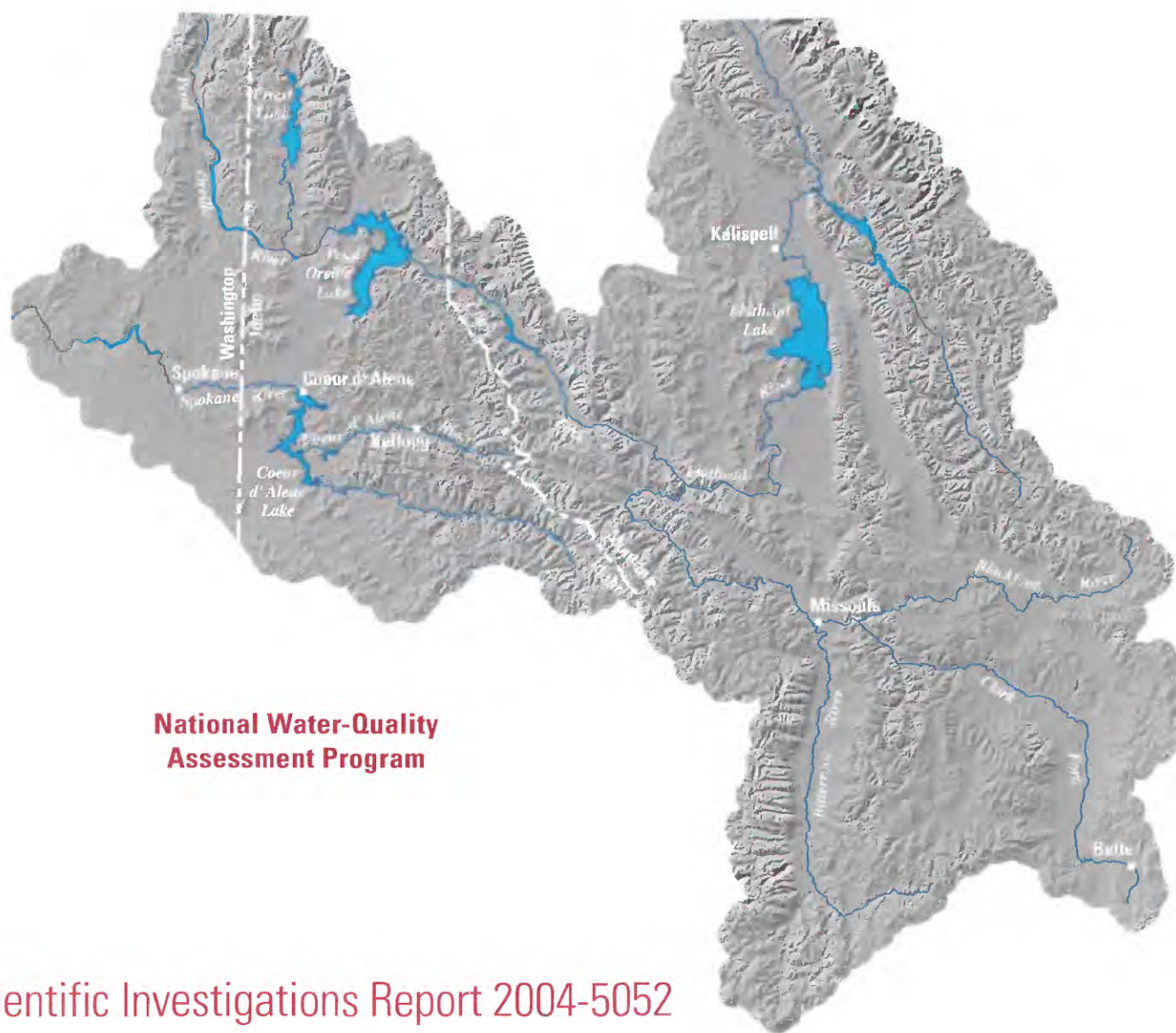


Ground-Water Quality of Selected Basin-Fill Aquifers of the Northern Rockies Intermontane Basins in Montana, Idaho, and Washington



Scientific Investigations Report 2004-5052

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By Rodney R. Caldwell, Craig L. Bowers, and
DeAnn M. Dutton

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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. 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. 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. 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. 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.

