom and others, 2006). However, much of the evidence for ground-water contamination by human activities in the Lander study area was based on water sampled from only one well (RL–6). More than one-half (14 of 25) of the organic compounds detected, and 9 of the 15 different organic compounds detected were found only in water sampled from well RL–6. In addition, other evidence of possible contamination by human activities in water sampled from well RL–6 included chloride and DOC concentrations greater than estimated background levels, and a large measured δ^{15}N value indicative of contamination by human or animal waste. In ground water, pesticides also are found frequently in samples containing other contaminants such as nitrate and VOCs (Squillace and others, 2002).

The frequent detection of two constituents may indicate widespread effects of human activities on ground water in aquifers underlying low-density development in the Lander study area. The pesticide prometon was detected at trace concentrations in water from 5 of 9 wells sampled, and the pesticide tebuthiuron was detected at trace concentrations in water from 4 of 9 wells sampled. Detections of both pesticides indicate relatively widespread use in the Lander study area for non-cropland pesticide application. Trace concentrations of MBAS (ingredients in laundry detergents) were detected in water from 4 of 9 wells sampled, indicating possible ground-water contamination from septic system effluent; however, as described previously, QC procedures indicate these detections are questionable, and evidence of widespread trace-level contamination by MBAS is inconclusive.

CFC age-dating (see “Hydrogeologic Setting and Apparent Ground-Water Age” section of report) indicated that much of the water sampled in the shallow aquifers in the Lander study area had been recharged during the mid-1980s to early 1990s. Chemical constituents in shallow ground water in 2001 may, therefore, not yet reflect low-density (rural ranchette) development surrounding the Lander study area that has occurred during the past decade. Although low-density development is continuing in and near the Lander study area, land use appears relatively stable, and most observed changes in the study area were small and localized. Consequently, the detection of relatively few chemical constituents indicative of contamination by human activities may indicate that overlying unsewered low-density development that occurred in the past has had minimal effects on underlying ground-water quality. Continued monitoring likely would be necessary to determine effects on water quality from increasing low-density development over time.

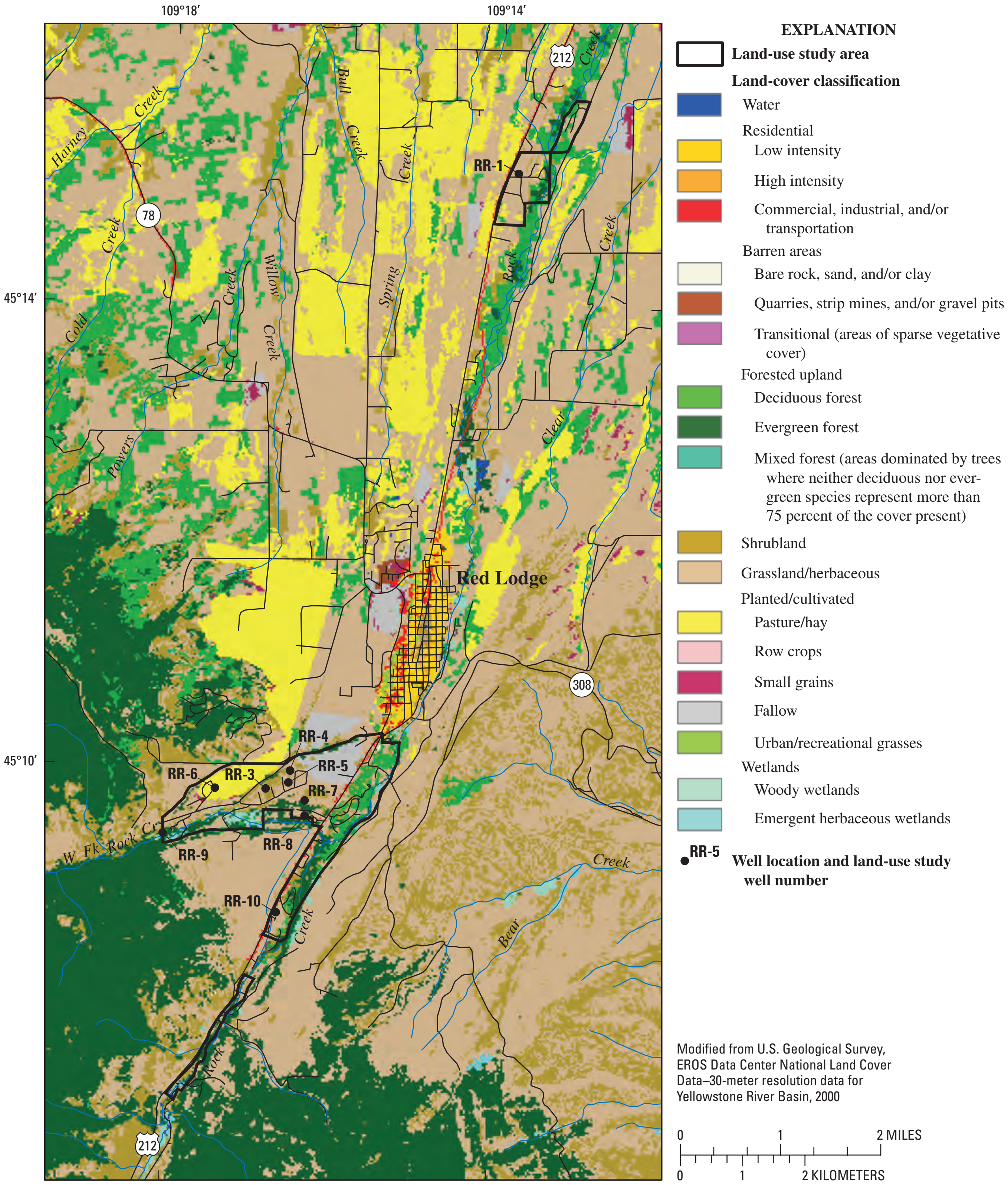
Red Lodge, Mont., Study Area

Red Lodge is located in south central Montana in Carbon County and has a population of 2,177 (U.S. Census Bureau, 2007). Ground-water quality samples were collected in August and September 2001 from nine monitoring wells installed in the Red Lodge area.

Land Use and Land Cover

Land use and land cover from the National Land Cover Database (U.S. Geological Survey, 2000) is shown for the Red Lodge study area and surrounding areas in figure 12. Land use and land cover for the larger Red Lodge area shown in figure 12 primarily consists of grassland, shrubland, forested upland, and pasture. Wells installed in the Red Lodge study area primarily are located along local streams (Rock Creek and West Fork Rock Creek) and on terrace deposits that form the western bench elevated above the Rock Creek stream valley (fig. 13). Land use and land cover in the vicinity of wells installed adjacent to and along Rock Creek and West Fork Rock Creek primarily is wetlands, forested land, and grassland. Land use and land cover in the vicinity of wells installed on the western bench primarily is shrubland and grassland, with small areas of pasture.

During the study, land use and land cover (“land use”) was mapped onsite at greater detail within a 500-m (1,640-ft) radius surrounding the nine wells installed and sampled in the Red Lodge study area (table 4; Appendix 1). Urban, which includes low-density residential land use, was the most abundant land use and was mapped within the radii of all nine sampled wells, ranging from about 10 to 53 percent with an average of about 31 percent. Riparian land (defined as “wetlands” in fig. 12, table 4, and Appendix 1) was the second most abundant land use and was mapped within the radii of all nine wells, ranging from about 6 to 42 percent with an average of about 23 percent. Grasslands were mapped within the radii of 8 of 9 wells and where present, ranged from about 13 to 61 percent, with an average of about 22 percent. Remaining land uses (cropland, agricultural infrastructure, livestock pasture, rangeland, and other categories) generally comprised small percentages or were mapped infrequently within 500 m of wells (table 4; Appendix 1).



Modified from U.S. Geological Survey, EROS Data Center National Land Cover Data–30-meter resolution data for Yellowstone River Basin, 2000

Base modified from Redistricting Census 2000 TIGER/Line Files, U.S. Census Bureau, 2001
Hydrography modified from U.S. Geological Survey National Hydrography Database digital data, 1997
Albers Equal-area Conic projection, Standard parallels 40°00′N and 45°00′N, central meridian 107°30′W

Figure 12. Distribution of land use and land cover in the Red Lodge study area, Montana.

Hydrogeologic Setting and Apparent Ground-Water Age

The Red Lodge, Mont., study area is located in the Middle Rocky Mountains physiographic province (fig. 1). The Middle Rocky Mountain Province has landforms varying from mountain ranges and high plateaus to intermontane basins, such as the Bighorn Basin (Zelt and others, 1999). The Red Lodge study area is located in the northern Bighorn Basin in the foothills of the Beartooth Mountains (fig. 1). Topography varies from relatively flat along the bottoms of stream valleys to sharp relief bounding the terrace deposits (benches) away from the valleys. Topography on the benches also is relatively flat with a relatively small foothill area.

The Beartooth Mountains are a broad, fault-bounded, Laramide uplift that consist of high plateaus atop several uplifted blocks that are dissected by numerous glaciated river valleys. The uplift contains a core of Precambrian crystalline rocks and is flanked on the east by younger sedimentary rocks (Paleozoic and lower Tertiary) of the northern Bighorn Basin. The Paleozoic rocks are exposed along the basin margins along the flanks of the Beartooth uplift, and the lower Tertiary rocks (Fort Union Formation) are exposed in the interior of the basin in the Red Lodge study area (fig. 13).

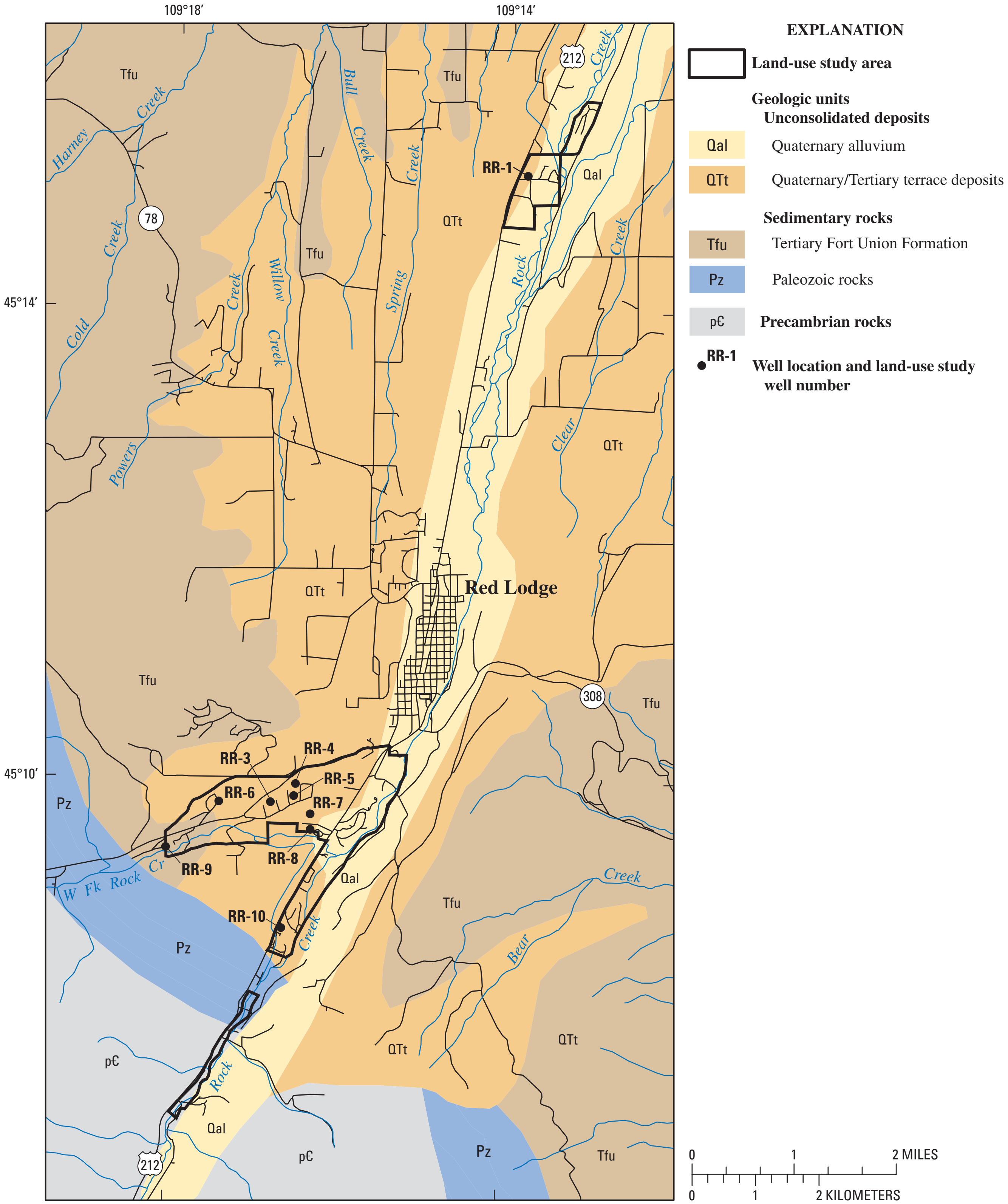
During several major intraglacial warming periods, large quantities of water, boulders, gravel, and sand were discharged onto the eroded surfaces of the Precambrian, Paleozoic, and lower Tertiary bedrock. Streams carrying these sediments flowed out of the canyons and deposited the sediments, forming thick accumulations of unconsolidated sand, gravel, and boulders near the main channels (Ritter, 1967; Waren, 2000). As the stream channels meandered over time, several terrace levels or benches were developed. Ritter (1967) described the geology of the alluvial terrace deposits in the Red Lodge area, and Waren (2000) described the hydrogeology of the deposits.

The land-use study areas were located on Quaternary-age alluvium along local streams (West Fork of Rock Creek and Rock Creek) and on Quaternary/Tertiary-age terrace deposits that form the western benches elevated above the stream valley (fig. 13). Terrace deposit thickness varies because of the eroded surface of the underlying bedrock and ranges from 15 to more than 1,000 feet (Ritter, 1967; Waren, 2000). Thickness of the alluvium near the West Fork Rock Creek and along Rock Creek likely is less. It is unlikely that the terrace deposits are in direct hydraulic connection with the Quaternary alluvium because the streams have cut through the terraces, into the underlying bedrock where most of the alluvium has been deposited near the present channel well below the elevated terraces. In some areas, seepage faces are visible along the elevated bench face, above the valley floor. Ground water is recharged to the terrace deposits from a combination of areal recharge and recharge from irrigation canals (diverted surface water) in the area (Waren, 2000). The alluvial deposits near West Fork Rock Creek and Rock Creek are in close hydraulic connection with the streams. Reported transmissivities of unconsolidated Quaternary deposits in the area are very large (about 10,318 to 12,596 feet squared per day) because of the large size of the sediments composing the Quaternary deposits in the area (Waren, 2000, and references therein); therefore, both the terrace and alluvium provide an abundant supply of water. Some hydraulic connection with the underlying lower Tertiary-age Fort Union Formation is likely, although the wells produce much less water compared to wells completed in the coarser grained and more permeable Quaternary unconsolidated deposits.

Unconfined aquifers sampled in the Red Lodge study area consist of unconsolidated alluvial and terrace deposits above, in, and adjacent to streams in the area (fig. 13). The reader should note that alluvium along some streams in the study area can not be seen on figure 13 because of mapping scale. Consequently, monitoring well RR–9 appears to be completed in Tertiary-age Fort Union Formation on figure 13 although it is actually completed in Quaternary-age alluvium along West Fork Rock Creek. Drilling and installation of nine monitoring wells for this study indicated that the unconsolidated deposits in the Red Lodge study area were very coarse and composed of sand, gravel, and boulders. Depths of the nine wells installed in the Red Lodge study area ranged from about 14 to 58 ft below land surface (table 5). Sediments encountered during drilling were very coarse (primarily cobble and larger sizes); consequently, well yields of the monitoring wells were large and were much larger than well yields in monitoring wells installed in the Sheridan and Lander study areas. The unconsolidated deposits overlie the lower Tertiary-age Fort Union Formation (fig. 13) composed of siliciclastic sedimentary rocks.

Water-quality samples were collected from monitoring wells installed for this study (fig. 13; table 5). A review of well records for the Red Lodge study area indicated that domestic wells generally are installed to greater depths than monitoring wells installed for this study and indicated that domestic wells are completed in the Quaternary unconsolidated deposits, lower Tertiary bedrock underlying the unconsolidated deposits, or are completed in both.

Water levels measured in wells installed in alluvium along streams (fig. 13; wells RR–1, RR–7, RR–8, and RR–9) indicated the water table was shallower than water levels for other wells in the study area and ranged from 4.24 ft below land surface at well RR–9 to 9.19 ft below land surface at well RR–7 (table 5). Water levels measured in the five remaining wells indicated the water table was deeper in unconsolidated terrace deposits located west and above Rock Creek in the study area (fig. 13), and ranged from 33.05 ft below land surface at well RR–10 to 48.2 ft below land surface at well RR–5 (table 5). The direction of ground-water flow in the terrace deposits was mapped by Waren (2000) and indicated ground-water flow in the terrace deposits generally is towards the north or northeast toward Rock Creek. The direction of ground-water flow has not been mapped in the alluvial deposits, but likely is toward the streams (Rock Creek) and in the direction of streamflow.



Base modified from Redistricting Census 2000
TIGER/Line Files, U.S. Census Bureau, 2001
Hydrography modified from U.S. Geological Survey National
Hydrography Database digital data, 1997
Albers Equal-Area Conic projection
Standard parallels 40°00′N and 45°00′N, central meridian 107°30′W

Geology modified from
Ross and others, 1955

Figure 13. Geologic map of the Red Lodge study area, Montana.

Paired $\delta^{18}O$ and $\delta^{2}H$ values in water samples grouped closely together and plotted slightly below the GMWL (fig. 14). This indicates that sampled waters were likely subject to similar recharge and (or) evolutional paths, so that the net differences in the $\delta^{18}O$ and $\delta^{2}H$ values were minimal.

Apparent ground-water ages were estimated for water samples from all nine wells using CFCs supplemented with dissolved-gas analyses (table 12; Appendix 3). The apparent age for water samples from all nine wells ranged from the mid-1980s to modern-day (2001).

Ground-water samples from three wells (RR–6, RR–8, and RR–10) also were analyzed for tritium. Tritium concentrations in water from all three wells sampled (Appendix 4) were similar (between about 36 and 46 pCi/L) and corroborated the "modern" CFC-based apparent age interpretation for waters from these wells.

Table 12. Apparent ground-water age estimated from chlorofluorocarbons, Red Lodge study area, Montana, 2001.

Well number	Sample date (month/day/year)	Apparent ground-water age
RR–1	08/08/01	Mid- to late 1980s.
RR–3	09/19/01	Mid- to late 1980s.
RR–4	09/18/01	Mid- to late 1980s.
RR–5	09/17/01	Modern.
RR–6	09/16/01	Late 1980s to early 1990s.
RR–7	08/18/01	Early 1990s.
RR–8	09/17/01	Early 1990s.
RR–9	09/18/01	Early 1990s.
RR–10	09/19/01	Early 1990s.

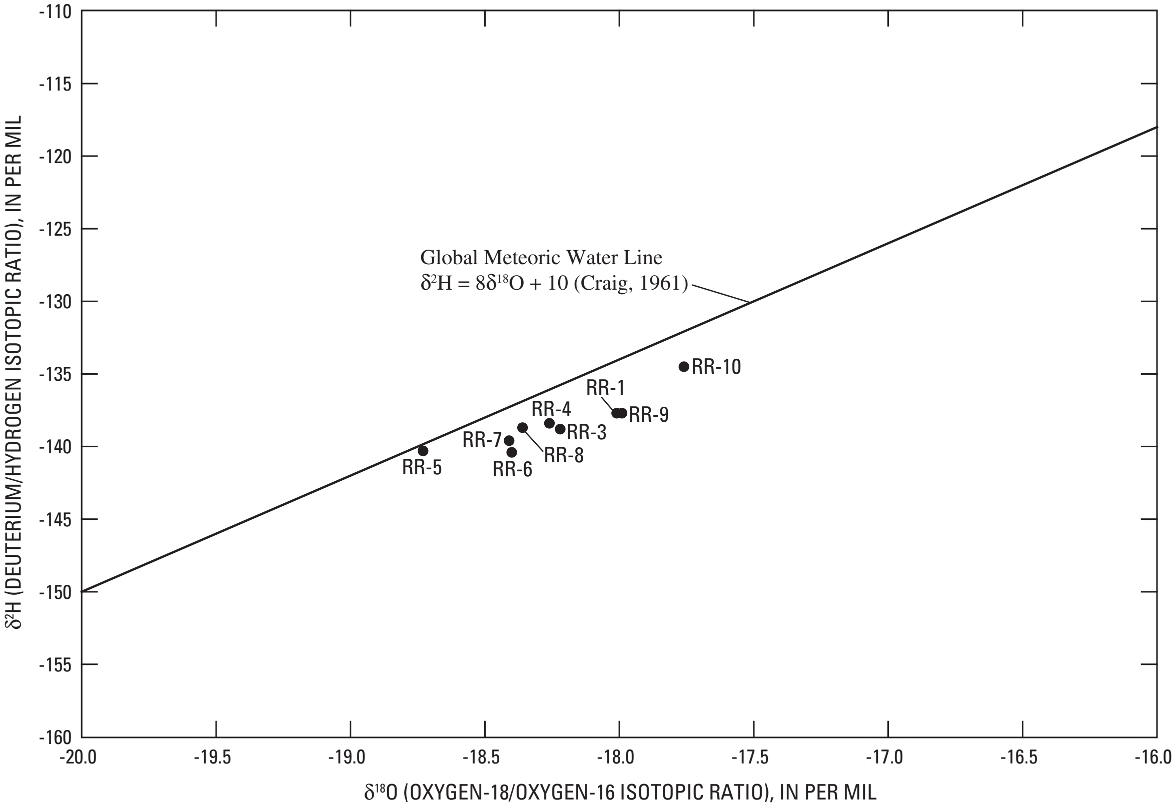


Figure 14. Relation between $\delta^{18}O$ and $\delta^{2}H$ for ground-water samples collected from Quaternary unconsolidated deposits, Red Lodge study area, Montana, 2001.