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 Datum

Multiply	By	To obtain
Length		
foot (ft)	0.3048	meter (m)
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
inch (in.)	254.0	micrometer (μm)
mile (mi)	1.609	kilometer (km)
Area		
square mile (mi^2)	2.590	square kilometer (km^2)
Volume		
gallon (gal)	3.785	liter (L)
Mass		
pound (lb)	0.4536	kilogram (kg)
Flow		
gallon per minute (gal/min)	0.06309	liter per second (L/s)
Hydraulic conductivity		
foot per day (ft/d)	0.3048	meter per day (m/d)
Transmissivity		
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

Temperature can be converted from degrees Celsius ($^{\circ}\text{C}$) to degrees Fahrenheit ($^{\circ}\text{F}$) by the following equation:

$$^{\circ}\text{F} = 9/5 (^{\circ}\text{C}) + 32$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29). Horizontal coordinate information is referenced to North American Datum of 1983 (NAD 83), unless otherwise noted.

Abbreviated water-quality units used in this report:

fmo/L	femtomoles per liter
$\mu\text{g/L}$	micrograms per liter
$\mu\text{S/cm}$	microsiemens per centimeter at 25 degrees Celsius
mg/L	milligrams per liter
pCi/L	picocuries per liter

Acronyms used in this report:

AMCL	Alternate Maximum Contaminant Level
CFC	chlorofluorocarbon
GC/MS	gas chromatography/mass spectrometry
GIS	geographic information system
ISDA	Idaho State Department of Agriculture
LC/MS	high performance liquid chromatography/mass spectrometry
LHA	Lifetime Health Advisory
LRL	laboratory reporting level
LT-MDL	long-term method detection level
MCL	Maximum Contaminant Level
MMM	multimedia mitigation
MRL	minimum-reporting level
MTBE	methyl tert-butyl ether
NAD 27	North American Datum of 1927
NAD 83	North American Datum of 1983
NGVD 29	National Geodetic Vertical Datum of 1929
NAWQA	National Water-Quality Assessment
NROK	Northern Rockies Intermontane Basins
NWIS	National Water Information System
NWQL	U.S. Geological Survey National Water Quality Laboratory, Denver, Colo.
PERC	tetrachloroethylene (perchloroethylene)
RL	reporting level
RPD	relative percent difference
SDWR	Secondary Drinking Water Regulation
SF ₆	sulfur hexafluoride

Acronyms used in this report:

SUS	subunit survey
SUS1	first subunit survey of basin-fill aquifers, northern Idaho and eastern Washington
SUS2	second subunit survey of basin-fill aquifers, Missoula-Bitterroot Valleys, western Montana
SVRP	Spokane Valley/Rathdrum Prairie
THMs	trihalomethanes
TTHMs	total trihalomethanes
TU	tritium units
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
VOC	volatile organic compound

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By Rodney R. Caldwell, Craig L. Bowers, and DeAnn M. Dutton

ABSTRACT

The purpose of this report is to document the quality of ground water in selected basin-fill aquifers within the Northern Rockies Intermontane Basins Study Unit, in western Montana, northern Idaho, and eastern Washington. This report describes the spatial distribution of selected chemical constituents, provides an evaluation of potential relations between water quality and natural and human-caused factors, and provides a comparison of the water quality of two areas within the Study Unit.

Ground-water samples were collected during the late spring and summer of 1999 and 2001 from 61 wells completed in the basin-fill aquifers. Water samples were analyzed for major ions, nutrients, trace elements, radon, pesticides, volatile organic compounds, and ground-water age-dating constituents. Physical properties of the water, including water temperature, specific conductance, dissolved oxygen, pH, and alkalinity were determined at all sites.

The ground water sampled generally was of good quality and acceptable for most purposes. Measured concentrations of nearly all constituents analyzed were less than U.S. Environmental Protection Agency (USEPA) drinking-water standards. Most of the samples were calcium-bicarbonate type water with dissolved-solids concentrations ranging from 32 to 369 milligrams per liter (mg/L) and a median of 131 mg/L. Nutrient concentrations generally were low and all were less than USEPA drinking-water standards. Nitrate concentrations ranged from less than 0.05 to 7.6 mg/L with a median of 0.36 mg/L. Concentrations of trace elements typically were low; however, USEPA drinking-water standards for arsenic, iron, and manganese concentrations were exceeded in a few instances. Arsenic concentrations ranged from less than 0.20 to 31 micrograms per liter ($\mu\text{g/L}$); samples from three wells had concentrations greater than the USEPA Maximum Contaminant Level (MCL) of 10 $\mu\text{g/L}$. Iron concentrations ranged from less than 10 $\mu\text{g/L}$ to 604 $\mu\text{g/L}$, and samples from three wells had iron concentrations greater than the USEPA Secondary Drinking Water Regulation (SDWR) of 300 $\mu\text{g/L}$. Manganese concentrations ranged from less than 0.10 to 129 $\mu\text{g/L}$; samples from three wells had concentrations greater than the USEPA SDWR of 50 $\mu\text{g/L}$. Radon was detected in water from all 61 wells sampled

and concentrations ranged from 253 to 3,047 picocuries per liter (pCi/L) with a median of 853 pCi/L. All but one of the water samples exceeded a proposed radon drinking-water standard of 300 pCi/L for States that choose not to develop a multimedia mitigation program to address indoor air radon concentrations.

The effects of human activities on ground-water quality were apparent from nitrate and organic-compound concentrations in samples from some wells; however, most concentrations were low and no concentrations exceeded USEPA drinking-water standards. Human influences are inferred by nitrate concentrations greater than or equal to the estimated natural background level of 2 milligrams per liter (mg/L) and (or) the detection of organic compounds in samples from 32 (52 percent) of the wells sampled. Nitrate concentrations in samples from 7 of the 61 wells sampled had concentrations of 2 mg/L or greater. Potential sources of the elevated nitrate were septic systems and agricultural activities. Organic compounds—pesticides and (or) volatile organic compounds—were identified mostly at low-level estimated concentrations in water from 29 of the 61 wells sampled. Concentrations of both pesticides and volatile organic compounds (VOCs) were detected in ground water from five wells. Pesticides were detected in ground water from 15 of the 61 wells sampled and multiple pesticides were detected in six wells. The most commonly detected pesticides were 3-hydroxycarbofuran, prometon, and carbofuran. The highest pesticide concentration was 0.044 $\mu\text{g/L}$ of tebuthiuron. VOCs were detected in ground water from 19 of the 61 wells sampled, and multiple VOCs were detected in seven wells. The most commonly detected VOCs were 1,1,1-trichloroethane, chloroform, and tetrachloroethylene. The highest VOC concentration was 4.31 $\mu\text{g/L}$ of toluene.

The results of environmental-tracer analyses used for age dating (tritium and sulfur hexafluoride) indicated relatively young ground water (early 1950s or younger recharge water) for all but 2 of 15 samples. Sulfur hexafluoride analysis of water from six wells within the Missoula Valley indicated apparent ages of 1.5 to 4.5 years. The apparent young age of ground water and the occurrence of nitrate and organic compounds indicated that some water can move rapidly from land surface and (or) point sources to locally recharge these basin-fill aquifers.

INTRODUCTION

Assessing the condition of our Nation's streams and ground water and the natural and human factors that can affect these resources are the major goals of the U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) Program (Gilliom and others, 1995). The NAWQA Program includes a combination of surface-water, ground-water, and ecological components to assess the water-quality and ecological conditions within river and aquifer systems. These assessments consist of the collection of physical, chemical, and biological data at sites representing a wide range of environmental conditions. NAWQA ground-water investigations have focused on water-quality conditions in major aquifers, with an emphasis on recently recharged ground water that might have been affected by present and recent human activities (Gilliom and others, 1995). The Northern Rockies Intermontane Basins (NROK) study area in western Montana, northern Idaho, and eastern Washington (fig. 1) is one of more than 50 major river basins and aquifer systems (referred to as Study Units) selected for assessment under the NAWQA Program since 1991. The NROK Study Unit was selected because it includes several large river systems and major aquifers with a mixture of forested, agricultural, urban, and developing areas. Study activities by the USGS in the NROK Study Unit began in 1996.