Physical Characteristics

Physical characteristics measured in the field during collection of water samples from nine wells in the Red Lodge study area included water temperature, pH, turbidity, and DO (table 13; Appendix 5). Water temperatures ranged from 9.0 to 16.0°C, with a median of 12.0°C. Field pH measurements ranged from 6.3 to 7.4, with a median of 6.8. The pH values were slightly acidic (pH less than 7.0) in water from 5 of 9 wells sampled and slightly alkaline (pH equal to or greater than 7.0) in the remaining 4 wells sampled. Turbidity ranged from 0.5 to 3.8 NTU, with a median of 1.8 NTU. DO concentrations ranged from 2.0 to 8.7 mg/L, with a median of 6.9, and indicated water from all wells sampled was under oxic conditions.

Major Ions and Related Water-Quality Characteristics

Water from all nine wells sampled in the Red Lodge study area was not very mineralized, and no major ions or related water-quality characteristic were measured at concentrations larger than USEPA standards (table 13; Appendix 6). Dissolved-solids concentrations in all water samples were very small and ranged from 36 to 121 mg/L, with a median of 61 mg/L (table 13; Appendix 6). Compared to the USGS salinity classification (Heath, 1983, p. 65, table 2), water from all nine wells sampled was classified as fresh (dissolved-solids concentrations less than 1,000 mg/L).

Calculated hardness ranged from 23 to 100 mg/L as $CaCO_3$, with a median of 39 mg/L as $CaCO_3$ (table 13; Appendix 6). Compared to the hardness scale of Durfor and Becker (1964), water from 8 of 9 wells sampled was classified as soft (less than or equal to 60 mg/L as $CaCO_3$), whereas water from the remaining well was classified as moderately hard (greater than 60 but less than or equal to 120 mg/L as $CaCO_3$).

The major-ion chemistry of ground water sampled from nine wells in the Red Lodge study area was classified using trilinear and stiff diagrams (figs. 15 and 16). Calcium and bicarbonate were the predominant ions in water from all wells sampled in the Red Lodge area (fig. 15).

Trace Elements and Radon

Trace elements detected in water from nine wells sampled in the Red Lodge study area were measured at small concentrations much less than applicable USEPA standards (table 13; Appendix 7). Cadmium, selenium, and silver were not detected in water from any wells sampled. Trace elements detected in water from less than one-half the wells sampled included arsenic (four detections), beryllium (one detection), bromide (three detections), chromium (one detection), iron (one detection), lead (two detections), and thallium (one detection). Eight trace elements (aluminum, antimony, boron, copper, molybdenum, nickel, and zinc) were detected more frequently, but all measured concentrations were much smaller than USEPA standards. Six trace elements (barium, cobalt, lithium, manganese, strontium, and vanadium) were detected in water from all nine wells sampled, but all measured concentrations were smaller than USEPA standards where applicable.

Uranium was detected in water from all nine wells sampled (table 13, Appendix 4). All measured concentrations were very small (less than 1 µg/L), much less than the USEPA MCL (30 µg/L).

Radon was detected in water from all nine wells sampled at activities ranging from 637 ± 27 pCi/L to 1,260 ± 35 pCi/L, with a median of 820 pCi/L (table 13, Appendix 4). All measured activities were greater than the proposed MCL (300 pCi/L). No measured activities were larger than the USEPA proposed AMCL (4,000 pCi/L).

Nutrients and Dissolved Organic Carbon

Nutrient concentrations were small in water from most wells sampled, and all concentrations were much smaller than applicable USEPA standards (table 13, Appendix 8). Nitrite as nitrogen (nitrite) was detected in water from 2 of 9 wells sampled, but at very small estimated concentrations (0.003 mg/L), much lower than the USEPA MCL (1 mg/L). Similarly, ammonia was detected infrequently at estimated concentrations in water from 2 of 9 wells sampled, and ammonia plus organic nitrogen was detected in water from one well at an estimated concentration (Appendix 8).

In contrast, nitrite plus nitrate as nitrogen was detected in all nine wells sampled, but at concentrations (less than 0.8 mg/L) much smaller than the USEPA MCL (10 mg/L) (table 13). Because nitrite concentrations were so small and composed very little of the nitrite plus nitrate as nitrogen concentrations (Appendix 8), nitrite plus nitrate as nitrogen are referred to as “nitrate” herein. The detection of nitrate in water samples from all wells was expected because DO concentrations indicated that water in all nine wells sampled was oxic (Appendix 5); nitrate is the most common form of nitrogen in oxic ground water and is stable over a wide range of geochemical conditions (Hem, 1985).

Ground-water samples from 7 of 9 wells had enough nitrate for analysis of $\delta^{15}N$. Water from 4 of 9 wells sampled (RR–3, RR–7, RR–8, and RR–10) had $\delta^{15}N$ values ranging from +5.3 to +7.5 per mil, within the +4 to +9 per mil range expected for nitrate derived from soil organic nitrogen (Gormly and Spalding, 1979; Heaton, 1986; Hubner, 1986). In the other three water samples, $\delta^{15}N$ values were similar but smaller, ranging from +3.2 to +3.9 per mil. These measured $\delta^{15}N$ values are within the range reported for fertilizer (+0 to +6 per mil) and approach the range reported for soil organic nitrogen (+4 to +9 per mil). In addition, these $\delta^{15}N$ values might have resulted from the mixing of nitrate derived from different sources (for example, atmospheric nitrate with livestock or septic effluent-derived nitrate).

Table 13. Summary of inorganic ground-water-quality samples collected from wells completed in the Red Lodge study area, Montana, 2001.

[USGS, U.S. Geological Survey; NWIS, National Water Information System; MRL, minimum reporting level, USEPA, U.S. Environmental Protection Agency; °C, degrees Celsius; --, not applicable; SMCL, Secondary Maximum Contaminant Level; NTU, nephelometric turbidity units; mg/L, milligrams per liter; HCO_3, bicarbonate; $CaCO_3$, calcium carbonate; µS/cm, microsiemens per centimeter at 25 degrees Celsius; E, estimated concentration; MCL, Maximum Contaminant Level; HAL, Health Advisory Level; AL, Action Level; C, carbon; µg/L, micrograms per liter; PMCL, proposed Maximum Contaminant Level; AMCL, alternate Maximum Contaminant Level; mL, milliliter; MCLG, Maximum Contaminant Level Goal; *E. coli*, *Escherichia coli*]

Constituent or characteristic	Number of detections/ number of samples	USGS NWIS parameter code	Highest MRL	Lowest MRL	Minimum concentration or value	Median concentration or value	Maximum concentration or value	USEPA drinking-water standards or health advisories
Physical characteristics								
Water temperature (°C)	9/9	00010	--	--	9.0	12.0	16.0	--
pH, field (standard units)	9/9	00400	--	--	6.3	6.8	7.4	6.5–8.5 (SMCL)
Turbidity (NTU)	9/9	61028	--	--	.5	1.8	3.8	5.0 (SMCL)
Dissolved oxygen (mg/L)	9/9	00300	--	--	2.0	6.9	8.7	--
Major ions and related water-quality characteristics, in milligrams per liter unless otherwise noted, dissolved (sample filtered through 0.45-micrometer filter)								
Calcium	9/9	00915	--	--	6.27	9.79	30.9	--
Magnesium	9/9	00925	--	--	1.82	3.53	6.47	--
Sodium	9/9	00930	--	--	1.3	1.6	3.2	--
Potassium	9/9	00935	--	--	.63	.83	1.73	--
Bicarbonate (mg/L as HCO_3)	9/9	00453	--	--	29	46	122	--
Chloride	9/9	00940	0.1	0.1	.2	.7	1.3	250 (SMCL)
Sulfate	9/9	00945	--	--	2.1	2.5	4.2	250 (SMCL)
Fluoride	9/9	00950	.2	.2	E.1	<.2	<.2	4 (MCL) 2 (SMCL)
Silica	9/9	00955	--	--	5.9	9.9	13.9	--
Dissolved solids	9/9	70300	--	--	36	61	121	500 (SMCL)
Alkalinity, field (mg/L as $CaCO_3$)	9/9	39086	--	--	24	38	100	--
Hardness, total (mg/L as $CaCO_3$)	9/9	00900	calculated	calculated	23	39	100	--
Specific conductance (µS/cm)	9/9	00095	--	--	56	95	212	--
Sodium-adsorption ratio (SAR)	9/9	00931	calculated	calculated	.1	.1	.2	--
Trace elements, in micrograms per liter unless otherwise noted, dissolved (sample filtered through 0.45-micrometer filter)								
Aluminum	6/9	01106	1	1	<1	1	3	50–200 (SMCL)
Antimony	5/9	01095	.05	.05	E.03	.04	.07	--
Arsenic	4/9	01000	.2	.2	<.2	[1].1	E.1	10 (MCL)
Barium	9/9	01005	--	--	5.6	15.3	23.5	2,000 (MCL)
Beryllium	1/9	01010	.06	.06	E.04	<.06	<.06	4 (MCL)
Boron	6/9	01020	7	--	E4	17	32	600 (Draft HAL)

Table 13. Summary of inorganic ground-water-quality samples collected from wells completed in the Red Lodge study area, Montana, 2001.—Continued

[USGS, U.S. Geological Survey; NWIS, National Water Information System; MRL, minimum reporting level, USEPA, U.S. Environmental Protection Agency; °C, degrees Celsius; --, not applicable; SMCL, Secondary Maximum Contaminant Level; NTU, nephelometric turbidity units; mg/L, milligrams per liter; HCO_3, bicarbonate; $CaCO_3$, calcium carbonate; µS/cm, microsiemens per centimeter at 25 degrees Celsius; E, estimated concentration; MCL, Maximum Contaminant Level; HAL, Health Advisory Level; AL, Action Level; C, carbon; µg/L, micrograms per liter; PMCL, proposed Maximum Contaminant Level; AMCL, alternate Maximum Contaminant Level; mL, milliliter; MCLG, Maximum Contaminant Level Goal; *E. coli*, *Escherichia coli*]

Constituent or characteristic	Number of detections/ number of samples	USGS NWIS parameter code	Highest MRL	Lowest MRL	Minimum concen-tration or value	Median concen-tration or value	Maximum concen-tration or value	USEPA drinking-water standards or health advisories
Bromide (mg/L)	3/9	71870	0.01	0.01	<0.01	[1]0.004	0.02	--
Cadmium	0/9	01025	.04	.04	<.04	<.04	<.04	5 (MCL)
Chromium	1/9	01030	.8	.8	<.8	<.8	.8	100 (MCL)
Cobalt	9/9	01035	--	--	.03	.08	.17	--
Copper	8/9	01040	.2	.2	<.2	.6	1.8	1,300 (AL) 1,000 (SMCL)
Iron	1/9	01046	10	10	<10	<10	70	300 (SMCL)
Lead	2/9	01049	.08	.08	<.08	<.08	.13	15 (AL)
Lithium	9/9	01130	--	--	.4	.7	1	--
Manganese	9/9	01056	--	--	.1	1.6	13.8	50 (SMCL)
Molybdenum	7/9	01060	.2	.2	E.1	E.2	.7	40 (HAL)
Nickel	7/9	01065	.06	.06	<.06	.21	.73	100 (HAL)
Selenium	0/9	01145	.3	.3	<.3	<.3	<.3	50 (MCL)
Silver	0/9	01075	1	1	<1	<1	<1	100 (HAL/SMCL)
Strontium	9/9	01080	--	--	24.7	39.1	74.8	17,000 (HAL)
Thallium	1/9	01057	.04	.04	<.04	<.04	E.02	2 (MCL)
Vanadium	9/9	01085	--	--	E.2	.3	.5	--
Zinc	5/9	01090	1	1	<1	1	4	2,000 (HAL) 5,000 (SMCL)
Nutrients, in milligrams per liter, dissolved (sample filtered through 0.45-micrometer filter), and dissolved organic carbon								
Nitrite, as nitrogen	2/9	00613	0.006	0.006	E0.003	<0.006	<0.006	1 (MCL)
Nitrite + nitrate, as nitrogen	9/9	00631	--	--	E.04	.278	.784	10 (MCL)
Ammonia, as nitrogen	2/9	00608	.04	.04	<.04	<.04	E.024	30 (HAL)
Ammonia + organic nitrogen, as nitrogen	1/9	00623	.1	.1	<.1	<.1	E.1	--
Phosphorus, as phosphorus	5/9	00666	.006	.006	E.003	[1].004	.016	--
Orthophosphate, as phosphorus	1/9	00671	.02	.02	<.02	<.02	.02	--
Dissolved organic carbon (mg/L as C)	9/9	00681	--	--	E.32	.47	2.7	--

Table 13. Summary of inorganic ground-water-quality samples collected from wells completed in the Red Lodge study area, Montana, 2001.—Continued

[USGS, U.S. Geological Survey; NWIS, National Water Information System; MRL, minimum reporting level, USEPA, U.S. Environmental Protection Agency; °C, degrees Celsius; --, not applicable; SMCL, Secondary Maximum Contaminant Level; NTU, nephelometric turbidity units; mg/L, milligrams per liter; HCO_3, bicarbonate; $CaCO_3$, calcium carbonate; µS/cm, microsiemens per centimeter at 25 degrees Celsius; E, estimated concentration; MCL, Maximum Contaminant Level; HAL, Health Advisory Level; AL, Action Level; C, carbon; µg/L, micrograms per liter; PMCL, proposed Maximum Contaminant Level; AMCL, alternate Maximum Contaminant Level; mL, milliliter; MCLG, Maximum Contaminant Level Goal; *E. coli*, *Escherichia coli*]

Constituent or characteristic	Number of detections/ number of samples	USGS NWIS parameter code	Highest MRL	Lowest MRL	Minimum concen-tration or value	Median concen-tration or value	Maximum concen-tration or value	USEPA drinking-water standards or health advisories
Radionuclides, in picocuries per liter unless otherwise noted								
Tritium (unfiltered)	3/3	07000	--	--	36.5	41.6	45.8	--
Uranium (µg/L) (filtered)	9/9	22703	--	--	.02	.12	.68	30 (MCL)
Radon-222 (unfiltered)	9/9	82303	--	--	637	820	1,260	300 (PMCL) 4,000 (AMCL)
Other constituents, in milligrams per liter unless otherwise noted								
Total coliform, colonies/100 mL	0/9	31501	1	1	<1	<1	<1	1 (MCLG)
E. Coli, colonies/100 mL	[2]0/0	31633	1	1	--	--	--	--
Methylene blue active substances (detergents)	2/9	38260	.05	.02	.02	.02	.03	[3].5 (SMCL)

[1] Median value was less than highest minimum reporting level and was estimated using log-probability regression (Helsel and Cohn, 1988).

[2] Samples analyzed for *E. coli* if total coliform detected.

[3] Foaming agents.

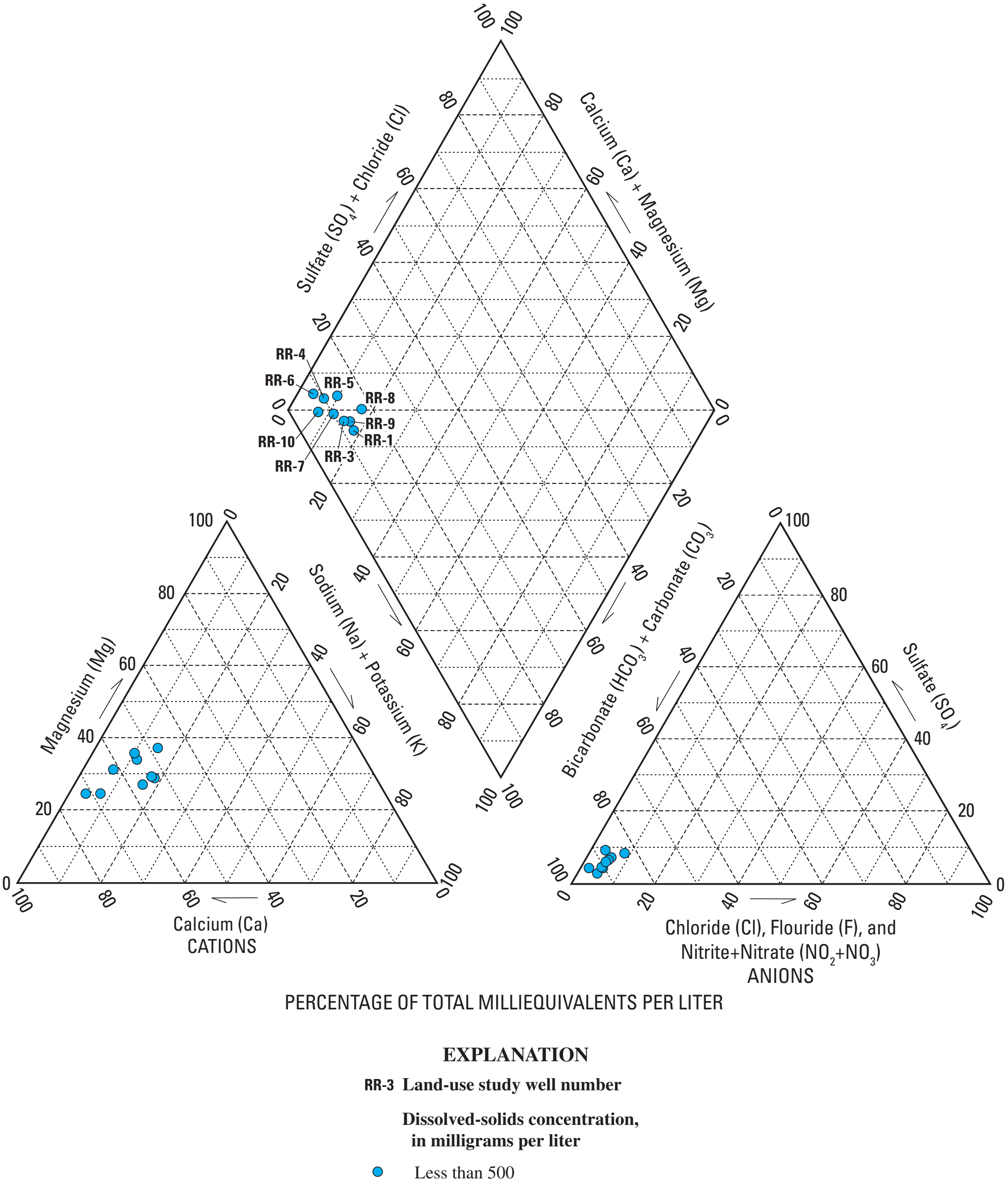
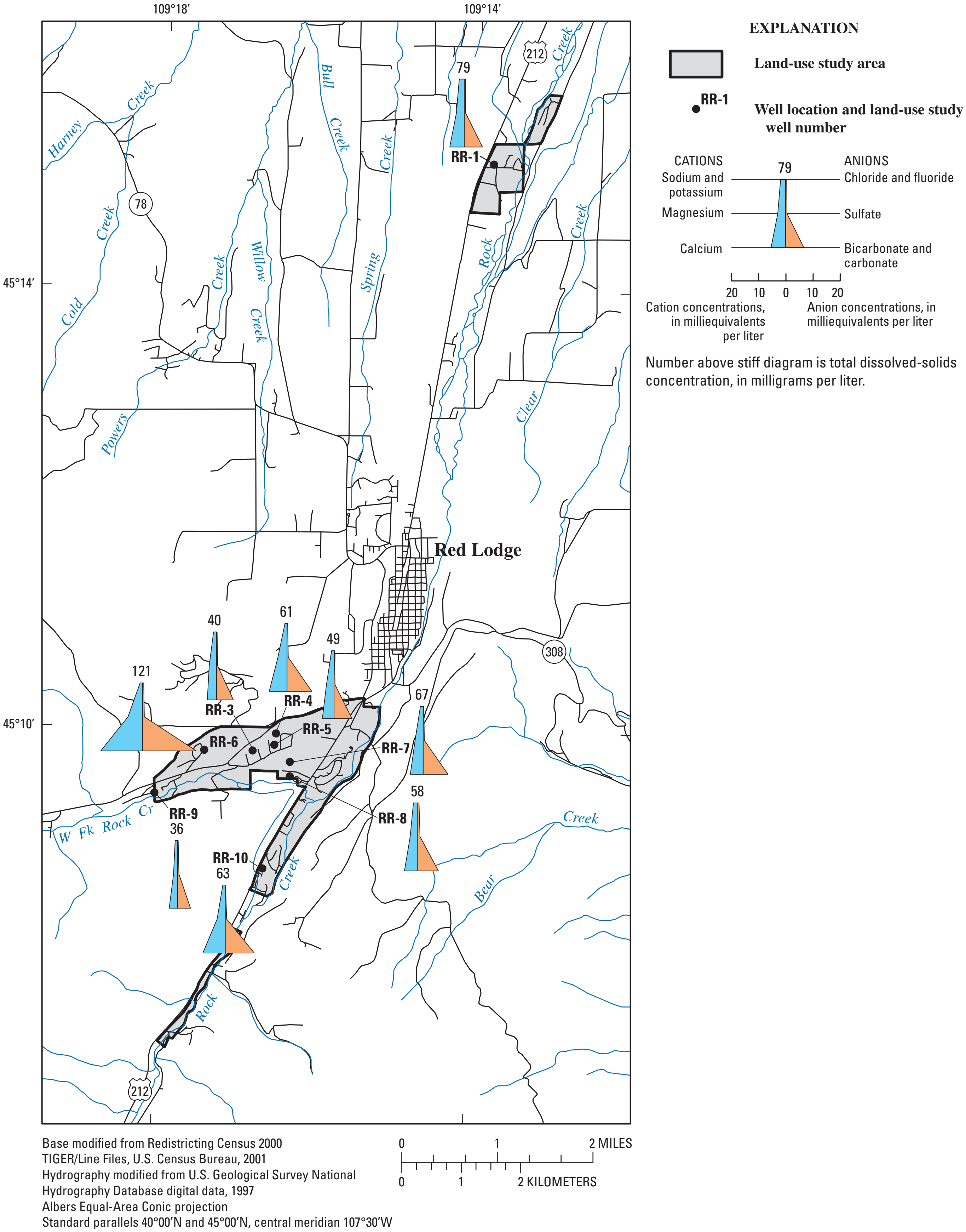


Figure 15. Trilinear diagram showing major-ion composition and dissolved-solids concentrations for ground-water samples collected from Quaternary unconsolidated deposits in the Red Lodge study area, Montana, 2001.



Base modified from Redistricting Census 2000
TIGER/Line Files, U.S. Census Bureau, 2001
Hydrography modified from U.S. Geological Survey National
Hydrography Database digital data, 1997
Albers Equal-Area Conic projection
Standard parallels 40°00′N and 45°00′N, central meridian 107°30′W

Figure 16. Stiff diagrams showing areal distribution of major-ion composition and dissolved-solids concentrations for ground-water samples collected from Quaternary unconsolidated deposits in the Red Lodge study area, Montana, 2001.

Dissolved phosphorus was detected in water from 5 of 9 wells sampled, but concentrations were small and ranged from an estimated 0.003 to 0.016 mg/L, with a median of 0.004 mg/L (table 13; Appendix 8). Dissolved orthophosphate (as phosphorus) was detected in water from 1 of 9 wells sampled at a very small concentration of 0.02 mg/L (table 13; Appendix 8). Ground water in the Red Lodge study area likely discharges to surface waters at some locations. No measured phosphorus concentrations were greater than the 0.1 mg/L USEPA recommendation for surface water to prevent eutrophication and resulting effects on aquatic life.

Concentrations of DOC for nine samples ranged from an estimated 0.32 to 2.7 mg/L, with a median of 0.47 mg/L (table 13; Appendix 8). These concentrations are within the 0 to about 3 mg/L range estimated for natural ground waters (Drever, 1997, fig. 6–1, p. 108).

Bacteria

Ground water from all nine wells sampled in the Red Lodge study area were analyzed for total coliform bacteria (table 13; Appendix 9). Total coliform bacteria were not detected in any water samples.

Methylene Blue Active Substances

Ground water from all nine wells sampled in the Red Lodge study area were analyzed for MBAS (table 13; Appendix 9). MBAS were detected at concentrations slightly greater than the reporting level of 0.02 mg/L in water from two wells (RR–1 and RR–8). It is difficult to determine if the concentrations detected were from wastewater (from septic system effluent) or other sources because the MBAS concentrations were less than or near the reporting level. However, as noted previously in the report (“Quality Assurance and Quality-Control Samples” section), interpretation of QC samples makes it difficult to determine if these trace-level MBAS detections are actually in water from the aquifers (environmental detections) or if they are due to sample contamination during sampling or laboratory analysis.

Pesticides and Volatile Organic Compounds

Ground water from all nine wells sampled in the Red Lodge study area were analyzed for pesticides and VOCs. No pesticides were detected (Appendix 10), but at least one VOC was detected in water from 8 of 9 wells sampled (detected in all but water from well RR–1) (table 14; Appendix 11). Six different VOCs were detected for a total of 19 detections, including three solvents (acetone, 2-butanone (methyl ethyl ketone), and tetrahydrofuran), two THMs (bromodichloromethane and chloroform), and one gasoline-related compound (1,2,4-trimethylbenzene).

The VOC 1,2,4-trimethylbenzene was detected in water from 8 of 9 wells sampled, and the VOC accounted for 8 of 19 detections (about 42 percent). Concentrations of 1,2,4-trimethylbenzene generally were small, and ranged from an estimated concentration of 0.03 to 0.21 µg/L, with a median of 0.09 µg/L. The VOC 1,2,4-trimethylbenzene commonly is associated with gasoline but can occur naturally in coal tar and petroleum crude oil (U.S. Environmental Protection Agency, 1995). The source of these detections is unknown but ground-water contamination by gasoline is not the likely source; several different VOCs commonly are found together in ground water contaminated by gasoline, and 1,2,4-trimethylbenzene was the only gasoline-related VOC detected in water from wells in the Red Lodge Study area.

Six of 19 VOC detections (about 32 percent) were in water sampled from one well (RR–8). Both THMs detected (chloroform and bromodichloromethane) were in water sampled from this well (RR–8).

USEPA standards have not been established for the three solvent VOCs (tetrahydrofuran, 2-butanone (methyl ethyl ketone), and acetone) detected in the Red Lodge study area (table 14). These three VOCs were the only organic compounds detected in any of the three study areas at concentrations greater than 1 µg/L. Tetrahydrofuran was detected in water from 4 of 9 wells sampled (RR–3, RR–5, RR–8, and RR–10) at concentrations ranging from an estimated concentration of 1 to 1,150 µg/L. Methyl ethyl ketone was detected in water from 2 of 9 wells sampled at concentrations of 4 µg/L (RR–8) and 18 µg/L (RR–5). Acetone was detected in water from 3 of 9 wells sampled (RR–3, RR–5, and RR–8) at concentrations ranging from an estimated 6 to 244 µg/L. The frequent detection of these VOCs at relatively large concentrations was unexpected.

The source of the three VOCs classified as solvents detected in water from as many as four wells in the Red Lodge study area is unknown, and it is difficult to determine if these detections are actually in water from the aquifers (environmental detections) or if they are due to contamination from well-construction procedures or materials. The VOC solvents tetrahydrofuran and methyl ethyl ketone are common constituents in primers and glues used to join PVC, including PVC well casing; both VOCs have been found in water samples collected from wells where these substances had been used to construct the well (Sosebee and others, 1983). Small concentrations of tetrahydrofuran in ground water can be attributable to natural sources, but the large concentrations measured in water from 4 of 9 wells sampled (ranging from an estimated concentration of 1 to 1,150 µg/L) make this an unlikely explanation. Many PVC glues and primers are mixtures of several different VOCs, including tetrahydrofuran and methyl ethyl ketone. The drilling contract describing monitoring-well construction in the Red Lodge study area was written to specify that all well-casing materials were to be factory cleaned and sealed, and mechanically joined by factory-threaded flush connections without the use of PVC glues and primers; however, the detection of a relatively large number of solvent VOCs commonly associated with PVC glues and primers, and detection of the

Table 14. Summary of organic chemical detections, Red Lodge study area, Montana, 2001.

[USGS, U.S. Geological Survey; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency; E, estimated concentration; NC, not calculated; --, not applicable]

Chemical name/trade or common name	USGS laboratory parameter code	Number of detections	Number of analyses	Well(s) where chemical was detected	Primary laboratory reporting level (µg/L)	Minimum concentration of detections (µg/L)	Median concentration of detections (µg/L)	Maximum concentration of detections (µg/L)	USEPA standard or health advisory (µg/L)
Volatile organic compounds									
Acetone	81552	3	9	RR–3, RR–5, RR–8	7	E6	77	244	--
Bromodichloromethane/ Dichlorobromomethane	32101	1	9	RR–8	.05	.04	NC	.04	[1,2]80
2-Butanone/methyl ethyl ketone	81595	2	9	RR–5, RR–8	2	4	11	18	--
Tetrahydrofuran/diethylene oxide	81607	4	9	RR–3, RR–5, RR–8, RR–10	2	E1	143	1,150	--
Trichloromethane/chloroform	32106	1	9	RR–8	.02	.67	NC	.67	[1,2]80
1,2,4-Trimethylbenzene/ pseudocumene	77222	8	9	RR–3, RR–4, RR–5, RR–6 RR–7, RR–8, RR–9, RR–10	.06	E.03	.09	.21	--

[1] U.S. Environmental Protection Agency Maximum Contaminant Level (MCL) (U.S. Environmental Protection Agency, 2006).

[2] Total for all trihalomethanes combined cannot exceed 80 µg/L (U.S. Environmental Protection Agency, 2006).

VOCs at relatively large concentrations, indicate that these materials may inadvertently be the source.

Acetone was detected only in wells where one or both other solvents (tetrahydrofuran and methyl ethyl ketone) were detected. If VOC-based solvents (for example, PVC glues, primers, or cleaners) were used to either clean or chemically join well casing, it is possible that the three acetone detections also could be attributed to the same source. Although acetone is not commonly described as a common solvent in PVC glues and primers, review of some online materials safety data sheets showed that many solvent-based glues, primers, and cleaners were mixtures of many different VOCs. Consequently, the authors speculate that acetone may have been a compound mixed with tetrahydrofuran and (or) methyl ethyl ketone, if it is assumed that a VOC-based solvent was used to clean and (or) join well casing, but local sources at the land surface for the three VOCs cannot be ruled out.

Summary of Extent of Possible Water-Quality Effects from Human Activities in the Red Lodge, Mont., Study Area

As described previously, the effects of human activities on shallow ground-water quality are indicated in the Red Lodge study area; however, the results of the study indicate that the shallow ground water is suitable for all uses without treatment, and effects from human activities (ground-water contamination) generally were minimal and limited in areal extent at the time of sampling (2001).

Evidence of ground-water contamination by human activities was indicated by VOC detections. Ground water from 4 of 9 wells sampled had mixtures of two or more VOCs. However, as noted previously, the authors speculate that many of the VOC detections may be attributable to well construction rather than ground-water contamination. If it is assumed this was the case, 1,2,4-trimethylbenzene was the only VOC detected throughout the Red Lodge study area (detected in water from 8 of 9 wells), and the VOC accounted for 42 percent of VOC detections. Most of the detections were measured at trace concentrations (less than 0.1 µg/L), and the source of this VOC in the study area is unknown.

CFC age-dating (see "Hydrogeology and Apparent Ground-Water Age" section of report) indicated much of the water sampled in the shallow aquifers in the Red Lodge study area had been recharged during the mid-1980s to early 1990s. Chemical constituents in shallow ground water in 2001 may, therefore, not yet reflect low-density (rural ranchette) development surrounding the Red Lodge study area during the past decade. Although low-density development is continuing in and near the Red Lodge study area, land use appears relatively stable and most observed changes in the study area were small and localized. Consequently, the detection of relatively few chemical constituents indicative of contamination by human activities may indicate that overlying unsewered low-density development that occurred in the past has had minimal effects on underlying ground-water quality. Continued monitoring likely would be necessary to determine effects on water quality from increasing low-density development over time.

Comparison of Study Areas in Relation to Possible Ground-Water-Quality Effects from Human Activities

Although some inorganic constituents were detected infrequently in ground water at the three study areas at concentrations larger than USEPA drinking-water standards or proposed standards, natural factors such as geology, aquifer properties, and ground-water recharge rates likely influence most concentrations of these constituents. These inorganic constituents generally occur naturally and were more likely to limit suitability of water for drinking or other intended uses rather than any constituents suspected of being introduced as a result of human activities.

Evidence of ground-water contamination by human activities in all three study areas was indicated primarily by detection of organic compounds in monitoring wells installed for this study. Twenty-one different organic compounds (9 pesticides and 12 VOCs) were detected in the three study areas, and the compounds detected generally differed among study areas.

One or more pesticides were detected in both the Sheridan and Lander study areas (both located in Wyoming), whereas one or more VOCs were detected in all three study areas. Most organic compounds were detected in water from one or two wells in a given study area, and most were detected at trace-level concentrations (less than or equal to 0.1 µg/L); this indicates most organic compounds detected were likely present as a contaminant in shallow ground water in the immediate vicinity of the sampled well. Two pesticides (prometon and tebuthiuron) and two VOCs (chloroform and 1,2,4-trimethylbenzene) were detected in more than one study area. Of the four organic compounds detected in more than one study area, the pesticides prometon and tebuthiuron were detected in water from at least one well in the Sheridan and Lander study areas, whereas the VOC 1,2,4-trimethylbenzene was detected in water from at least one well in the Lander and Red Lodge study areas.

The VOC chloroform (trichloromethane) was the only organic compound detected in water from at least one well from each study area; it was detected in water from one well in both the Lander and Red Lodge study areas and in water from two wells in the Sheridan study area. Concentrations of chloroform detected in water from the two wells in the Sheridan study area were small (both estimated concentrations less than 0.05 µg/L), whereas concentrations in water from one well in the Lander study area (0.12 µg/L) and in water from one well in the Red Lodge study area (0.67 µg/L) were larger than most detected VOCs. Chloroform was the most frequently detected VOC in ground water from rural, self-supplied domestic wells in the United States (Moran and others, 2002). In a recent national assessment of VOCs in ground water conducted as part of the NAWQA Program, chloroform was the most frequently detected VOC in major aquifers of the United States (Zogorski and others, 2006).

The pesticide prometon was the only organic compound in this study that was detected frequently enough in a given study area, and in more than one study area, that indicated any widespread contamination of unconsolidated-deposit aquifers by human activities. As noted previously, prometon is an herbicide not registered for agricultural use, but is applied in small amounts for nonagricultural general-use weed-control purposes, often in urban areas. Prometon was the most frequently detected organic compound, and the pesticide was detected in water from 8 of 10 wells sampled for the compound in the Sheridan study area and in water from 5 of 9 wells sampled for the compound in the Lander study area. Although detected frequently in the Sheridan and Lander study areas, all measured prometon concentrations were small (less than 0.05 μg/L) and were much less than the USEPA lifetime HAL (100 μg/L). In fact, 10 of 13 prometon detections were small enough to be reported as estimated concentrations. The pesticide was detected only in the Wyoming study areas, and was not detected in water from any of the nine wells sampled for the compound in the Red Lodge (Montana) study area.

Whether the frequent detection of prometon is due to the amount of pesticide use in the study areas, vulnerability and (or) susceptibility of the aquifers in the study areas, or other reasons is unknown. However, pesticides were not detected in water sampled from wells in the Red Lodge study area, whereas several pesticides were detected in both Wyoming study areas. Nationally, prometon is one of the most frequently detected pesticides in ground water from both urban and agricultural (nonagricultural use) land-use areas, as well as in ground water from major aquifers throughout the United States (Gilliom and others, 2006). Frequent detection of the pesticide during this study is not surprising and is consistent with likely use in the mixed land use (characteristics of both urban and agricultural land use) mapped during this study. Frequent detection of prometon in ground water may be due to physical properties, because the pesticide is persistent (based on soil half-life), highly soluble, and mobile (Gilliom and others, 2006, and references therein), and the depth to ground water was shallow in both Wyoming study areas.

Summary

The quality of shallow ground water underlying unsewered low-density development outside of Sheridan and Lander, Wyo., and Red Lodge, Mont., was evaluated. In 2001, 29 wells (10 each in Sheridan and Lander, Wyo., and 9 in Red Lodge, Mont.) were installed at or near the water table. These wells were sampled for a wide variety of constituents—chlorofluorocarbons (CFCs), tritium, stable isotopes of oxygen, hydrogen, and nitrogen, physical characteristics, major ions, trace elements, radon-222 (radon), nutrients, dissolved organic carbon (DOC), coliform bacteria, methylene blue active substances, pesticides, and volatile organic compounds (VOCs)—to characterize current (2001) water-quality conditions and more importantly, to identify potential effects of human activities on shallow ground-water quality resulting from development on the land surface. All wells were completed in unconfined aquifers in unconsolidated deposits of Quaternary age with shallow water tables (less than 50 feet below land surface). This U.S. Geological Survey National Water-Quality Assessment ground-water study was conducted to examine the effects of unsewered low-density development that often surrounds cities and towns of many different sizes in the western United States—a type of development that often is informally referred to as “exurban” or “rural ranchette” development. This type of development has both urban and rural characteristics. Residents in these developments typically rely on a private ground-water well for domestic water supply and a private septic system for waste disposal.

Because land use and land cover (land use) can influence the presence and distribution of constituents in shallow ground water, land use was mapped at great detail within a 500-meter (m) (1,640-feet) radius around each installed monitoring well using a combination of aerial photographs and onsite reconnaissance/surveys. Onsite surveys also were conducted within the 500-m radius surrounding each well to locate and inventory potential sources of contamination, such as fuel storage, septic systems, and above-ground storage tanks. Agricultural practices within the radii, such as animal grazing, type/source of irrigation water, pesticide/fertilizer application, crop type, and lawn/garden practices were inventoried where possible. Mapping indicated that land uses near most wells commonly included both urban and rural characteristics.

Although the quality of shallow ground water generally was suitable for domestic or other uses without treatment, some inorganic constituents were detected in ground water from the Sheridan and Lander study areas at concentrations larger than U.S. Environmental Protection Agency (USEPA) drinking-water standards or proposed standards. Concentrations of sulfate were larger than the USEPA Secondary Maximum Contaminant Level (SMCL) of 250 milligrams per liter (mg/L) in water from 3 wells in the Sheridan study area and 5 wells in the Lander study area. Dissolved-solids concentrations frequently were large in both study areas, and the USEPA SMCL of 500 mg/L was exceeded in water from six wells in both the Sheridan and Lander study areas. Several trace elements were detected infrequently in the Sheridan study area (manganese and uranium) and Lander study area (boron, iron, and manganese) at concentrations greater than USEPA standards or recommendations. Radon concentrations in water from all 29 wells were larger than the proposed USEPA Maximum Contaminant Level (MCL) of 300 picocuries per liter (pCi/L), and radon concentrations in water from 2 wells in the Lander study area were larger than the proposed USEPA alternate MCL of 4,000 pCi/L. Natural factors such as geology, aquifer properties, and ground-water recharge rates likely influence most concentrations of these constituents. These inorganic constituents generally occur naturally in the study areas and were more likely to limit suitability of water for drinking or other intended uses rather than any constituents suspected of being introduced as a result of human activities.

Effects of human activities associated with low-density development such as septic systems; fertilizer and pesticide use on pastures, lawns and gardens; manure from horses, cattle, and pets; and increases in road construction and vehicular traffic were minimal at the time of sampling (2001) but were indicated by the presence of several types of constituents in shallow ground water in some areas.

Concentrations of nitrate in ground water from all three study areas generally were less than a nationwide background level (1.1 milligrams per liter) assumed to indicate effects from human activities. Total coliform bacteria were detected infrequently (in water from 2 wells from the Sheridan study area and 1 well in the Lander study area), and *Escherichia coli* were never detected. Trace concentrations of methylene blue active substances—ingredients in laundry detergents—were detected at or slightly above laboratory reporting levels in 5 wells in the Sheridan study area, 4 wells in the Lander study area, and 2 wells in the Red Lodge study area; however, it is unclear if the detections are indicative of natural sources or possible aquifer contamination from septic-tank effluent.

Evidence of possible ground-water contamination by human activities in all three study areas was indicated primarily by detection of organic compounds in monitoring wells installed for this study. Twenty-one different organic compounds (9 pesticides and 12 VOCs) were detected in the three study areas, and the compounds detected generally differed between study areas. Pesticides were detected in both the Sheridan and Lander study areas, and VOCs were detected in all three study areas. Four different pesticides (imazethapyr, oryzalin, prometon, and tebuthiuron) and one VOC (chloroform) were detected in the Sheridan study area. Most of these organic compounds were detected infrequently in water from 1 or 2 wells, but the herbicide prometon was detected frequently, in water from 8 of 10 wells in the study area. Seven different pesticides (atrazine, carbaryl, dinoseb, fenuron, picloram, prometon, and tebuthiuron) and eight VOCs (six commonly associated with gasoline (not listed), carbon disulfide, and chloroform) were detected in the Lander study area. All of the VOCs and 5 of 7 pesticides detected in the Lander study area were found in water from 1 or 2 wells; exceptions were the herbicides prometon (5 wells) and tebuthiuron (4 wells). The VOC carbon disulfide may be naturally occurring. No pesticides were detected in the Red Lodge study area but six VOCs (3 solvents, 2 trihalomethanes, and 1,2,4-trimethylbenzene) were detected. The authors speculate that 3 of 6 VOCs detected (all three solvent detections) in the Red Lodge study area may be attributable to well construction rather than ground-water contamination, but local sources at the land surface for the three VOCs cannot be ruled out.

Most pesticides and VOCs were found in water from only a few wells in each study area, and commonly as mixtures. The primary exception to this generalization was the relatively widespread detection of the pesticide prometon at trace levels in the Sheridan and Lander study areas. The VOC chloroform (trichloromethane) was the only organic compound detected in water from at least one well from each study area; however, chloroform was not detected frequently in the study areas, as chloroform was detected in water from one well in both the Lander and Red Lodge study areas, and in water from two wells in the Sheridan study area. Concentrations of pesticides and VOCs generally were very small and always were much less than applicable drinking-water standards.

Chlorofluorocarbon age-dating indicated much of the water sampled in the shallow aquifers had been recharged during the early 1990s or earlier. Chemical constituents in shallow ground water in 2001 may, therefore, not yet reflect unsewered low-density development surrounding the Sheridan, Lander, and Red Lodge study areas during the past decade. In contrast, the detection of relatively few chemical constituents indicative of contamination by human activities could indicate that overlying unsewered low-density development that occurred in the past has had minimal effects on underlying ground-water quality. Continued monitoring is needed to determine effects on water quality from increasing development over time.

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Appendixes 1–11

Appendix 1. Land use and land cover mapped within 500-meter radius of sampled wells in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2000 and 2001.

[USGS, U.S. Geological Survey; --, not present]

Well number	USGS site-identification number	Date of land-use assessment (month/day/year)	Cropland			Agricultural infra-structure (percent)	Livestock pasture		
			Grass for hay (percent)	Alfalfa for hay (percent)	Miscellaneous (percent)		Domestic, mixed, pasture (percent)	Horses, pasture (percent)	Beef cattle, pasture (percent)
Sheridan, Wyo., study area monitoring wells									
RS–1	444554107043101	07/25/00	8.7	--	--	--	28.0	--	--
RS–2	444536107052201	07/25/00	--	--	--	--	30.6	16.8	--
RS–3	444333106571001	07/26/00	19.4	6.7	--	--	4.1	17.3	9.8
RS–4	444317106572601	04/16/01	--	--	10.5	--	9.0	9.3	14.8
RS–5	444249106572301	07/27/00	27.3	--	--	2.4	--	10.1	12.9
RS–6	444240106581401	07/26/00	27.1	5.5	--	--	16.3	22.7	--
RS–7	444225106580701	07/25/00	--	--	--	--	14.5	25.3	10.7
RS–8	444047106590901	04/16/01	8.3	--	--	--	14.7	--	--
RS–9	444012106593201	08/09/00	27.0	--	--	--	8.3	7.7	--
RS–10	443943106594001	08/09/00	36.6	--	--	9.7	12.1	--	--
Lander, Wyo., study area monitoring wells									
RL–1	425313108440701	04/19/01	16.1	--	--	--	9.8	7.4	--
RL–2	425253108434501	04/19/01	10.7	--	--	--	16.7	28.4	--
RL–3	425158108433801	04/19/01	22.5	--	--	--	10.7	23.5	18.4
RL–4	425140108430901	04/19/01	--	--	--	--	54.6	--	--
RL–5	425129108432401	04/19/01	9.2	--	--	--	63.7	--	--
RL–6	425116108430101	04/20/01	--	--	--	--	15.8	--	36.5
RL–7	425111108430501	04/19/01	--	--	--	--	9.4	--	36.1
RL–8	424830108450101	04/19/01	--	--	--	--	44.4	--	--
RL–9	424808108453101	04/19/01	--	--	--	--	8.3	7.9	--
RL–10	424751108455901	04/19/01	14.7	--	--	--	9.9	13.6	--
Red Lodge, Mont., study area monitoring wells									
RR–1	451510109134801	04/17/01	22.2	--	--	--	16.0	--	--
RR–3	450949109164601	04/17/01	--	--	--	--	--	17.9	--
RR–4	450958109162801	04/17/01	--	--	--	--	--	15.1	--
RR–5	450952109162901	04/17/01	--	--	--	--	--	3.2	--
RR–6	450949109172301	04/17/01	--	--	--	--	--	11.8	--
RR–7	450943109161701	04/17/01	--	--	--	--	--	--	--
RR–8	450935109161701	04/17/01	--	--	--	--	--	--	--
RR–9	450925109180001	04/17/01	--	--	--	--	--	--	--
RR–10	450845109163701	04/17/01	--	--	--	--	--	--	--

Appendix 1. Land use and land cover mapped within 500-meter radius of sampled wells in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2000 and 2001.—Continued

[USGS, U.S. Geological Survey; --, not present]

Grasslands		Rangeland		Wetlands		Urban			
Unmanaged (percent)	Managed (percent)	Grass (percent)	Grass, trees, shrubs (percent)	Mixed (percent)	Riparian (percent)	Residential, low density (percent)	Miscellaneous (percent)	Other (percent)	Total (percent)
Sheridan, Wyo., study area monitoring wells									
--	--	7.4	--	19.5	--	32.2	--	4.2	100.0
--	--	15.9	--	4.6	--	27.7	--	4.5	100.0
--	--	--	--	--	21.2	20.5	--	1.0	100.0
--	--	--	--	--	19.4	29.8	--	7.3	100.0
--	--	--	--	26.0	--	21.4	--	--	100.0
--	--	--	--	--	--	20.4	--	8.0	100.0
--	--	--	--	--	20.4	18.7	--	10.5	100.0
--	11.7	14.9	--	--	26.7	--	20.7	3.2	100.0
--	--	12.0	--	--	28.1	12.6	--	4.4	100.0
--	--	13.7	--	--	17.8	7.4	--	2.7	100.0
Lander, Wyo., study area monitoring wells									
--	--	32.6	--	--	25.3	6.4	--	2.3	100.0
--	--	17.5	--	--	11.3	14.0	--	1.4	100.0
--	--	--	--	--	--	19.3	--	5.6	100.0
--	--	13.6	--	--	18.2	8.0	--	5.5	100.0
--	--	--	--	--	--	13.4	9.9	3.8	100.0
--	--	--	--	--	31.2	12.4	--	4.1	100.0
--	--	--	--	--	35.9	9.6	--	9.0	100.0
--	--	8.4	--	--	25.7	11.0	--	10.6	100.0
--	--	28.5	--	--	34.6	17.2	--	3.5	100.0
--	--	24.3	--	--	23.4	14.1	--	--	100.0
Red Lodge, Mont., study area monitoring wells									
--	12.6	--	--	--	26.6	18.3	--	4.3	100.0
19.4	--	--	--	--	21.3	39.2	--	2.3	100.0
28.9	--	--	--	--	6.4	46.7	--	2.8	100.0
26.3	--	--	--	--	17.3	53.1	--	--	100.0
61.3	--	--	--	--	10.1	16.6	--	.3	100.0
20.8	--	--	--	--	33.7	43.2	--	2.3	100.0
15.1	--	--	16.8	--	41.5	26.3	--	.4	100.0
14.0	--	--	39.3	--	27.8	10.5	--	8.5	100.0
--	--	--	46.3	--	18.5	27.0	--	8.2	100.0

Appendix 2. Replicate data for major ions, trace elements, nutrients, and dissolved organic carbon in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.

[<, less than; NC, not calculated; E, estimated concentration; mg/L, milligrams per liter; C, carbon]

Well number	Constituent	Environmental sample	Replicate sample	Calculated relative percent difference
Major ions, in milligrams per liter				
RS–3	Calcium	80.7	81.9	1.5
RL–4	Calcium	73	74	1.4
RR–1	Calcium	10.7	10.7	0
RS–3	Magnesium	60.5	61.3	1.3
RL–4	Magnesium	27.2	27.8	2.2
RR–1	Magnesium	3.53	3.54	.3
RS–3	Sodium	34.7	35.7	2.8
RL–4	Sodium	45.2	46.2	2.2
RR–1	Sodium	3.2	3.2	0
RS–3	Potassium	1.86	1.9	2.1
RL–4	Potassium	3.61	3.64	.8
RR–1	Potassium	1.73	1.73	0
RS–3	Chloride	8.7	9.6	9.8
RL–4	Chloride	2.4	2.3	4.3
RR–1	Chloride	1.1	1	9.5
RS–3	Sulfate	77.6	76.5	1.4
RL–4	Sulfate	153	154	.7
RR–1	Sulfate	2.5	2.5	0
RS–3	Fluoride	.4	.5	22.2
RL–4	Fluoride	.4	.4	0
RR–1	Fluoride	<.2	<.2	NC
RS–3	Silica	11.5	11.7	1.7
RL–4	Silica	15.3	15.4	.7
RR–1	Silica	13.9	14	.7
Trace elements, in micrograms per liter unless noted otherwise				
RS–3	Aluminum	<1	<1	NC
RL–4	Aluminum	3	3	0
RR–1	Aluminum	3	3	0
RS–3	Antimony	.05	.05	0
RL–4	Antimony	.12	.12	0
RR–1	Antimony	E.04	E.04	0
RS–3	Arsenic	.2	.2	0
RL–4	Arsenic	.4	.4	0
RR–1	Arsenic	E.1	<.2	NC
RS–3	Barium	88.7	89.4	.8
RL–4	Barium	48.5	49.6	2.2
RR–1	Barium	23.5	23.9	1.7
RS–3	Boron	112	110	1.8

Appendix 2. Replicate data for major ions, trace elements, nutrients, and dissolved organic carbon in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[<, less than; NC, not calculated; E, estimated concentration; mg/L, milligrams per liter; C, carbon]

Well number	Constituent	Environmental sample	Replicate sample	Calculated relative percent difference
Trace elements, in micrograms per liter unless noted otherwise—Continued				
RL–4	Boron	128	131	2.3
RR–1	Boron	E7	E6	15.4
RS–3	Bromide (mg/L)	.07	.07	0
RL–4	Bromide (mg/L)	.02	.01	66.7
RR–1	Bromide (mg/L)	.01	<.01	NC
RS–3	Cadmium	E.03	E.02	40.0
RL–4	Cadmium	<.04	<.04	NC
RR–1	Cadmium	<.04	<.04	NC
RS–3	Chromium	<.8	<.8	NC
RL–4	Chromium	<.8	<.8	NC
RR–1	Chromium	<.8	<.8	NC
RS–3	Cobalt	.53	.49	7.8
RL–4	Cobalt	.34	.34	0
RR–1	Cobalt	.06	.05	18.2
RS–3	Copper	1.3	1.2	8.0
RL–4	Copper	2.8	2.8	0
RR–1	Copper	1.8	1.8	0
RS–3	Iron	<10	<10	NC
RL–4	Iron	<10	<10	NC
RR–1	Iron	<10	<10	NC
RS–3	Lead	<.08	<.08	NC
RL–4	Lead	<.08	<.08	NC
RR–1	Lead	<.08	<.08	NC
RS–3	Lithium	18.1	18.2	.6
RL–4	Lithium	35.5	36.4	2.5
RR–1	Lithium	.4	.3	28.6
RS–3	Manganese	150	140	6.9
RL–4	Manganese	49.6	43.3	13.6
RR–1	Manganese	.4	.4	0
RS–3	Molybdenum	1.2	1.2	0
RL–4	Molybdenum	2.1	2.1	0
RR–1	Molybdenum	.6	.6	0
RS–3	Nickel	.86	.73	16.4
RL–4	Nickel	<.06	<.06	NC
RR–1	Nickel	.73	.77	5.3
RS–3	Selenium	<.3	E.2	NC
RL–4	Selenium	<.3	<.3	NC
RR–1	Selenium	<.3	<.3	NC

Appendix 2. Replicate data for major ions, trace elements, nutrients, and dissolved organic carbon in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[<, less than; NC, not calculated; E, estimated concentration; mg/L, milligrams per liter; C, carbon]

Well number	Constituent	Environmental sample	Replicate sample	Calculated relative percent difference
Trace elements, in micrograms per liter unless noted otherwise—Continued				
RS–3	Silver	<1	<1	NC
RL–4	Silver	<1	<1	NC
RR–1	Silver	<1	<1	NC
RS–3	Strontium	455	434	4.7
RL–4	Strontium	694	712	2.6
RR–1	Strontium	74.8	74.8	0
RS–3	Thallium	<.04	<.04	NC
RL–4	Thallium	<.04	<.04	NC
RR–1	Thallium	<.04	<.04	NC
RS–3	Vanadium	.8	1.9	81.5
RL–4	Vanadium	2.1	1.9	10.0
RR–1	Vanadium	.4	.5	22.2
RS–3	Zinc	<1	<1	NC
RL–4	Zinc	1	1	0
RR–1	Zinc	<1	<1	NC
Nutrients, in milligrams per liter, and dissolved organic carbon				
RS–3	Nitrite, as nitrogen	<0.006	<0.006	NC
RL–4	Nitrite, as nitrogen	.011	.011	0
RR–1	Nitrite, as nitrogen	<.006	<.006	NC
RS–3	Nitrite + nitrate, as nitrogen	<.05	<.05	NC
RL–4	Nitrite + nitrate, as nitrogen	.057	.057	0
RR–1	Nitrite + nitrate, as nitrogen	E.04	E.042	4.9
RS–3	Ammonia, as nitrogen	<.04	<.04	NC
RL–4	Ammonia, as nitrogen	<.04	E.031	NC
RR–1	Ammonia, as nitrogen	E.024	E.026	8.0
RS–3	Ammonia + organic nitrogen, as nitrogen	.16	.16	0
RL–4	Ammonia + organic nitrogen, as nitrogen	.12	.15	22.2
RR–1	Ammonia + organic nitrogen, as nitrogen	E.1	E.06	50.0
RS–3	Phosphorus, as phosphorus	.007	.007	0
RL–4	Phosphorus, as phosphorus	.008	.01	22.2
RR–1	Phosphorus, as phosphorus	.016	.017	6.1
RS–3	Orthophosphate, as phosphorus	<.02	<.02	NC
RL–4	Orthophosphate, as phosphorus	<.02	<.02	NC
RR–1	Orthophosphate, as phosphorus	.061	E.015	121.1
RS–3	Dissolved organic carbon, mg/L as C	2.8	2.5	11.3

Appendix 2. Replicate data for major ions, trace elements, nutrients, and dissolved organic carbon in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[<, less than; NC, not calculated; E, estimated concentration; mg/L, milligrams per liter; C, carbon]

Well number	Constituent	Environmental sample	Replicate sample	Calculated relative percent difference
Nutrients, in milligrams per liter, and dissolved organic carbon—Continued				
RL–4	Dissolved organic carbon, mg/L as C	2.2	2.2	0
RR–1	Dissolved organic carbon, mg/L as C	1.5	1.4	6.9
Radionuclides, in picocuries per liter unless otherwise noted, dissolved				
RS–3	Radon-222 (unfiltered)	678	694	2.3
RL–4	Radon-222 (unfiltered)	1,390	1,370	1.4
RR–1	Radon-222 (unfiltered)	1,100	1,050	4.7
RS–3	Tritium (unfiltered)	52.8	53.1	.6
RL–4	Tritium (unfiltered)	40.6	--	NC
RR–1	Tritium (unfiltered)	--	--	NC
RS–3	Uranium (µg/L)	8.65	8.53	1.4
RL–4	Uranium (µg/L)	3.05	3.11	1.9
RR–1	Uranium (µg/L)	.35	.35	0
Other constituents, in milligrams per liter				
RS–3	Methylene blue active substances (detergents)	<0.02	<0.02	NC
RL–4	Methylene blue active substances (detergents)	.02	<.02	NC
RR–1	Methylene blue active substances (detergents)	.03	<.02	NC

Appendix 3. Analyses for dissolved gases in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.

[NAVD88, North American Vertical Datum of 1988; mg/L, milligrams per liter; --, not analyzed or reported]

Well number	Sample date (month/day/year)	Sample time (24 hour)	Temperature, field (degrees Celsius)	Recharge elevation, in feet above NAVD 88	Dissolved-gas concentration, in mg/L									
					Methane (CH_4)		Carbon dioxide (CO_2)		Nitrogen (N_2)		Oxygen (O_2)		Argon (Ar)	
					Vial 1	Vial 2	Vial 1	Vial 2	Vial 1	Vial 2	Vial 1	Vial 2	Vial 1	Vial 2
Sheridan, Wyo., study area monitoring wells														
RS–1	06/17/01	1355	12.0	3,930	0	0	32	31	17	17	3.8	5.3	0.62	0.63
RS–2	06/27/01	1255	13.5	4,000	0	0	44	44	16	16	4.0	4.1	.60	.60
RS–3	06/18/01	1330	10.0	3,900	0	0	48	49	19	19	.10	.08	.65	.64
RS–4	06/19/01	1250	11.0	3,910	0	0	33	33	18	18	1.4	1.2	.65	.65
RS–5	06/24/01	1308	9.0	3,920	0	0	58	58	20	20	.21	.16	.65	.66
RS–6	06/20/01	1235	9.0	3,950	.001	.001	38	38	2.1	2.3	.09	.08	.69	.69
RS–7	06/21/01	1100	11.0	3,950	0	0	32	32	18	18	1.5	1.5	.64	.64
RS–8	06/25/01	1604	12.0	4,080	0	0	4.0	4.0	18	18	4.4	4.4	.65	.65
RS–9	06/25/01	1125	10.0	4,100	0	0	32	33	18	18	1.3	.96	.65	.65
RS–10	06/26/01	1230	10.6	4,160	0	0	37	37	2.7	2.2	4.3	4.3	.74	.72
Lander, Wyo., study area monitoring wells														
RL–1	07/08/01	1650	13.0	5,365	0	0	16	16	18	18	0.14	0.19	0.63	0.62
RL–2	07/12/01	1025	12.0	5,345	0	0	19	19	16	16	.31	.38	.58	.58
RL–3	07/17/01	1205	11.5	5,320	0	0	34	34	2.1	2.2	.11	.62	.66	.66
RL–4	07/09/01	1350	15.0	5,290	0	0	20	2.3	19	19	.06	.09	.61	.61
[1]RL–4	07/09/01	1400	15.0	5,290	0	0	2.2	20	19	18	.09	.07	.62	.61
RL–5	07/15/01	1448	10.5	5,295	0	0	34	35	19	19	.06	.07	.65	.65
RL–6	08/06/01	1605	34.0	5,285	0	--	32	--	16	--	1.2	--	.57	--
RL–7	07/18/01	1220	13.5	5,285	0	0	4.6	40	18	18	.08	.06	.62	.62
RL–8	07/10/01	1320	15.0	5,495	0	0	34	34	18	18	1.2	1.2	.61	.61
RL–9	07/11/01	1640	13.2	5,570	0	0	27	27	18	18	.13	.08	.62	.62
RL–10	07/16/01	1215	12.0	5,590	0	0	23	23	18	18	.24	.23	.62	.62

Appendix 3. Analyses for dissolved gases in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[NAVD 88, North American Vertical Datum of 1988; mg/L, milligrams per liter; --, not analyzed or reported]

Well number	Sample date (month/ day/year)	Sample time (24 hour)	Temperature, field (degrees Celsius)	Recharge elevation, in feet above NAVD 88	Dissolved-gas concentration, in mg/L									
					Methane (CH_4)		Carbon dioxide (CO_2)		Nitrogen (N_2)		Oxygen (O_2)		Argon (Ar)	
					Vial 1	Vial 2	Vial 1	Vial 2	Vial 1	Vial 2	Vial 1	Vial 2	Vial 1	Vial 2
Red Lodge, Mont., study area monitoring wells														
RR–1	08/08/01	1215	28.5	5,265	0	0	29	29	16	16	0.11	0.26	0.57	0.57
[1]RR–1	08/08/01	1225	28.5	5,265	0	0	30	30	17	16	.13	.27	.57	.57
RR–3	09/19/01	1210	11.0	5,965	0	0	12	12	16	16	7.2	8.1	.61	.61
RR–4	09/18/01	1155	12.0	5,900	0	0	13	14	19	19	6.8	5.5	.69	.69
RR–5	09/17/01	1235	12.0	5,930	0	0	7.9	8.6	20	2	8.0	7.2	.74	.74
RR–6	09/16/01	1230	17.0	6,050	0	0	14	13	17	17	4.4	4.9	.62	.63
RR–7	08/09/01	1135	18.0	5,810	0	0	24	24	18	18	2.4	2.8	.62	.62
RR–8	09/17/01	1650	12.0	5,815	0	0	26	26	18	18	2.4	2.4	.66	.66
RR–9	09/18/01	1640	14.0	6,060	0	0	22	22	16	16	.24	.21	.57	.57
RR–10	09/19/01	1705	12.0	5,900	0	0	9.4	9.4	18	18	4.4	4.1	.61	.61

[1] Replicate sample.

Appendix 4. Analyses for radionuclides in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.

[USGS, U.S. Geological Survey; pCi/L, picocuries per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; SSMDC, sample-specific minimum detectable concentration; µg/L, micrograms per liter; ±, plus or minus; --, not analyzed or reported]

Well number	USGS site-identification number	Sample date (month/day/year)	Sample time (24 hour)	Radon-222 (pCi/L) (82303)	Radon-222, SSMDC (pCi/L) (99327)	Radon-222, precision estimate (pCi/L) (76002)	Tritium (pCi/L) (07000)	Tritium, precision estimate (pCi/L) (75985)	Uranium, natural, dissolved (µg/L) (22703)
Sheridan, Wyo., study area monitoring wells									
RS–1	444554107043101	06/17/01	1200	1,090	30	±37	48.6	±3.2	8.89
RS–2	444536107052201	06/27/01	1200	1,070	22	±30	--	--	40.5
RS–3	444333106571001	06/18/01	1100	678	32	±32	52.8	±3.2	8.65
RS–4	444317106572601	06/19/01	1200	846	28	±32	--	--	12.2
RS–5	444249106572301	06/24/01	1100	505	26	±26	--	--	19.9
RS–6	444240106581401	06/20/01	1000	1,440	28	±39	--	--	11.2
RS–7	444225106580701	06/21/01	1100	1,190	25	±34	--	--	8.65
RS–8	444047106590901	06/25/01	1500	764	26	±30	--	--	3.05
RS–9	444012106593201	06/25/01	1100	1,290	26	±37	--	--	2.12
RS–10	443943106594001	06/26/01	1000	1,390	27	±38	--	--	3.95
Lander, Wyo., study area monitoring wells									
RL–1	425313108440701	07/08/01	1600	1,840	26	±43	--	--	2.53
RL–2	425253108434501	07/12/01	1100	1,110	24	±33	--	--	3.41
RL–3	425158108433801	07/17/01	1100	900	29	±33	--	--	15.6
RL–4	425140108430901	07/09/01	1100	1,390	27	±38	40.6	±2.6	3.05
RL–5	425129108432401	07/15/01	1300	880	26	±31	--	--	28.6
RL–6	425116108430101	08/06/01	1300	774	30	±32	--	--	12
RL–7	425111108430501	07/18/01	1100	1,700	27	±41	--	--	8.81
RL–8	424830108450101	07/10/01	1300	4,180	27	±61	41.6	±2.6	1.48
RL–9	424808108453101	07/11/01	1500	4,370	27	±65	--	--	3.96
RL–10	424751108455901	07/16/01	1100	3,200	22	±50	--	--	2.23
Red Lodge, Mont., study area monitoring wells									
RR–1	451510109134801	08/08/01	1000	1,100	33	±39	--	--	0.35
RR–3	450949109164601	09/19/01	1100	637	24	±27	--	--	.02
RR–4	450958109162801	09/18/01	1100	820	24	±30	--	--	.1
RR–5	450952109162901	09/17/01	1000	737	25	±29	--	--	.06
RR–6	450949109172301	09/16/01	1200	789	24	±29	41.6	±2.6	.12
RR–7	450943109161701	08/09/01	1000	783	25	±29	--	--	.12
RR–8	450935109161701	09/17/01	1600	1,150	24	±34	45.8	±2.6	.3
RR–9	450925109180001	09/18/01	1500	1,040	24	±32	--	--	.13
RR–10	450845109163701	09/19/01	1600	1,260	23	±35	36.5	±2.6	.68

Appendix 5. Analyses for physical characteristics in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.

[USGS, U.S. Geological Survey; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; NTU, nephelometric turbidity units; mg/L, milligrams per liter]

Well number	USGS site-identification number	Sample date (month/day/year)	Sample time (24 hour)	Water temperature, field (degrees Celsius) (00010)	pH, laboratory (standard units) (00403)	pH, field (standard units) (00400)	Turbidity, field (NTU) (61028)	Dissolved oxygen, field (mg/L) (00300)
Sheridan, Wyo., study area monitoring wells								
RS–1	444554107043101	06/17/01	1200	12.0	7.5	7.4	2.9	5.6
RS–2	444536107052201	06/27/01	1200	13.5	7.3	7.2	6.1	5.7
RS–3	444333106571001	06/18/01	1100	10.0	7.4	7.3	.4	.2
RS–4	444317106572601	06/19/01	1200	11.0	7.6	7.5	12	3.2
RS–5	444249106572301	06/24/01	1100	9.0	7.4	7.3	1.7	.8
RS–6	444240106581401	06/20/01	1000	9.0	7.5	7.5	2.7	.3
RS–7	444225106580701	06/21/01	1100	11.0	7.5	7.5	4.3	3.4
RS–8	444047106590901	06/25/01	1500	12.0	7.5	7.4	5.6	5.6
RS–9	444012106593201	06/25/01	1100	10.0	7.4	7.3	1.6	1.7
RS–10	443943106594001	06/26/01	1000	10.5	7.4	7.3	2.4	5.8
Lander, Wyo., study area monitoring wells								
RL–1	425313108440701	07/08/01	1600	13.0	7.6	7.6	20	1.5
RL–2	425253108434501	07/12/01	1100	12.0	7.5	7.5	2	1.1
RL–3	425158108433801	07/17/01	1100	11.5	7.2	7.2	1.4	1.9
RL–4	425140108430901	07/09/01	1100	15.0	7.5	7.4	1.6	1.0
RL–5	425129108432401	07/15/01	1300	10.5	7.4	7.5	1.8	.2
RL–6	425116108430101	08/06/01	1300	18.0	7.4	7.2	81	3.2
RL–7	425111108430501	07/18/01	1100	13.0	7.3	7.2	4.5	1.9
RL–8	424830108450101	07/10/01	1300	15.0	7.1	7.0	2.6	3.2
RL–9	424808108453101	07/11/01	1500	13.0	7.4	7.3	40	.3
RL–10	424751108455901	07/16/01	1100	12.0	7.3	7.3	1.2	1.0
Red Lodge, Mont., study area monitoring wells								
RR–1	451510109134801	08/08/01	1000	16.0	6.8	6.5	2	2.8
RR–3	450949109164601	09/19/01	1100	11.5	7.1	6.8	1.3	7.8
RR–4	450958109162801	09/18/01	1100	12.0	7.4	7.0	.5	6.9
RR–5	450952109162901	09/17/01	1000	9.0	7.1	7.1	3.8	7.6
RR–6	450949109172301	09/16/01	1200	9.5	7.5	7.4	1.8	8.7
RR–7	450943109161701	08/09/01	1000	10.5	6.7	6.3	1.8	7.1
RR–8	450935109161701	09/17/01	1600	12.0	7.0	6.6	2.8	5.1
RR–9	450925109180001	09/18/01	1500	14.0	6.8	6.4	1.8	2.0
RR–10	450845109163701	09/19/01	1600	12.0	7.5	7.2	2.9	5.9

Appendix 6. Analyses for major ions and related water-quality characteristics in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.

[USGS, U.S. Geological Survey; mg/L, milligrams per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; HCO_3, bicarbonate; $CaCO_3$, calcium carbonate]

Well number	USGS site-identification number	Sample date (month/day/year)	Sample time (24 hour)	Calcium, dissolved (mg/L) (00915)	Magnesium, dissolved (mg/L) (00925)	Sodium, dissolved (mg/L) (00930)	Sodium adsorption ratio (SAR) (00931)	Potassium, dissolved (mg/L) (00935)	Bicarbonate, dissolved (mg/L as HCO_3) (00453)	Chloride, dissolved (mg/L) (00935)	Sulfate, dissolved (mg/L) (00945)	Dissolved solids[1] (mg/L) (70300)	Hardness, total (mg/L as $CaCO_3$) (00900)
Sheridan, Wyo., study area monitoring wells													
RS–1	444554107043101	06/17/01	1200	118	62.6	56.1	1	2.82	460	9.4	271	828	550
RS–2	444536107052201	06/27/01	1200	120	88.7	89.2	2	2.86	458	2.4	464	1,100	660
RS–3	444333106571001	06/18/01	1100	80.7	60.5	34.7	.7	1.86	510	8.7	77.6	563	450
RS–4	444317106572601	06/19/01	1200	54.9	78.3	30.7	.6	1.87	573	6.2	61.8	572	460
RS–5	444249106572301	06/24/01	1100	116	127	69.1	1	3.29	626	<.1	366	1,100	810
RS–6	444240106581401	06/20/01	1000	88.1	70.1	39.2	.8	2.26	592	3.8	134	674	510
RS–7	444225106580701	06/21/01	1100	55.2	58.3	24.9	.6	1.25	460	5.1	49.5	456	380
RS–8	444047106590901	06/25/01	1500	86.0	33.3	13.8	.3	1.74	376	2.1	74.0	434	350
RS–9	444012106593201	06/25/01	1100	68.9	25.6	8.6	.2	1.4	320	2.3	25.1	320	280
RS–10	443943106594001	06/26/01	1000	58.0	45.1	17	.4	1.94	410	2.6	20.2	371	330
Lander, Wyo., study area monitoring wells													
RL–1	425313108440701	07/08/01	1600	71.3	21.2	12.3	0.3	3.67	280	2.8	48.5	334	270
RL–2	425253108434501	07/12/01	1100	68.7	24.6	13.5	.4	5.48	310	1.8	47.8	340	270
RL–3	425158108433801	07/17/01	1100	198	58.4	57.3	.9	4.17	317	3.2	608	1,210	740
RL–4	425140108430901	07/09/01	1100	73.0	27.2	45.2	1	3.61	277	2.4	153	492	300
RL–5	425129108432401	07/15/01	1300	253	158	377	5	6.85	467	11.8	1,590	2,850	1,300
RL–6	425116108430101	08/06/01	1300	354	170	243	3	10.1	383	31.8	1,780	3,180	1,600
RL–7	425111108430501	07/18/01	1100	147	58.9	46.4	.8	2.93	384	5	401	966	610
RL–8	424830108450101	07/10/01	1300	44.1	15.6	6.9	.2	1.91	157	1.9	46.7	227	170
RL–9	424808108453101	07/11/01	1500	106	35.6	20.3	.4	2.46	285	6	207	583	410
RL–10	424751108455901	07/16/01	1100	149	33.1	7.8	.1	2.02	223	1.8	328	713	510

Appendix 6. Analyses for major ions and related water-quality characteristics in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[USGS, U.S. Geological Survey; mg/L, milligrams per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; HCO_3, bicarbonate; $CaCO_3$, calcium carbonate]

Well number	USGS site-identification number	Sample date (month/day/year)	Sample time (24 hour)	Calcium, dissolved (mg/L) (00915)	Magnesium, dissolved (mg/L) (00925)	Sodium, dissolved (mg/L) (00930)	Sodium adsorption ratio (SAR) (00931)	Potassium, dissolved (mg/L) (00935)	Bicarbonate, dissolved (mg/L as HCO_3) (00453)	Chloride, dissolved (mg/L) (00935)	Sulfate, dissolved (mg/L) (00945)	Dissolved solids[1] (mg/L) (70300)	Hardness, total (mg/L as $CaCO_3$) (00900)
Red Lodge, Mont., study area monitoring wells													
RR–1	451510109134801	08/08/01	1000	10.7	3.53	3.2	0.2	1.73	41	1.1	2.5	79	41
RR–3	450949109164601	09/19/01	1100	6.79	3.21	1.9	.2	.83	38	.4	2.1	40	30
RR–4	450958109162801	09/18/01	1100	13.1	4.06	1.3	.1	.63	56	.7	2.2	61	49
RR–5	450952109162901	09/17/01	1000	8.33	3.25	1.3	.1	.77	41	.7	2.5	49	34
RR–6	450949109172301	09/16/01	1200	30.9	6.47	1.5	.1	.66	122	1.3	3.2	121	100
RR–7	450943109161701	08/09/01	1000	9.39	3.55	1.7	.1	.84	56	.6	2.4	67	38
RR–8	450935109161701	09/17/01	1600	9.79	3.38	2.9	.2	1.14	46	1.3	4.2	58	38
RR–9	450925109180001	09/18/01	1500	6.27	1.82	1.6	.1	.79	29	.2	2.5	36	23
RR–10	450845109163701	09/19/01	1600	16.4	3.64	1.3	.1	1.22	66	.3	2.5	63	56

[1] Measured residue on evaporation at 180 degrees Celsius.

Appendix 7. Analyses for trace elements in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.

[USGS, U.S. Geological Survey; µg/L, micrograms per liter; mg/L, milligrams per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than; E, estimated concentration; M, constituent detected but not quantified]

Well number	USGS site-identification number	Sample date (month/day/year)	Sample time (24 hour)	Aluminum, dissolved (µg/L) (01106)	Antimony, dissolved (µg/L) (01095)	Arsenic, dissolved (µg/L) (01000)	Barium, dissolved (µg/L) (01005)	Beryllium, dissolved (µg/L) (01010)	Boron, dissolved (µg/L) (01020)	Bromide, dissolved (mg/L) (71870)	Cadmium, dissolved (µg/L) (01025)	Chromium, dissolved (µg/L) (01030)	Cobalt, dissolved (µg/L) (01035)
Sheridan, Wyo., study area monitoring wells													
RS–1	444554107043101	06/17/01	1200	<1	E0.04	0.3	69.7	<0.06	100	0.04	<0.04	<0.8	0.31
RS–2	444536107052201	06/27/01	1200	<1	.06	.7	16.1	<.06	220	.02	E.03	2	.34
RS–3	444333106571001	06/18/01	1100	<1	.05	.2	88.7	<.06	112	.07	E.03	<.8	.53
RS–4	444317106572601	06/19/01	1200	<1	.09	.3	116	<.06	137	.07	<.04	.9	.12
RS–5	444249106572301	06/24/01	1100	<1	E.04	.2	74.1	<.06	249	.04	<.04	<.8	.22
RS–6	444240106581401	06/20/01	1000	1	.06	.2	55.7	<.06	108	.04	<.04	<.8	.49
RS–7	444225106580701	06/21/01	1100	<1	.06	E.2	94.1	<.06	107	.02	.07	E.8	.12
RS–8	444047106590901	06/25/01	1500	2	.06	.2	46.6	<.06	50	<.01	<.04	E.7	.24
RS–9	444012106593201	06/25/01	1100	1	.05	E.1	76.6	<.06	24	<.01	<.04	E.6	.15
RS–10	443943106594001	06/26/01	1000	<1	E.05	.3	105	<.06	57	.01	E.02	1.2	.2
Lander, Wyo., study area monitoring wells													
RL–1	425313108440701	07/08/01	1600	1	0.11	0.7	123	<0.06	27	<0.01	<0.04	<0.8	0.3
RL–2	425253108434501	07/12/01	1100	1	.09	.2	102	<.06	40	<.01	<.04	<.8	.95
RL–3	425158108433801	07/17/01	1100	1	.08	.6	29	<.06	210	.01	<.04	E.5	1.45
RL–4	425140108430901	07/09/01	1100	3	.12	.4	48.5	<.06	128	.02	<.04	<.8	.34
RL–5	425129108432401	07/15/01	1300	<2	E.08	.8	8.7	<.1	722	.1	E.04	1.2	1.13
RL–6	425116108430101	08/06/01	1300	<1	.08	.5	11.5	<.06	254	.11	.05	2.2	1.9
RL–7	425111108430501	07/18/01	1100	<1	E.04	.8	23.5	<.06	148	.03	<.04	E.5	.43
RL–8	424830108450101	07/10/01	1300	2	E.05	E.1	39.8	<.06	23	<.01	E.03	E.5	2.6
RL–9	424808108453101	07/11/01	1500	1	E.03	.3	77.4	<.06	73	.02	E.02	<.8	17.6
RL–10	424751108455901	07/16/01	1100	1	E.03	.7	35.9	<.06	40	.02	.07	E.7	.61
Red Lodge, Mont., study area monitoring wells													
RR–1	451510109134801	08/08/01	1000	3	E0.04	E0.1	23.5	<0.06	E7	0.01	<0.04	<0.8	0.06
RR–3	450949109164601	09/19/01	1100	<1	E.03	E.1	6.9	<.06	23	<.01	<.04	<.8	.17
RR–4	450958109162801	09/18/01	1100	<1	<.05	<.2	7.6	<.06	<7	.01	<.04	<.8	.04

Appendix 7. Analyses for trace elements in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[USGS, U.S. Geological Survey; µg/L, micrograms per liter; mg/L, milligrams per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than; E, estimated concentration; M, constituent detected but not quantified]

Well number	USGS site-identification number	Sample date (month/ day/year)	Sample time (24 hour)	Aluminum, dissolved (µg/L) (01106)	Antimony, dissolved (µg/L) (01095)	Arsenic, dissolved (µg/L) (01000)	Barium, dissolved (µg/L) (01005)	Beryllium, dissolved (µg/L) (01010)	Boron, dissolved (µg/L) (01020)	Bromide, dissolved (mg/L) (71870)	Cadmium, dissolved (µg/L) (01025)	Chromium, dissolved (µg/L) (01030)	Cobalt, dissolved (µg/L) (01035)
Red Lodge, Montana study area monitoring wells—continued													
RR–5	450952109162901	09/17/01	1000	1	0.07	<0.2	5.6	<0.06	8	<0.01	<0.04	<0.8	0.15
RR–6	450949109172301	09/16/01	1200	1	.06	E.1	15.3	E.04	E4	<.01	<.04	.8	.11
RR–7	450943109161701	08/09/01	1000	<1	<.05	<.2	16.9	<.06	E4	.02	<.04	<.8	.15
RR–8	450935109161701	09/17/01	1600	2	<.05	<.2	15.8	<.06	<7	<.01	<.04	<.8	.08
RR–9	450925109180001	09/18/01	1500	2	<.05	<.2	10.8	<.06	<7	<.01	<.04	<.8	.03
RR–10	450845109163701	09/19/01	1600	1	E.03	E.1	21.5	<.06	32	<.01	<.04	<.8	.05

Well number	USGS site-identification number	Sample date (month/ day/year)	Sample time (24 hour)	Copper, dissolved (µg/L) (01040)	Iron, dissolved (µg/L) (01046)	Lead, dissolved (µg/L) (01049)	Lithium, dissolved (µg/L) (01130)	Manganese, dissolved (µg/L) (01056)	Molybdenum, dissolved (µg/L) (01060)	Nickel, dissolved (µg/L) (01065)	Selenium, dissolved (µg/L) (01145)	Silica, dissolved (mg/L) (00955)	Silver, dissolved (µg/L) (01075)
Sheridan, Wyo., study area monitoring wells													
RS–1	444554107043101	06/17/01	1200	2.1	<10	<0.08	23.5	0.2	0.3	1.03	1	11.1	<1
RS–2	444536107052201	06/27/01	1200	4.5	M	.12	55.9	7	.7	3.07	6.7	13.7	<1
RS–3	444333106571001	06/18/01	1100	1.3	<10	<.08	18.1	150	1.2	.86	<.3	11.5	<1
RS–4	444317106572601	06/19/01	1200	1	<10	<.08	24	1.9	1.7	.2	.6	13.6	<1
RS–5	444249106572301	06/24/01	1100	3.3	<10	E.07	19.1	29.2	1.2	.57	.9	11.2	<1
RS–6	444240106581401	06/20/01	1000	1.1	120	<.08	18.1	146	3.6	1.06	<.3	11.9	<1
RS–7	444225106580701	06/21/01	1100	1	<10	.11	21	.3	1.3	.23	<.3	14.7	<1
RS–8	444047106590901	06/25/01	1500	1.2	<10	<.08	8	E.1	.4	.66	.5	10.7	<1
RS–9	444012106593201	06/25/01	1100	.7	<10	<.08	5	6.5	.4	.6	.4	12.8	<1
RS–10	443943106594001	06/26/01	1000	2.5	<10	.1	10.5	.9	.6	.87	1.1	14.3	<1
Lander, Wyo., study area monitoring wells													
RL–1	425313108440701	07/08/01	1600	1.2	<10	<0.08	9.1	43.8	1.2	0.87	E0.2	12	<1
RL–2	425253108434501	07/12/01	1100	11.7	<10	<.08	12.4	E.1	1.6	<.06	<.3	14.1	<1
RL–3	425158108433801	07/17/01	1100	4.1	<10	<.08	84.6	.5	1.3	<.3	1.5	13.3	<1

Appendix 7. Analyses for trace elements in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[USGS, U.S. Geological Survey; µg/L, micrograms per liter; mg/L, milligrams per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than; E, estimated concentration; M, constituent detected but not quantified]

Well number	USGS site-identification number	Sample date (month/day/year)	Sample time (24 hour)	Copper, dissolved (µg/L) (01040)	Iron, dissolved (µg/L) (01046)	Lead, dissolved (µg/L) (01049)	Lithium, dissolved (µg/L) (01130)	Man-ganese, dissolved (µg/L) (01056)	Molyb-denum, dissolved (µg/L) (01060)	Nickel, dissolved (µg/L) (01065)	Selenium, dissolved (µg/L) (01145)	Silica, dissolved (mg/L) (00955)	Silver, dissolved (µg/L) (01075)
Lander, Wyo., study area monitoring wells—continued													
RL–4	425140108430901	07/09/01	1100	2.8	<10	<0.08	35.5	49.6	2.1	<0.06	<0.3	15.3	<1
RL–5	425129108432401	07/15/01	1300	8.7	<30	<.2	356	367	6.6	1.31	4.5	24.6	<2
RL–6	425116108430101	08/06/01	1300	6.9	10	<.08	103	1,550	8.3	2.38	.9	15.4	<1
RL–7	425111108430501	07/18/01	1100	2.4	650	<.08	44.2	519	3.2	<.3	<.3	15.8	<1
RL–8	424830108450101	07/10/01	1300	.9	<10	<.08	3.8	16.9	1.2	.85	<.3	11.2	<1
RL–9	424808108453101	07/11/01	1500	72.2	260	<.08	6.6	510	1.4	<.06	<.3	15.3	<1
RL–10	424751108455901	07/16/01	1100	2.6	110	<.08	11.8	45.3	2.7	1.36	.7	15.7	<1
Red Lodge, Mont., study area monitoring wells													
RR–1	451510109134801	08/08/01	1000	1.8	<10	<0.08	0.4	0.4	0.6	0.73	<0.3	13.9	<1
RR–3	450949109164601	09/19/01	1100	1.3	<10	.13	.7	9.3	<.2	.26	<.3	10.3	<1
RR–4	450958109162801	09/18/01	1100	.6	<10	<.08	.6	.1	E.1	<.06	<.3	8.9	<1
RR–5	450952109162901	09/17/01	1000	1.1	70	<.08	.5	13.8	E.2	.21	<.3	9.6	<1
RR–6	450949109172301	09/16/01	1200	.4	<10	<.08	.7	5.6	<.2	<.06	<.3	9.9	<1
RR–7	450943109161701	08/09/01	1000	<.2	<10	<.08	.9	1.6	E.2	.36	<.3	12.2	<1
RR–8	450935109161701	09/17/01	1600	.7	<10	<.08	.8	.4	.3	.32	<.3	12.1	<1
RR–9	450925109180001	09/18/01	1500	.5	<10	<.08	.6	.9	.2	.16	<.3	7.5	<1
RR–10	450845109163701	09/19/01	1600	.5	<10	E.08	1	2.4	.7	.21	<.3	5.9	<1

Appendix 7. Analyses for trace elements in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[USGS, U.S. Geological Survey; µg/L, micrograms per liter; mg/L, milligrams per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than; E, estimated concentration; M, constituent detected but not quantified]

Well number	USGS site-identification number	Sample date (month/day/year)	Sample time (24 hour)	Strontium, dissolved (µg/L) (01080)	Thallium, dissolved (µg/L) (01057)	Vanadium, dissolved (µg/L) (01085)	Zinc, dissolved (µg/L) (01090)
Sheridan, Wyo., study area monitoring wells							
RS–1	444554107043101	06/17/01	1200	480	<0.04	3.6	1
RS–2	444536107052201	06/27/01	1200	462	<.04	E.1	2
RS–3	444333106571001	06/18/01	1100	455	<.04	.8	<1
RS–4	444317106572601	06/19/01	1200	542	.11	1.5	<1
RS–5	444249106572301	06/24/01	1100	1,150	<.04	1.1	2
RS–6	444240106581401	06/20/01	1000	559	<.04	<.2	<1
RS–7	444225106580701	06/21/01	1100	416	<.04	.5	<1
RS–8	444047106590901	06/25/01	1500	372	<.04	.4	<1
RS–9	444012106593201	06/25/01	1100	271	<.04	E.1	1
RS–10	443943106594001	06/26/01	1000	577	<.04	.4	2
Lander, Wyo., study area monitoring wells							
RL–1	425313108440701	07/08/01	1600	421	<0.04	2.1	<1
RL–2	425253108434501	07/12/01	1100	488	.04	1.7	<1
RL–3	425158108433801	07/17/01	1100	2,070	<.04	1.2	3
RL–4	425140108430901	07/09/01	1100	694	<.04	2.1	1
RL–5	425129108432401	07/15/01	1300	3,550	<.08	1.2	5
RL–6	425116108430101	08/06/01	1300	2,370	<.04	.5	7
RL–7	425111108430501	07/18/01	1100	1,990	<.04	E.1	2
RL–8	424830108450101	07/10/01	1300	422	<.04	.5	<1
RL–9	424808108453101	07/11/01	1500	1,030	E.03	.6	4
RL–10	424751108455901	07/16/01	1100	1,520	<.04	2.2	2

Appendix 7. Analyses for trace elements in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[USGS, U.S. Geological Survey; µg/L, micrograms per liter; mg/L, milligrams per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than; E, estimated concentration; --, not analyzed; M, constituent detected but not quantified]

Well number	USGS site-identification number	Sample date (month/day/year)	Sample time (24 hour)	Strontium, dissolved (µg/L) (01080)	Thallium, dissolved (µg/L) (01057)	Vanadium, dissolved (µg/L) (01085)	Zinc, dissolved (µg/L) (01090)
Red Lodge, Mont., study area monitoring wells							
RR–1	451510109134801	08/08/01	1000	74.8	<0.04	0.4	<1
RR–3	450949109164601	09/19/01	1100	26.2	<.04	E.2	4
RR–4	450958109162801	09/18/01	1100	37.0	<.04	.2	<1
RR–5	450952109162901	09/17/01	1000	31.2	<.04	E.2	4
RR–6	450949109172301	09/16/01	1200	39.1	E.02	.3	<1
RR–7	450943109161701	08/09/01	1000	48.6	<.04	.3	<1
RR–8	450935109161701	09/17/01	1600	56.7	<.04	.3	1
RR–9	450925109180001	09/18/01	1500	24.7	<.04	E.2	3
RR–10	450845109163701	09/19/01	1600	52.0	<.04	.5	2

Appendix 8. Analyses for nutrients and dissolved organic carbon in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.

[USGS, U.S. Geological Survey; mg/L, milligrams per liter; N, nitrogen; P, phosphorus; C, carbon; $\delta^{15}N$, nitrogen-15/nitrogen-14 isotopic ratio; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than; E, estimated concentration; --, not analyzed or reported]

Well number	USGS site-identification number	Sample date (month/day/year)	Sample time (24 hour)	Nitrite, dissolved (mg/L as N) (00613)	Nitrate plus nitrite, dissolved (mg/L as N) (00631)	Ammonia, dissolved (mg/L as N) (00608)	Ammonia plus organic nitrogen, dissolved (mg/L as N) (00623)	Phosphorus, dissolved (mg/L as P) (00666)	Orthophosphate, dissolved (mg/L as P) (00671)	Dissolved organic carbon, (mg/L as C) (00681)	$\delta^{15}N$ (per mil) (82690)
Sheridan, Wyo., study area monitoring wells											
RS–1	444554107043101	06/17/01	1200	<0.006	1.38	<0.04	0.13	E0.004	<0.02	1.7	11.3
RS–2	444536107052201	06/27/01	1200	<.006	1.29	.048	.19	.015	E.009	--	8.1
RS–3	444333106571001	06/18/01	1100	<.006	<.05	<.04	.16	.007	<.02	2.8	--
RS–4	444317106572601	06/19/01	1200	E.003	.487	<.04	.17	.01	<.02	1.8	6.8
RS–5	444249106572301	06/24/01	1100	E.005	.16	E.023	.16	<.006	<.02	3.6	14.1
RS–6	444240106581401	06/20/01	1000	<.006	<.05	<.04	.12	E.006	E.009	2.9	--
RS–7	444225106580701	06/21/01	1100	<.006	.202	<.04	.14	.008	E.015	2.4	6.5
RS–8	444047106590901	06/25/01	1500	E.005	.262	E.023	E.08	.01	E.011	1.4	10.8
RS–9	444012106593201	06/25/01	1100	E.005	E.037	E.026	<.1	<.006	<.02	--	--
RS–10	443943106594001	06/26/01	1000	E.004	.518	<.04	<.1	.009	<.02	1.2	7.3
Lander, Wyo., study area monitoring wells											
RL–1	425313108440701	07/08/01	1600	0.012	0.167	<0.04	0.11	0.023	0.025	1.5	9.7
RL–2	425253108434501	07/12/01	1100	<.006	.053	<.04	.11	E.004	<.02	1.8	--
RL–3	425158108433801	07/17/01	1100	<.006	.181	<.04	.14	.028	.022	2.4	--
RL–4	425140108430901	07/09/01	1100	.011	.057	<.04	.12	.008	<.02	2.2	--
RL–5	425129108432401	07/15/01	1300	.015	.202	<.04	.21	.008	<.02	4.6	--
RL–6	425116108430101	08/06/01	1300	.01	.177	E.038	.34	E.004	<.02	4.5	23
RL–7	425111108430501	07/18/01	1100	.008	<.05	<.04	.13	E.005	<.02	2.1	--
RL–8	424830108450101	07/10/01	1300	<.006	.065	<.04	E.08	.008	<.02	1.3	--
RL–9	424808108453101	07/11/01	1500	E.004	E.026	<.04	<.1	E.005	<.02	1.4	--
RL–10	424751108455901	07/16/01	1100	.008	.099	<.04	E.07	.016	<.02	2.2	--

Appendix 8. Analyses for nutrients and dissolved organic carbon in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[USGS, U.S. Geological Survey; mg/L, milligrams per liter; N, nitrogen; P, phosphorus; C, carbon; $\delta^{15}N$, nitrogen-15/nitrogen-14 isotopic ratio; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than; E, estimated concentration; --, not analyzed or reported]

Well number	USGS site-identification number	Sample date (month/day/year)	Sample time (24 hour)	Nitrite, dissolved (mg/L as N) (00613)	Nitrate plus nitrite, dissolved (mg/L as N) (00631)	Ammonia, dissolved (mg/L as N) (00608)	Ammonia plus organic nitrogen, dissolved (mg/L as N) (00623)	Phosphorus, dissolved (mg/L as P) (00666)	Orthophosphate, dissolved (mg/L as P) (00671)	Dissolved organic carbon, (mg/L as C) (00681)	$\delta^{15}N$ (per mil) (82690)
				Red Lodge, Mont., study area monitoring wells							
RR–1	451510109134801	08/08/01	1000	<0.006	E0.04	E0.024	E0.1	0.016	0.02	1.5	--
RR–3	450949109164601	09/19/01	1100	E.003	.21	<.04	<.1	<.006	<.02	.4	7.5
RR–4	450958109162801	09/18/01	1100	E.003	.432	<.04	<.1	<.006	<.02	.4	3.2
RR–5	450952109162901	09/17/01	1000	<.006	.278	<.04	<.1	<.006	<.02	1.2	3.9
RR–6	450949109172301	09/16/01	1200	<.006	.784	<.04	<.1	.007	<.02	2.7	3.5
RR–7	450943109161701	08/09/01	1000	<.006	.321	E.031	<.1	E.005	<.02	.47	5.7
RR–8	450935109161701	09/17/01	1600	<.006	.407	<.04	<.1	<.006	<.02	.96	6.7
RR–9	450925109180001	09/18/01	1500	<.006	E.041	<.04	<.1	E.003	<.02	.45	--
RR–10	450845109163701	09/19/01	1600	<.006	.167	<.04	<.1	E.003	<.02	E.32	5.3

Appendix 9. Analyses for bacteria and methylene blue active substances in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.

[USGS, U.S. Geological Survey; mL, milliliter; mg/L, milligrams per liter; <, less than; --, not analyzed or reported; E, estimated concentration]

Well number	USGS site-identification number	Sample date (month/day/ year)	Sample time (24 hour)	Total coliform (colonies per 100 mL)	*Escherichia coli* (colonies per 100 mL)	Methylene blue active substances (mg/L)
Sheridan, Wyo., study area monitoring wells						
RS–1	444554107043101	06/17/01	1200	<1	--	<0.02
RS–2	444536107052201	06/27/01	1200	<1	--	--
RS–3	444333106571001	06/18/01	1100	<1	--	<.02
RS–4	444317106572601	06/19/01	1200	<1	--	<.02
RS–5	444249106572301	06/24/01	1100	<1	--	E.01
RS–6	444240106581401	06/20/01	1000	E2	<1	.02
RS–7	444225106580701	06/21/01	1100	--	--	.03
RS–8	444047106590901	06/25/01	1500	<1	--	E.01
RS–9	444012106593201	06/25/01	1100	<1	--	--
RS–10	443943106594001	06/26/01	1000	E19	<1	E.12
Lander, Wyo., study area monitoring wells						
RL–1	425313108440701	07/08/01	1600	<1	--	E0.02
RL–2	425253108434501	07/12/01	1100	<1	--	--
RL–3	425158108433801	07/17/01	1100	E3	<1	<.02
RL–4	425140108430901	07/09/01	1100	<1	--	.02
RL–5	425129108432401	07/15/01	1300	<1	--	<.02
RL–6	425116108430101	08/06/01	1300	<1	--	.02
RL–7	425111108430501	07/18/01	1100	<1	--	<.02
RL–8	424830108450101	07/10/01	1300	<1	--	<.02
RL–9	424808108453101	07/11/01	1500	<1	--	.02
RL–10	424751108455901	07/16/01	1100	<1	--	<.02
Red Lodge, Mont., study area monitoring wells						
RR–1	451510109134801	08/08/01	1000	<1	--	0.03
RR–3	450949109164601	09/19/01	1100	<1	--	<.1
RR–4	450958109162801	09/18/01	1100	<1	--	<.05
RR–5	450952109162901	09/17/01	1000	<1	--	<.02
RR–6	450949109172301	09/16/01	1200	<1	--	<.02
RR–7	450943109161701	08/09/01	1000	<1	--	<.02
RR–8	450935109161701	09/17/01	1600	<1	--	.02
RR–9	450925109180001	09/18/01	1500	<1	--	<.05
RR–10	450845109163701	09/19/01	1600	<1	--	<.05

Appendix 10. Pesticides in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.

[Detection in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; --, not analyzed; E, estimated concentration; U, chemical was analyzed for, but not detected]

Well number	USGS site-identification number	Sample date (month/ day/year)	Sample time (24 hour)	Acetochlor (µg/L) P49260	Acifluorfen (µg/L) P49315	Alachlor (µg/L) P46342	Aldicarb (µg/L) P49312	Aldicarb sulfone (µg/L) P49313	Aldicarb sulfoxide (µg/L) P49314	Atrazine (µg/L) P39632	Azinphos-methyl (µg/L) P82686	Bendiocarb (µg/L) P50299
Sheridan, Wyo., study area monitoring wells												
RS–1	444554107043101	06/17/01	1200	<0.004	<0.01	<0.002	<0.04	<0.02	<0.01	<0.007	<0.050	<0.025
RS–2	444536107052201	06/27/01	1200	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RS–3	444333106571001	06/18/01	1100	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RS–4	444317106572601	06/19/01	1200	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RS–5	444249106572301	06/24/01	1100	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RS–6	444240106581401	06/20/01	1000	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RS–7	444225106580701	06/21/01	1100	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RS–8	444047106590901	06/25/01	1500	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RS–9	444012106593201	06/25/01	1100	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RS–10	443943106594001	06/26/01	1000	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
Lander, Wyo., study area monitoring wells												
RL–1	425313108440701	07/08/01	1600	<0.004	<0.01	<0.002	<0.04	<0.02	<0.01	<0.007	<0.050	<0.025
RL–2	425253108434501	07/12/01	1100	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RL–3	425158108433801	07/17/01	1100	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RL–4	425140108430901	07/09/01	1100	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RL–5	425129108432401	07/15/01	1300	<.004	<.01	<.002	<.04	<.02	<.01	**E.004**	<.050	<.025
RL–6	425116108430101	08/06/01	1300	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RL–7	425111108430501	07/18/01	1100	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RL–8	424830108450101	07/10/01	1300	--	<.01	--	<.04	<.02	<.01	--	--	<.025
RL–9	424808108453101	07/11/01	1500	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RL–10	424751108455901	07/16/01	1100	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
Red Lodge, Mont., study area monitoring wells												
RR–1	451510109134801	08/08/01	1000	<0.004	<0.01	<0.002	<0.04	<0.02	<0.01	<0.007	<0.050	<0.025
RR–3	450949109164601	09/19/01	1100	<.004	<.01	<.002	<.04	<.02	<.01	<.009	<.050	<.025
RR–4	450958109162801	09/18/01	1100	<.004	<.01	<.002	<.04	<.02	<.01	<.009	<.050	<.025
RR–5	450952109162901	09/17/01	1000	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025

Appendix 10. Pesticides in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detection in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; --, not analyzed; E, estimated concentration; U, chemical was analyzed for, but not detected]

Well number	USGS site-identification number	Sample date (month/ day/year)	Sample time (24 hour)	Acetochlor (µg/L) P49260	Acifluorfen (µg/L) P49315	Alachlor (µg/L) P46342	Aldicarb (µg/L) P49312	Aldicarb sulfone (µg/L) P49313	Aldicarb sulfoxide (µg/L) P49314	Atrazine (µg/L) P39632	Azinphos-methyl (µg/L) P82686	Bendiocarb (µg/L) P50299
Red Lodge, Mont., study area monitoring wells—Continued												
RR–6	450949109172301	09/16/01	1200	<0.004	<0.01	<0.002	<0.04	<0.02	<0.01	<0.007	<0.050	<0.025
RR–7	450943109161701	08/09/01	1000	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RR–8	450935109161701	09/17/01	1600	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RR–9	450925109180001	09/18/01	1500	<.004	<.01	<.002	<.04	<.02	<.01	<.007	<.050	<.025
RR–10	450845109163701	09/19/01	1600	<.004	<.01	<.002	<.04	<.02	<.01	<.009	<.050	<.025

Well number	Benfluralin (µg/L) P82673	Benomyl (µg/L) P50300	Bensulfuron, methyl (µg/L) P61693	Bentazon (µg/L) P38711	Bromacil (µg/L) P04029	Bromoxynil (µg/L) P49311	Butylate (µg/L) P04028	Caffeine[1] (µg/L) P50305	Carbaryl (µg/L) P49310	Carbaryl (µg/L) P82680	Carbofuran (µg/L) P49309	Carbofuran (µg/L) P82674	Chloramben, methyl ester (µg/L) P61188
Sheridan, Wyo., study area monitoring wells													
RS–1	<0.010	<0.004	<0.0158	<0.01	<0.03	<0.02	<0.002	<0.010	<0.03	<0.041	<0.01	<0.020	<0.02
RS–2	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RS–3	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RS–4	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RS–5	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RS–6	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RS–7	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RS–8	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RS–9	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RS–10	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
Lander, Wyo., study area monitoring wells													
RL–1	<0.010	<0.004	<0.0158	<0.01	<0.03	<0.02	<0.002	<0.010	<0.03	<0.041	<0.01	<0.020	<0.02
RL–2	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02

Appendix 10. Pesticides in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detection in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; --, not analyzed; E, estimated concentration; U, chemical was analyzed for, but not detected]

Well number	Benfluralin (µg/L) P82673	Benomyl (µg/L) P50300	Bensulfuron, methyl (µg/L) P61693	Bentazon (µg/L) P38711	Bromacil (µg/L) P04029	Bromoxynil (µg/L) P49311	Butylate (µg/L) P04028	Caffeine[1] (µg/L) P50305	Carbaryl (µg/L) P49310	Carbaryl (µg/L) P82680	Carbofuran (µg/L) P49309	Carbofuran (µg/L) P82674	Chloramben, methyl ester (µg/L) P61188
Lander, Wyo., study area monitoring wells—Continued													
RL–3	<0.010	<0.004	<0.0158	<0.01	<0.03	<0.02	<0.002	<0.010	<0.03	<0.041	<0.01	<0.020	<0.02
RL–4	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RL–5	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RL–6	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	**E.01**	<.041	<.01	<.020	<.02
RL–7	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RL–8	--	<.004	<.0158	<.01	<.03	<.02	--	<.010	<.03	--	<.01	--	<.02
RL–9	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RL–10	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
Red Lodge, Mont., study area monitoring wells													
RR–1	<0.010	<0.004	<0.0158	<0.01	<0.03	<0.02	<0.002	<0.010	<0.03	<0.041	<0.01	<0.020	<0.02
RR–3	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RR–4	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RR–5	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	**E.006**	<.03	<.041	<.01	<.020	<.02
RR–6	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RR–7	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	**E.023**	<.03	<.041	<.01	<.020	<.02
RR–8	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RR–9	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02
RR–10	<.010	<.004	<.0158	<.01	<.03	<.02	<.002	<.010	<.03	<.041	<.01	<.020	<.02

Appendix 10. Pesticides in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detection in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; --, not analyzed; E, estimated concentration; U, chemical was analyzed for, but not detected]

Well number	Chlorimuron (µg/L) P50306	Chlorothalonil (µg/L) P49306	Chlorpyrifos (µg/L) P38933	Clopyralid (µg/L) P49305	Cyanazine (µg/L) P04041	Cycloate (µg/L) P04031	2,4–D (µg/L) P39732	2,4–DB (µg/L) P38746	2,4–D Methyl ester (µg/L) P50470	Dacthal mono-acid (µg/L) P49304	DCPA (µg/L) P82682	p,p′ DDE (µg/L) P34653	Deethylatrazine (µg/L) P04040
Sheridan, Wyo., study area monitoring wells													
RS–1	<0.010	<0.04	<0.005	<0.01	<0.018	<0.01	<0.02	<0.02	<0.009	<0.01	<0.003	<0.003	<0.006
RS–2	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RS–3	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RS–4	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RS–5	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RS–6	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RS–7	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RS–8	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.032	<.01	<.003	<.003	<.006
RS–9	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.025	<.01	<.003	<.003	<.006
RS–10	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.019	<.01	<.003	<.003	<.006
Lander, Wyo., study area monitoring wells													
RL–1	<0.010	<0.04	<0.005	<0.01	<0.018	<0.01	<0.02	<0.02	<0.009	<0.01	<0.003	<0.003	<0.006
RL–2	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RL–3	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RL–4	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RL–5	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RL–6	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RL–7	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RL–8	<.010	<.04	--	<.01	--	<.01	<.02	<.02	<.009	<.01	--	--	--
RL–9	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RL–10	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
Red Lodge, Mont., study area monitoring wells													
RR–1	<0.010	<0.04	<0.005	<0.01	<0.018	<0.01	<0.02	<0.02	<0.009	<0.01	<0.003	<0.003	<0.006
RR–3	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.028

Appendix 10. Pesticides in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detection in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; --, not analyzed; E, estimated concentration; U, chemical was analyzed for, but not detected]

Well number	Chlorimuron (µg/L) P50306	Chlorothalonil (µg/L) P49306	Chlorpyrifos (µg/L) P38933	Clopyralid (µg/L) P49305	Cyanazine (µg/L) P04041	Cycloate (µg/L) P04031	2,4–D (µg/L) P39732	2,4–DB (µg/L) P38746	2,4–D Methyl ester (µg/L) P50470	Dacthal mono-acid (µg/L) P49304	DCPA (µg/L) P82682	p,p′ DDE (µg/L) P34653	Deethylatrazine (µg/L) P04040
Red Lodge, Mont., study area monitoring wells—Continued													
RR–4	<0.010	<0.04	<0.005	<0.01	<0.018	<0.01	<0.02	<0.02	<0.009	<0.01	<0.003	<0.003	<0.028
RR–5	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RR–6	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RR–7	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RR–8	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RR–9	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.006
RR–10	<.010	<.04	<.005	<.01	<.018	<.01	<.02	<.02	<.009	<.01	<.003	<.003	<.028

Well number	Deethyl, deisopropyl-atrazine (µg/L) P04039	Deisopropyl-atrazine (µg/L) P04038	Diazinon (µg/L) P39572	Dicamba (µg/L) P38442	Dichloroprop (µg/L) P49302	Dieldrin (µg/L) P39381	2,6-Diethyl- aniline (µg/L) P82660	Dinoseb (µg/L) P49301	Diphenamid (µg/L) P04033	Disulfoton (µg/L) P82677	Diuron (µg/L) P49300	EPTC (µg/L) P82668	Ethalfluralin (µg/L) P82663
Sheridan, Wyo., study area monitoring wells													
RS–1	<0.01	<0.04	<0.005	<0.01	<0.01	<0.005	<0.002	<0.01	<0.03	<0.021	<0.01	<0.002	<0.009
RS–2	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RS–3	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RS–4	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RS–5	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RS–6	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RS–7	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RS–8	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RS–9	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RS–10	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009

Appendix 10. Pesticides in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detection in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; --, not analyzed; E, estimated concentration; U, chemical was analyzed for, but not detected]

Well number	Deethyl, deisopropyl-atrazine (µg/L) P04039	Deisopropyl-atrazine (µg/L) P04038	Diazinon (µg/L) P39572	Dicamba (µg/L) P38442	Dichloroprop (µg/L) P49302	Dieldrin (µg/L) P39381	2,6-Diethyl- aniline (µg/L) P82660	Dinoseb (µg/L) P49301	Diphenamid (µg/L) P04033	Disulfoton (µg/L) P82677	Diuron (µg/L) P49300	EPTC (µg/L) P82668	Ethalfluralin (µg/L) P82663
Lander, Wyo., study area monitoring wells													
RL–1	<0.01	<0.04	<0.005	<0.01	<0.01	<0.005	<0.002	<0.01	<0.03	<0.021	<0.01	<0.002	<0.009
RL–2	<.01	<.04	<.005	<.01	.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RL–3	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RL–4	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RL–5	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RL–6	<.01	<.04	<.005	<.01	<.01	<.005	<.002	**E.01**	<.03	<.021	<.01	<.002	<.009
RL–7	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RL–8	<.01	<.04	--	<.01	<.01	--	--	<.01	<.03	--	<.01	--	--
RL–9	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RL–10	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
Red Lodge, Mont., study area monitoring wells													
RR–1	<0.01	<0.04	<0.005	<0.01	<0.01	<0.005	<0.002	<0.01	<0.03	<0.021	<0.01	<0.002	<0.009
RR–3	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RR–4	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RR–5	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RR–6	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RR–7	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RR–8	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RR–9	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009
RR–10	<.01	<.04	<.005	<.01	<.01	<.005	<.002	<.01	<.03	<.021	<.01	<.002	<.009

Appendix 10. Pesticides in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detection in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; --, not analyzed; E, estimated concentration; U, chemical was analyzed for, but not detected]

Well number	Ethoprop (µg/L) P82672	Fenuron (µg/L) P49297	Flumetsulam (µg/L) P61694	Fluometuron (µg/L) P38811	Fonofos (µg/L) P04095	alpha-HCH (µg/L) P34253	gamma-HCH (µg/L) P39341	Hydroxyatrazine (µg/L) P50355	3-Hydroxycarbofuran (µg/L) P49308	Imazaquin (µg/L) P50356	Imazethapyr (µg/L) P50407	Imidacloprid (µg/L) P61695	3-keto carbofuran (µg/L) P50295
Sheridan, Wyo., study area monitoring wells													
RS–1	<0.005	<0.03	<0.0110	<0.03	<0.003	<0.005	<0.004	<0.008	<0.01	<0.016	<0.017	<0.0068	<1.50
RS–2	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	**E.055**	<.0068	<1.50
RS–3	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RS–4	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RS–5	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RS–6	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RS–7	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RS–8	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RS–9	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RS–10	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	**E.011**	<.0068	<1.50
Lander, Wyo., study area monitoring wells													
RL–1	<0.005	<0.03	<0.0110	<0.03	<0.003	<0.005	<0.004	<0.008	<0.01	<0.016	<0.017	<0.0068	<1.50
RL–2	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RL–3	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RL–4	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RL–5	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RL–6	<.005	**E.01**	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RL–7	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RL–8	--	<.03	<.0110	<.03	--	--	--	<.008	<.01	<.016	<.017	<.0068	<1.50
RL–9	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RL–10	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
Red Lodge, Mont., study area monitoring wells													
RR–1	<0.005	<0.03	<0.0110	<0.03	<0.003	<0.005	<0.004	<0.008	<0.01	<0.016	<0.017	<0.0068	<1.50
RR–3	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RR–4	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50

Appendix 10. Pesticides in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detection in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; --, not analyzed; E, estimated concentration; U, chemical was analyzed for, but not detected]

Well number	Ethoprop (µg/L) P82672	Fenuron (µg/L) P49297	Flumetsulam (µg/L) P61694	Fluometuron (µg/L) P38811	Fonofos (µg/L) P04095	alpha-HCH (µg/L) P34253	gamma-HCH (µg/L) P39341	Hydroxyatrazine (µg/L) P50355	3-Hydroxycarbofuran (µg/L) P49308	Imazaquin (µg/L) P50356	Imazethapyr (µg/L) P50407	Imidacloprid (µg/L) P61695	3-keto carbofuran (µg/L) P50295
Red Lodge, Mont., study area monitoring wells—Continued													
RR–5	<0.005	<0.03	<0.0110	<0.03	<0.003	<0.005	<0.004	<0.008	<0.01	<0.016	<0.017	<0.0068	<1.50
RR–6	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RR–7	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RR–8	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RR–9	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50
RR–10	<.005	<.03	<.0110	<.03	<.003	<.005	<.004	<.008	<.01	<.016	<.017	<.0068	<1.50

Well number	Linuron (µg/L) P38478	Linuron (µg/L) P82666	Malathion (µg/L) P39532	MCPA (µg/L) P38482	MCPB (µg/L) P38487	Metalaxyl (µg/L) P50359	Methiocarb (µg/L) P38501	Methomyl (µg/L) P49296	Methomyloxime (µg/L) P61696	Methyl parathion (µg/L) P82667	Metholachlor (µg/L) P39415	Metribuzin (µg/L) P82630	Metsulfuron (µg/L) P61697
Sheridan, Wyo., study area monitoring wells													
RS–1	<0.01	<0.035	<0.027	<0.02	<0.01	<0.020	<0.01	<0.0044	<0.0110	<0.006	<0.013	<0.006	<0.0250
RS–2	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RS–3	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RS–4	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RS–5	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RS–6	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RS–7	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RS–8	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RS–9	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RS–10	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
Lander, Wyo., study area monitoring wells													
RL–1	<0.01	<0.035	<0.027	<0.02	<0.01	<0.020	<0.01	<0.0044	<0.0110	<0.006	<0.013	<0.006	<0.0250
RL–2	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RL–3	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250

Appendix 10. Pesticides in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detection in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; --, not analyzed; E, estimated concentration; U, chemical was analyzed for, but not detected]

Well number	Linuron (µg/L) P38478	Linuron (µg/L) P82666	Malathion (µg/L) P39532	MCPA (µg/L) P38482	MCPB (µg/L) P38487	Metalaxyl (µg/L) P50359	Methiocarb (µg/L) P38501	Methomyl (µg/L) P49296	Methomyl-oxime (µg/L) P61696	Methyl parathion (µg/L) P82667	Metholachlor (µg/L) P39415	Metribuzin (µg/L) P82630	Metsulfuron (µg/L) P61697
Lander, Wyo., study area monitoring wells—Continued													
RL–4	<0.01	<0.035	<0.027	<0.02	<0.01	<0.020	<0.01	<0.0044	<0.0110	<0.006	<0.013	<0.006	<0.0250
RL–5	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RL–6	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RL–7	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RL–8	<.01	--	--	<.02	<.01	<.020	<.01	<.0044	<.0110	--	--	--	<.0250
RL–9	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RL–10	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
Red Lodge, Mont., study area monitoring wells													
RR–1	<0.01	<0.035	<0.027	<0.02	<0.01	<0.020	<0.01	<0.0044	<0.0110	<0.006	<0.013	<0.006	<0.0250
RR–3	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RR–4	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RR–5	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RR–6	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RR–7	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RR–8	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RR–9	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250
RR–10	<.01	<.035	<.027	<.02	<.01	<.020	<.01	<.0044	<.0110	<.006	<.013	<.006	<.0250

Well number	Molinate (µg/L) P82671	Napropamide (µg/L) P82684	Neburon (µg/L) P49294	Nicosulfuron (µg/L) P50364	Norflurazon (µg/L) P49293	Oryzalin (µg/L) P49292	Oxamyl (µg/L) P38866	Oxamyl-oxime (µg/L) P50410	Parathion (µg/L) P39542	Pebulate (µg/L) P82669	Pendimethalin (µg/L) P82683	*cis*-Permethrin (µg/L) P82687	Phorate (µg/L) P82664
Sheridan, Wyo., study area monitoring wells													
RS–1	<0.002	<0.007	<0.01	<0.013	<0.02	<0.02	<0.01	<0.013	<0.007	<0.002	<0.010	<0.006	<0.011
RS–2	<.002	<.007	<.01	<.013	<.02	**.02**	<.01	<.013	<.007	<.002	<.010	<.006	<.011

Appendix 10. Pesticides in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detection in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; --, not analyzed; E, estimated concentration; U, chemical was analyzed for, but not detected]

Well number	Molinate (µg/L) P82671	Napropamide (µg/L) P82684	Neburon (µg/L) P49294	Nicosulfuron (µg/L) P50364	Norflurazon (µg/L) P49293	Oryzalin (µg/L) P49292	Oxamyl (µg/L) P38866	Oxamyl-oxime (µg/L) P50410	Parathion (µg/L) P39542	Pebulate (µg/L) P82669	Pendimethalin (µg/L) P82683	*cis*-Permethrin (µg/L) P82687	Phorate (µg/L) P82664
Sheridan, Wyo., study area monitoring wells—Continued													
RS–3	<0.002	<0.007	<0.01	<0.013	<0.02	<0.02	<0.01	<0.013	<0.007	<0.002	<0.010	<0.006	<0.011
RS–4	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RS–5	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RS–6	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RS–7	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RS–8	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RS–9	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RS–10	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
Lander, Wyo., study area monitoring wells													
RL–1	<0.002	<0.007	<0.01	<0.013	<0.02	<0.02	<0.01	<0.013	<0.007	<0.002	<0.010	<0.006	<0.011
RL–2	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RL–3	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RL–4	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RL–5	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RL–6	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RL–7	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RL–8	--	--	<.01	<.013	<.02	<.02	<.01	<.013	--	--	--	--	--
RL–9	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RL–10	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
Red Lodge, Mont., study area monitoring wells													
RR–1	<0.002	<0.007	<0.01	<0.013	<0.02	<0.02	<0.01	<0.013	<0.007	<0.002	<0.010	<0.006	<0.011
RR–3	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RR–4	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RR–5	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RR–6	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011

Appendix 10. Pesticides in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detection in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; --, not analyzed; E, estimated concentration; U, chemical was analyzed for, but not detected]

Well number	Molinate (µg/L) P82671	Naprop-amide (µg/L) P82684	Neburon (µg/L) P49294	Nicosul-furon (µg/L) P50364	Norflura-zon (µg/L) P49293	Oryzalin (µg/L) P49292	Oxamyl (µg/L) P38866	Oxamyl-oxime (µg/L) P50410	Parathion (µg/L) P39542	Pebulate (µg/L) P82669	Pendi-methalin (µg/L) P82683	*cis*-Permethrin (µg/L) P82687	Phorate (µg/L) P82664
Red Lodge, Mont., study area monitoring wells—Continued													
RR–7	<0.002	<0.007	<0.01	<0.013	<0.02	<0.02	<0.01	<0.013	<0.007	<0.002	<0.010	<0.006	<0.011
RR–8	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RR–9	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011
RR–10	<.002	<.007	<.01	<.013	<.02	<.02	<.01	<.013	<.007	<.002	<.010	<.006	<.011

Well number	Picloram (µg/L) P49291	Prometon (µg/L) P04037	Pronamide (µg/L) P82676	Propachlor (µg/L) P04024	Propanil (µg/L) P82679	Propargite (µg/L) P82685	Propham (µg/L) P49236	Propicon-azole (µg/L) P50471	Propoxur (µg/L) P38538	Siduron (µg/L) P38548	Simazine (µg/L) P04035	Sulfometru-ron, methyl (µg/L) P50337
Sheridan, Wyo., study area monitoring wells												
RS–1	<0.02	**E0.005**	<0.004	<0.010	<0.011	<0.023	<0.01	<0.021	<0.01	<0.017	<0.011	<0.009
RS–2	<.02	<.015	<.004	<.010	<.011	<.023	<.01	<.030	<.01	<.017	<.011	<.009
RS–3	<.02	**E.007**	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RS–4	<.02	**.024**	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RS–5	<.02	**E.003**	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RS–6	<.02	**E.009**	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RS–7	<.02	<.015	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RS–8	<.02	**E.003**	<.004	<.010	<.011	<.023	<.01	<.022	<.01	<.017	<.011	<.009
RS–9	<.02	**.033**	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RS–10	<.02	**E.003**	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
Lander, Wyo., study area monitoring wells												
RL–1	<0.02	<0.015	<0.004	<0.010	<0.011	<0.023	<0.01	<0.021	<0.01	<0.017	<0.011	<0.009
RL–2	<.02	**E.002**	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RL–3	<.02	<.015	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RL–4	<.02	<.015	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RL–5	<.02	**E.004**	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009

Appendix 10. Pesticides in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detection in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; --, not analyzed; E, estimated concentration; U, chemical was analyzed for, but not detected]

Well number	Picloram (µg/L) P49291	Prometon (µg/L) P04037	Pronamide (µg/L) P82676	Propachlor (µg/L) P04024	Propanil (µg/L) P82679	Propargite (µg/L) P82685	Propham (µg/L) P49236	Propiconazole (µg/L) P50471	Propoxur (µg/L) P38538	Siduron (µg/L) P38548	Simazine (µg/L) P04035	Sulfometuron, methyl (µg/L) P50337
Lander, Wyo., study area monitoring wells—Continued												
RL–6	**0.10**	**0.025**	<0.004	<0.010	<0.011	<0.023	<0.01	<0.021	<0.01	<0.017	<0.011	<0.009
RL–7	<.02	<.015	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RL–8	<.02	--	--	--	--	--	<.01	<.021	<.01	<.017	--	<.009
RL–9	<.02	**E.002**	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RL–10	<.02	**E.006**	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
Red Lodge, Mont., study area monitoring wells												
RR–1	<0.02	<0.015	<0.004	<0.010	<0.011	<0.023	<0.01	<0.021	<0.01	<0.017	<0.011	<0.009
RR–3	<.02	<.015	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RR–4	<.02	<.015	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RR–5	<.02	<.015	<.004	<0.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RR–6	<.02	<.015	<.004	<.010	<.011	<.023	<.01	<.065	<.01	<.017	<.011	<.009
RR–7	<.02	<.015	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RR–8	<.02	<.015	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RR–9	<.02	<.015	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009
RR–10	<.02	<.015	<.004	<.010	<.011	<.023	<.01	<.021	<.01	<.017	<.011	<.009

Well number	Tebuthiuron (µg/L) P82670	Terbacil (µg/L) P04032	Terbacil (µg/L) P82665	Terbufos (µg/L) P82675	Terbuthylazine (µg/L) P04022	Thiobencarb (µg/L) P82681	Triallate (µg/L) P82678	Tribenuron methyl (µg/L) P61159	Triclopyr (µg/L) P49235	Trifluralin (µg/L) P82661	Urea, 3,4-Chlorophenyl, methyl (µg/L) P61692
Sheridan, Wyo., study area monitoring wells											
RS–1	**E0.004**	<0.01	<0.034	<0.017	U	<0.005	<0.002	<0.01	<0.02	<0.009	<0.0242
RS–2	<.016	<.01	<.034	<.017	U	<.005	<.002	--	<.02	<.009	<.0242
RS–3	<.016	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242
RS–4	<.016	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242

Appendix 10. Pesticides in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detection in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; --, not analyzed; E, estimated concentration; U, chemical was analyzed for, but not detected]

Well number	Tebuthiuron (µg/L) P82670	Terbacil (µg/L) P04032	Terbacil (µg/L) P82665	Terbufos (µg/L) P82675	Terbuthylazine (µg/L) P04022	Thiobencarb (µg/L) P82681	Triallate (µg/L) P82678	Tribenuron methyl (µg/L) P61159	Triclopyr (µg/L) P49235	Trifluralin (µg/L) P82661	Urea, 3,4-Chlorophenyl, methyl (µg/L) P61692
Sheridan, Wyo., study area monitoring wells—Continued											
RS–5	<0.016	<0.01	<0.034	<0.017	U	<0.005	<0.002	<0.01	<0.02	<0.009	<0.0242
RS–6	<.016	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242
RS–7	<.016	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242
RS–8	<.016	<.01	<.034	<.017	U	<.005	<.002	--	<.02	<.009	<.0242
RS–9	<.016	<.01	<.034	<.017	U	<.005	<.002	--	<.02	<.009	<.0242
RS–10	<.016	<.01	<.034	<.017	U	<.005	<.002	--	<.02	<.009	<.0242
Lander, Wyo., study area monitoring wells											
RL–1	<0.016	<0.01	<0.034	<0.017	U	<0.005	<0.002	<0.01	<0.02	<0.009	<0.0242
RL–2	**E.003**	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242
RL–3	<.016	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242
RL–4	<.016	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242
RL–5	**.102**	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242
RL–6	**E.104**	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242
RL–7	**E.004**	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242
RL–8	--	<.01	--	--	--	--	--	<.01	<.02	--	<.0242
RL–9	<.016	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242
RL–10	<.016	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242
Red Lodge, Mont., study area monitoring wells											
RR–1	<0.016	<0.01	<0.034	<0.017	U	<0.005	<0.002	<0.01	<0.02	<0.009	<0.0242
RR–3	<.006	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242
RR–4	<.006	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242
RR–5	<.016	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242
RR–6	<.016	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242
RR–7	<.016	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242

Appendix 10. Pesticides in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detection in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; --, not analyzed; E, estimated concentration; U, chemical was analyzed for, but not detected]

Well number	Tebuthiuron (µg/L) P82670	Terbacil (µg/L) P04032	Terbacil (µg/L) P82665	Terbufos (µg/L) P82675	Terbuthylazine (µg/L) P04022	Thiobencarb (µg/L) P82681	Triallate (µg/L) P82678	Tribenuron methyl (µg/L) P61159	Triclopyr (µg/L) P49235	Trifluralin (µg/L) P82661	Urea, 3,4-Chlorophenyl, methyl (µg/L) P61692
Red Lodge, Mont., study area monitoring wells—Continued											
RR–8	<0.016	<0.01	<0.034	<0.017	U	<0.005	<0.002	<0.01	<0.02	<0.009	<0.0242
RR–9	<.016	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242
RR–10	<.006	<.01	<.034	<.017	U	<.005	<.002	<.01	<.02	<.009	<.0242

[1] Although caffeine is not a pesticide, it is included in the analytical method for pesticides of this project.

Appendix 11. Volatile organic compounds in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.

[Detections in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; E, estimated concentration]

Well number	USGS site-identification number	Sample date (month/ day/year)	Sample time (24 hour)	Acetone (µg/L) P81552	*tert*-Amyl methyl ether (µg/L) P50005	Benzene (µg/L) P34030	Bromo-benzene (µg/L) P81555	Bromo-chloro-methane (µg/L) P77297	Bromo-dichloro-methane (µg/L) P32101	Bromo-ethene (µg/L) P50002	Bromo-methane (µg/L) P34413	2-Buta-none (µg/L) P81595
Sheridan, Wyo., study area monitoring wells												
RS–1	444554107043101	06/17/01	1200	<7	<0.1	<0.04	<0.04	<0.04	<0.05	<0.1	<0.3	<2
RS–2	444536107052201	06/27/01	1200	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RS–3	444333106571001	06/18/01	1100	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RS–4	444317106572601	06/19/01	1200	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RS–5	444249106572301	06/24/01	1100	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RS–6	444240106581401	06/20/01	1000	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RS–7	444225106580701	06/21/01	1100	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RS–8	444047106590901	06/25/01	1500	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RS–9	444012106593201	06/25/01	1100	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RS–10	443943106594001	06/26/01	1000	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
Lander, Wyo., study area monitoring wells												
RL–1	425313108440701	07/08/01	1600	<7	<0.1	<0.04	<0.04	<0.04	<0.05	<.1	<0.3	<2
RL–2	425253108434501	07/12/01	1100	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RL–3	425158108433801	07/17/01	1100	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RL–4	425140108430901	07/09/01	1100	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RL–5	425129108432401	07/15/01	1300	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RL–6	425116108430101	08/06/01	1300	<7	<.1	**.17**	<.04	<.04	<.05	<.1	<.3	<2
RL–7	425111108430501	07/18/01	1100	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RL–8	424830108450101	07/10/01	1300	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RL–9	424808108453101	07/11/01	1500	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RL–10	424751108455901	07/16/01	1100	<7	<.1	**E.01**	<.04	<.04	<.05	<.1	<.3	<2
Red Lodge, Mont., study area monitoring wells												
RR–1	451510109134801	08/08/01	1000	<7	<0.1	<0.04	<0.04	<0.04	<0.05	<0.1	<0.3	<2
RR–3	450949109164601	09/19/01	1100	**E6**	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RR–4	450958109162801	09/18/01	1100	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2

Appendix 11. Volatile organic compounds in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detections in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; E, estimated concentration]

Well number	USGS site-identification number	Sample date (month/ day/year)	Sample time (24 hour)	Acetone (µg/L) P81552	*tert*-Amyl methyl ether (µg/L) P50005	Benzene (µg/L) P34030	Bromo-benzene (µg/L) P81555	Bromo-chloro-methane (µg/L) P77297	Bromo-dichloro-methane (µg/L) P32101	Bromo-ethene (µg/L) P50002	Bromo-methane (µg/L) P34413	2-Buta-none (µg/L) P81595
Red Lodge, Mont., study area monitoring wells—Continued												
RR–5	450952109162901	09/17/01	1000	**244**	<0.1	<0.04	<0.04	<0.04	<0.05	<0.1	<0.3	**18**
RR–6	450949109172301	09/16/01	1200	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RR–7	450943109161701	08/09/01	1000	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RR–8	450935109161701	09/17/01	1600	**77**	<.1	<.04	<.04	<.04	**E.04**	<.1	<.3	**4**
RR–9	450925109180001	09/18/01	1500	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2
RR–10	450845109163701	09/19/01	1600	<7	<.1	<.04	<.04	<.04	<.05	<.1	<.3	<2

Well number	*n*-Butyl-benzene (µg/L) P77342	Carbon disulfide (µg/L) P77041	Chloro-benzene (µg/L) P34301	Chloro-ethane (µg/L) P34311	Chloro-ethene (µg/L) P39175	Chloro-methane (µg/L) P34418	1-Chloro-2-methyl-benzene (µg/L) P77275	1-Chloro-4-methyl-benzene (µg/L) P77277	3-Chloro-1-propene (µg/L) P78109	Dibromo-chloro-methane (µg/L) P32105	1,2-Dibro-mo-3-chlo-ropropane (µg/L) P82625	1,2-Dibro-moethane (µg/L) P77651	Dibromo-methane (µg/L) P30217
Sheridan, Wyo., study area monitoring wells													
RS–1	<0.2	<0.07	<0.03	<0.1	<0.1	<0.2	<0.03	<0.06	<0.1	<0.2	<0.2	<0.04	<0.05
RS–2	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05
RS–3	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05
RS–4	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05
RS–5	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05
RS–6	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05
RS–7	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05
RS–8	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05
RS–9	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05
RS–10	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05

Appendix 11. Volatile organic compounds in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detections in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; E, estimated concentration]

Well number	*n*-Butylbenzene (µg/L) P77342	Carbon disulfide (µg/L) P77041	Chlorobenzene (µg/L) P34301	Chloroethane (µg/L) P34311	Chloroethene (µg/L) P39175	Chloromethane (µg/L) P34418	1-Chloro-2-methylbenzene (µg/L) P77275	1-Chloro-4-methylbenzene (µg/L) P77277	3-Chloro-1-propene (µg/L) P78109	Dibromochloromethane (µg/L) P32105	1,2-Dibromo-3-chloropropane (µg/L) P82625	1,2-Dibromoethane (µg/L) P77651	Dibromomethane (µg/L) P30217
Lander, Wyo., study area monitoring wells													
RL–1	<0.2	<0.07	<0.03	<0.1	<0.1	<0.2	<0.03	<0.06	<0.1	<0.2	<0.2	<0.04	<0.05
RL–2	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05
RL–3	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05
RL–4	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05
RL–5	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05
RL–6	<.2	**E.05**	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.5	<.04	<.05
RL–7	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05
RL–8	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05
RL–9	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05
RL–10	<.2	**E.03**	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.2	<.04	<.05
Red Lodge, Mont., study area monitoring wells													
RR–1	<0.2	<0.07	<0.03	<0.1	<0.1	<0.2	<0.03	<0.06	<0.1	<0.2	<0.5	<0.04	<0.05
RR–3	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.5	<.04	<.05
RR–4	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.5	<.04	<.05
RR–5	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.5	<.04	<.05
RR–6	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.5	<.04	<.05
RR–7	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.5	<.04	<.05
RR–8	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.5	<.04	<.05
RR–9	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.5	<.04	<.05
RR–10	<.2	<.07	<.03	<.1	<.1	<.2	<.03	<.06	<.1	<.2	<.5	<.04	<.05

Appendix 11. Volatile organic compounds in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detections in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; E, estimated concentration]

Well number	1,2-Di-chloro-benzene (µg/L) P34536	1,3-Di-chloro-benzene (µg/L) P34566	1,4-Di-chloro-benzene (µg/L) P34571	*trans*-1,4-Dichloro-2-butene (µg/L) P73547	Dichloro-difluoro-methane (µg/L) P34668	1,1-Di-chloro-ethane (µg/L) P34496	1,2-Di-chloro-ethane (µg/L) P32103	1,1-Di-chloro-ethene µg/L) P34501	*cis*-1,2-Dichloro-ethene (µg/L) P77093	*trans*-1,2-Dichloro-ethene (µg/L) P34546	Dichloro-methane (µg/L) P34423	1,2-Di-chloro-propane (µg/L) P34541	1,3-Di-chloro-propane (µg/L) P77173
Sheridan, Wyo., study area monitoring wells													
RS–1	<0.03	<0.03	<0.05	<0.7	<0.3	<0.04	<0.1	<0.04	<0.04	<0.03	<0.2	<0.03	<0.1
RS–2	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RS–3	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RS–4	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RS–5	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RS–6	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RS–7	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RS–8	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RS–9	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RS–10	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
Lander, Wyo., study area monitoring wells													
RL–1	<0.03	<0.03	<0.05	<0.7	<0.3	<0.04	<0.1	<0.04	<0.04	<0.03	<0.2	<0.03	<0.1
RL–2	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RL–3	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RL–4	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RL–5	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RL–6	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RL–7	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RL–8	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RL–9	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RL–10	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
Red Lodge, Mont., study area monitoring wells													
RR–1	<0.03	<0.03	<0.05	<0.7	<0.3	<0.04	<0.1	<0.04	<0.04	<0.03	<0.2	<0.03	<0.1
RR–3	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1

Appendix 11. Volatile organic compounds in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detections in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; E, estimated concentration]

Well number	1,2-Dichlorobenzene (µg/L) P34536	1,3-Dichlorobenzene (µg/L) P34566	1,4-Dichlorobenzene (µg/L) P34571	*trans*-1,4-Dichloro-2-butene (µg/L) P73547	Dichlorodifluoromethane (µg/L) P34668	1,1-Dichloroethane (µg/L) P34496	1,2-Dichloroethane (µg/L) P32103	1,1-Dichloroethene µg/L) P34501	*cis*-1,2-Dichloroethene (µg/L) P77093	*trans*-1,2-Dichloroethene (µg/L) P34546	Dichloromethane (µg/L) P34423	1,2-Dichloropropane (µg/L) P34541	1,3-Dichloropropane (µg/L) P77173
Red Lodge, Mont., study area monitoring wells—Continued													
RR–4	<0.03	<0.03	<0.05	<0.7	<0.3	<0.04	<0.1	<0.04	<0.04	<0.03	<0.2	<0.03	<0.1
RR–5	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RR–6	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RR–7	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RR–8	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RR–9	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1
RR–10	<.03	<.03	<.05	<.7	<.3	<.04	<.1	<.04	<.04	<.03	<.2	<.03	<.1

Well number	2,2-Dichloropropane (µg/L) P77170	1,1-Dichloropropene, (µg/L) P77168	*cis*-1,3-Dichloropropene (µg/L) P34704	*trans*-1,3-Dichloropropene (µg/L) P34699	Diethyl ether (µg/L) P81576	Diisopropyl ether (µg/L) P81577	1,2-Dimethylbenzene (µg/L) P77135	1,3- & 1,4-Dimethylbenzene (µg/L) P85795	(1,1-Dimethylethyl) benzene (µg/L) P77353	Ethenylbenzene (µg/L) P77128	Ethylbenzene (µg/L) P34371	Ethyl methacrylate (µg/L) P73570	Ethyl *tert*-butyl ether (µg/L) P50004
Sheridan, Wyo., study area monitoring wells													
RS–1	<0.05	<0.03	<0.09	<0.09	<0.2	<0.1	<0.04	<0.06	<0.06	<0.04	<0.03	<0.2	<0.05
RS–2	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RS–3	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RS–4	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RS–5	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RS–6	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RS–7	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RS–8	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RS–9	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RS–10	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05

Appendix 11. Volatile organic compounds in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detections in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; E, estimated concentration]

Well number	2,2-Dichloropropane (µg/L) P77170	1,1-Dichloropropene, (µg/L) P77168	*cis*-1,3-Dichloropropene (µg/L) P34704	*trans*-1,3-Dichloropropene (µg/L) P34699	Diethyl ether (µg/L) P81576	Diisopropyl ether (µg/L) P81577	1,2-Dimethylbenzene (µg/L) P77135	1,3- & 1,4-Dimethylbenzene (µg/L) P85795	(1,1-Dimethylethyl) benzene (µg/L) P77353	Ethenylbenzene (µg/L) P77128	Ethylbenzene (µg/L) P34371	Ethyl methacrylate (µg/L) P73570	Ethyl *tert*-butyl ether (µg/L) P50004
Lander, Wyo., study area monitoring wells													
RL–1	<0.05	<0.03	<0.09	<0.09	<0.2	<0.1	<0.04	<0.06	<0.06	<0.04	<0.03	<0.2	<0.05
RL–2	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RL–3	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RL–4	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RL–5	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RL–6	<.05	<.03	<.09	<.09	<.2	<.1	**E.02**	**E.04**	<.06	<.04	**E.03**	<.2	<.05
RL–7	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RL–8	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RL–9	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RL–10	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
Red Lodge, Mont., study area monitoring wells													
RR–1	<0.05	<0.03	<0.09	<0.09	<0.2	<0.1	<0.04	<0.06	<0.06	<0.04	<0.03	<0.2	<0.05
RR–3	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RR–4	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RR–5	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RR–6	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RR–7	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RR–8	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RR–9	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05
RR–10	<.05	<.03	<.09	<.09	<.2	<.1	<.04	<.06	<.06	<.04	<.03	<.2	<.05

Appendix 11. Volatile organic compounds in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detections in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; E, estimated concentration]

Well number	2-Ethyl-toluene (µg/L) P77220	1,1,2,3,4,4-Hexa-chloro-1,3-butadiene (µg/L) P39702	1,1,1,2,2,2-Hexa-chloro-ethane (µg/L) P34396	2-Hexa-none (µg/L) P77103	Iodo-methane (µg/L) P77424	1-Isopro-pyl-4-methyl-benzene (µg/L) P77356	Methyl acrylo-nitrile (µg/L) P81593	Methyl-benzene (µg/L) P34010	(1-Methyl-ethyl) benzene (µg/L) P77223	Methyl meth-acrylate (µg/L) P81597	4-Methyl-2-penta-none (µg/L) P78133	Methyl-2-propeno-ate (µg/L) P49991	(1-Methyl-propyl) benzene (µg/L) P77350
Sheridan, Wyo., study area monitoring wells													
RS–1	<0.06	<0.1	<0.2	<0.7	<0.1	<0.07	<0.6	<0.05	<0.03	<0.3	<0.4	<1	<0.03
RS–2	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RS–3	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RS–4	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RS–5	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RS–6	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RS–7	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RS–8	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RS–9	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RS–10	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
Lander, Wyo., study area monitoring wells													
RL–1	<0.06	<0.1	<0.2	<0.7	<0.1	<0.07	<0.6	<0.05	<0.03	<0.3	<0.4	<1	<0.03
RL–2	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RL–3	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RL–4	<.06	<.1	<.2	<.7	<.1	<.07	<.6	**E.01**	<.03	<.3	<.4	<1	<.03
RL–5	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RL–6	<.06	<.1	<.2	<.7	<.1	<.07	<.6	**.13**	<.03	<.3	<.4	<1	<.03
RL–7	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RL–8	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RL–9	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RL–10	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03

Appendix 11. Volatile organic compounds in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detections in **bold** type and <u>underlined</u>. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; E, estimated concentration]

Well number	2-Ethyl-toluene (µg/L) P77220	1,1,2,3,4,4-Hexa-chloro-1,3-butadiene (µg/L) P39702	1,1,1,2,2,2-Hexa-chloro-ethane (µg/L) P34396	2-Hexa-none (µg/L) P77103	Iodo-methane (µg/L) P77424	1-Isopro-pyl-4-methyl-benzene (µg/L) P77356	Methyl acrylo-nitrile (µg/L) P81593	Methyl-benzene (µg/L) P34010	(1-Methyl-ethyl) benzene (µg/L) P77223	Methyl meth-acrylate (µg/L) P81597	4-Methyl-2-penta-none (µg/L) P78133	Methyl-2-propeno-ate (µg/L) P49991	(1-Methyl-propyl) benzene (µg/L) P77350
Red Lodge, Mont., study area monitoring wells													
RR–1	<0.06	<0.1	<0.2	<0.7	<0.1	<0.07	<0.6	<0.05	<0.03	<0.3	<0.4	<1	<0.03
RR–3	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RR–4	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RR–5	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RR–6	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RR–7	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RR–8	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RR–9	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03
RR–10	<.06	<.1	<.2	<.7	<.1	<.07	<.6	<.05	<.03	<.3	<.4	<1	<.03

Well number	Methyl *tert*-butyl ether (MTBE) (µg/L) P78032	Naph-thalene (µg/L) P34696	2-Pro-penenitrile (µg/L) P34215	*n*-Propyl-benzene (µg/L) P77224	1,1,1,2-Tetra-chloro-ethane (µg/L) P77562	1,1,2,2-Tetra-chloro-ethane (µg/L) P34516	Tetra-chloro-ethene (µg/L) P34475	Tetra-chloro-methane (µg/L) P32102	Tetra-hydro-furan (µg/L) P81607	1,2,3,4-Tetra-methyl-benzene (µg/L) P49999	1,2,3,5-Tet-ra-methyl-benzene (µg/L) P50000	Tribromo-methane (µg/L) P32104	1,2,3-Tri-chloro-benzene (µg/L) P77613
Sheridan, Wyo., study area monitoring wells													
RS–1	<0.2	<0.2	<1	<0.04	<0.03	<0.09	<0.1	<0.06	<2	<0.2	<0.2	<0.06	<0.3
RS–2	<.2	<.2	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RS–3	<.2	<.2	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RS–4	<.2	<.2	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RS–5	<.2	<.2	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RS–6	<.2	<.2	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RS–7	<.2	<.2	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3

Appendix 11. Volatile organic compounds in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detections in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; E, estimated concentration]

Well number	Methyl *tert*-butyl ether (MTBE) (µg/L) P78032	Naphthalene (µg/L) P34696	2-Propenenitrile (µg/L) P34215	*n*-Propylbenzene (µg/L) P77224	1,1,1,2-Tetrachloroethane (µg/L) P77562	1,1,2,2-Tetrachloroethane (µg/L) P34516	Tetrachloroethene (µg/L) P34475	Tetrachloromethane (µg/L) P32102	Tetrahydrofuran (µg/L) P81607	1,2,3,4-Tetramethylbenzene (µg/L) P49999	1,2,3,5-Tetramethylbenzene (µg/L) P50000	Tribromomethane (µg/L) P32104	1,2,3-Trichlorobenzene (µg/L) P77613
Sheridan, Wyo., study area monitoring wells—Continued													
RS–8	<0.2	<0.2	<1	<0.04	<0.03	<0.09	<0.1	<0.06	<2	<0.2	<0.2	<0.06	<0.3
RS–9	<.2	<.2	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RS–10	<.2	<.2	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
Lander, Wyo., study area monitoring wells													
RL–1	<0.2	<0.2	<1	<0.04	<0.03	<0.09	<0.1	<0.06	<2	<0.2	<0.2	<0.06	<0.3
RL–2	<.2	<.2	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RL–3	<.2	<.2	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RL–4	<.2	<.2	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RL–5	<.2	<.2	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RL–6	<.2	<.5	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RL–7	<.2	<.2	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RL–8	<.2	<.2	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RL–9	<.2	<.2	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RL–10	<.2	<.2	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
Red Lodge, Mont., study area monitoring wells													
RR–1	<0.2	<0.5	<1	<0.04	<0.03	<0.09	<0.1	<0.06	<2	<0.2	<0.2	<0.06	<0.3
RR–3	<.2	<.5	<1	<.04	<.03	<.09	<.1	<.06	**29**	<.2	<.2	<.06	<.3
RR–4	<.2	<.5	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RR–5	<.2	<.5	<1	<.04	<.03	<.09	<.1	<.06	**1,150**	<.2	<.2	<.06	<.3
RR–6	<.2	<.5	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RR–7	<.2	<.5	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RR–8	<.2	<.5	<1	<.04	<.03	<.09	<.1	<.06	**256**	<.2	<.2	<.06	<.3
RR–9	<.2	<.5	<1	<.04	<.03	<.09	<.1	<.06	<2	<.2	<.2	<.06	<.3
RR–10	<.2	<.5	<1	<.04	<.03	<.09	<.1	<.06	**E1**	<.2	<.2	<.06	<.3

Appendix 11. Volatile organic compounds in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detections in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; E, estimated concentration]

Well number	1,2,4-Trichloro-benzene (µg/L) P34551	1,1,1-Trichloro-ethane (µg/L) P34506	1,1,2-Trichloro-ethane (µg/L) P34511	Trichloro-ethene (µg/L) P39180	Trichloro-fluoro-methane (µg/L) P34488	Trichloro-methane (µg/L) P32106	1,2,3-Trichloro-propane (µg/L) P77443	1,1,2-Trichloro-1,2,2-trifluoro-ethane (µg/L) P77652	1,2,3-Tri-methyl-benzene (µg/L) P77221	1,2,4-Trimethyl-benzene (µg/L) P77222	1,3,5-Trimethyl-benzene (µg/L) P77226	Number of tentatively identified compounds found in sample P99871
Sheridan, Wyo., study area monitoring wells												
RS–1	<0.2	<0.03	<0.06	<0.04	<0.09	<0.02	<0.2	<0.06	<0.1	<0.06	<0.04	0
RS–2	<.2	<.03	<.06	<.04	<.09	**E.04**	<.2	<.06	<.1	<.06	<.04	0
RS–3	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	<.06	<.04	0
RS–4	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	<.06	<.04	0
RS–5	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	<.06	<.04	0
RS–6	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	<.06	<.04	0
RS–7	<.2	<.03	<.06	<.04	<.09	**E.01**	<.2	<.06	<.1	<.06	<.04	0
RS–8	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	<.06	<.04	0
RS–9	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	<.06	<.04	0
RS–10	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	<.06	<.04	0
Lander, Wyo., study area monitoring wells												
RL–1	<0.2	<0.03	<0.06	<0.04	<0.09	<0.02	<0.2	<0.06	<0.1	<0.06	<0.04	0
RL–2	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	<.06	<.04	0
RL–3	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	<.06	<.04	0
RL–4	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	<.06	<.04	0
RL–5	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	<.06	<.04	0
RL–6	<.2	<.03	<.06	<.04	<.09	**.12**	<.2	<.06	<.1	**E.05**	<.04	0
RL–7	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	<.06	<.04	0
RL–8	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	<.06	<.04	0
RL–9	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	<.06	<.04	0
RL–10	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	<.06	<.04	0

Appendix 11. Volatile organic compounds in ground-water samples collected from wells completed in the Sheridan, Lander, and Red Lodge study areas, Wyoming and Montana, 2001.—Continued

[Detections in **bold** type and underlined. USGS, U.S. Geological Survey; µg/L, micrograms per liter; number below the compound is the data parameter code, which is a 5-digit number used in the USGS computerized data system, National Water Information System (NWIS), to uniquely identify a specific constituent or property; <, less than symbol indicates chemical was not detected. The value following the less than symbol is the laboratory reporting level; E, estimated concentration]

Well number	1,2,4-Trichloro-benzene (µg/L) P34551	1,1,1-Trichloro-ethane (µg/L) P34506	1,1,2-Trichloro-ethane (µg/L) P34511	Trichloro-ethene (µg/L) P39180	Trichloro-fluoro-methane (µg/L) P34488	Trichloro-methane (µg/L) P32106	1,2,3-Trichloro-propane (µg/L) P77443	1,1,2-Trichloro-1,2,2-trifluoro-ethane (µg/L) P77652	1,2,3-Tri-methyl-benzene (µg/L) P77221	1,2,4-Trimethyl-benzene (µg/L) P77222	1,3,5-Trimethyl-benzene (µg/L) P77226	Number of tentatively identified compounds found in sample P99871
Red Lodge, Mont., study area monitoring wells												
RR–1	<0.2	<0.03	<0.06	<0.04	<0.09	<0.02	<0.2	<0.06	<0.1	<0.06	<0.04	0
RR–3	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	**.11**	<.04	0
RR–4	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	**E.10**	<.04	0
RR–5	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	**E.07**	<.04	0
RR–6	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	**.12**	<.04	0
RR–7	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	**E.04**	<.04	0
RR–8	<.2	<.03	<.06	<.04	<.09	**.67**	<.2	<.06	<.1	**E.08**	<.04	0
RR–9	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	**E.03**	<.04	0
RR–10	<.2	<.03	<.06	<.04	<.09	<.02	<.2	<.06	<.1	**.21**	<.04	0

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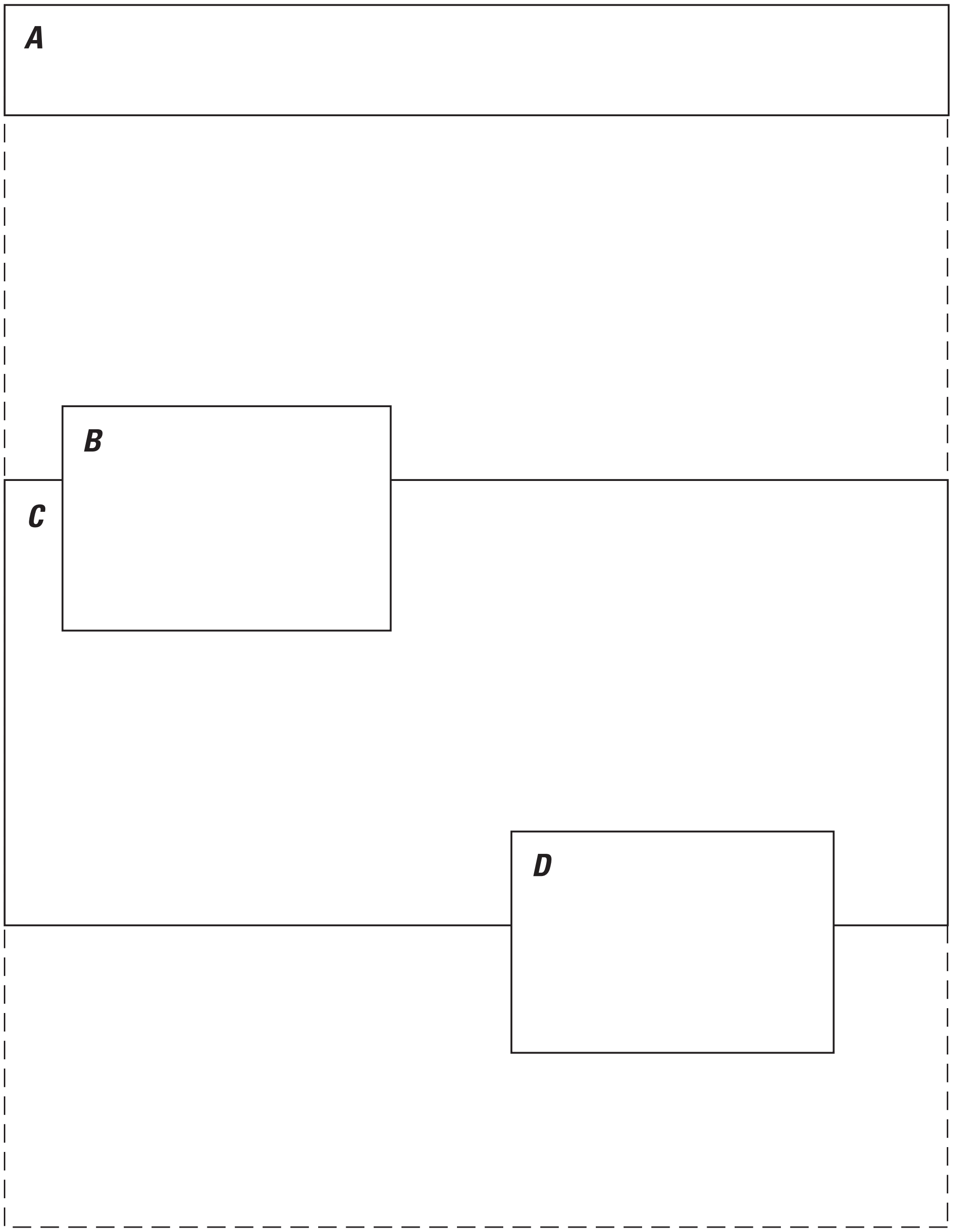

Back cover photographs: ***A***, Low-density development in Lander, Wyo., study area.
B, Sampling of flush-mounted monitoring well.
C, Hydrologist mapping land use in Red Lodge, Mont., study area.
D, Geologist collecting and describing core during monitoring-well installation.

Photographs by Timothy T. Bartos, Laura L. Hallberg, and Peter R. Wright, U.S. Geological Survey.

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