Basin-fill aquifers are the principal source of ground water within the NROK Study Unit (fig. 1) and are the focus of the ground-water studies conducted in this Study Unit. These aquifers are potentially susceptible to contamination from human activities because of locally shallow water tables, porous aquifer materials, and relatively rapid rates of recharge. As a group, trace elements are potential contaminants of concern. Elevated trace-element concentrations in ground water have been reported at several locations within the NROK Study Unit (Mok and others, 1988; Nimick and others, 1993; Brumbaugh and others, 1994; Moore, 1994; Barton, 2002; Caldwell and Bowers, 2003). Areas, including four U.S. Environmental Protection Agency (USEPA) designated Superfund sites, with high trace-element concentrations in ground water, surface water, and streambed sediment are associated with past mining activities. Historically, metal-rich sediments, mostly from metals extraction and processing activities, were transported to nearby streams where they became incorporated into stream channels and flood-plain deposits. Maret and Skinner (2000) documented elevated trace-element concentrations in streambed-sediment samples collected in 1998 from 16 sites in the NROK Study Unit. The most elevated trace-element concentrations were in streambed-sediment samples collected downstream from substantial mineral deposits or mining activities.

To assess the water quality of basin-fill aquifers in the NROK Study Unit, the USGS collected and compiled hydrologic and water-quality data in two areas. The water-quality investigation of an area of basin fill is hereinafter referred to as a subunit survey (SUS). The aquifers selected for assessment are the principal sources of drinking water within their respec-

tive areas and have physical properties and overlying land uses that make them potentially susceptible to water-quality degradation.

Two subunit surveys are the focus of this report (fig. 1). Basin-fill aquifers located in northern Idaho and eastern Washington composed the first subunit survey (SUS1) (fig. 2) and basin-fill aquifers located in the Missoula-Bitterroot Valleys of western Montana (fig. 3) composed the second subunit survey (SUS2). Both subunits contain USEPA designated Sole Source Aquifers as defined under section 1424(e) of the Safe Drinking Water Act of 1974 (U.S. Environmental Protection Agency, 2000a). The USEPA defines such an aquifer as one that supplies at least 50 percent of the drinking water consumed in the area overlying the aquifer (U.S. Environmental Protection Agency, 2000a). People depending on a Sole Source Aquifer generally do not have a viable alternative drinking-water source.

Purpose and Scope

The purpose of this report is to document the quality of ground water in selected basin-fill aquifers within the Northern Rockies Intermontane Basins Study Unit of western Montana, northern Idaho, and eastern Washington. Additionally, the report describes the spatial distribution of selected chemical constituents within the basin-fill aquifers, provides an evaluation of potential relations between water quality and natural and human-related factors, and describes a comparison of the water quality of the two subunit-survey areas.

A total of 61 wells were sampled during the late spring and summer of 1999 and 2001. Water samples were analyzed for physical properties, major ions, nutrients, trace elements, radon-222 (hereinafter referred to as radon), pesticides, volatile organic compounds, and constituents used to date the age of ground water. Data are summarized in tables 1-5 (main body of report) and appendixes 1-4 (back of report). Most of the hydrologic and water-quality data from this study are available in a companion report (Bowers and others, 2003) that contains the data collected for all components of the NROK NAWQA study.

Description of Study Area

The NROK Study Unit encompasses about 31,500 mi² in western Montana, northern Idaho, and eastern Washington (fig. 1). A small part of the study area near Spokane, Wash., lies within the Columbia Plateaus physiographic province, whereas most of the study area lies within the Northern Rocky Mountains physiographic province. The study area includes two major river basins: the Clark Fork-Pend Oreille River Basin and the Spokane River Basin. Topography in the area is varied and includes rugged peaks of the northern Rocky Mountains, steep valleys with little or no valley fill, and broad alluvial valleys with as much as 6,800 ft of valley fill (Kendy and Tresch, 1996).

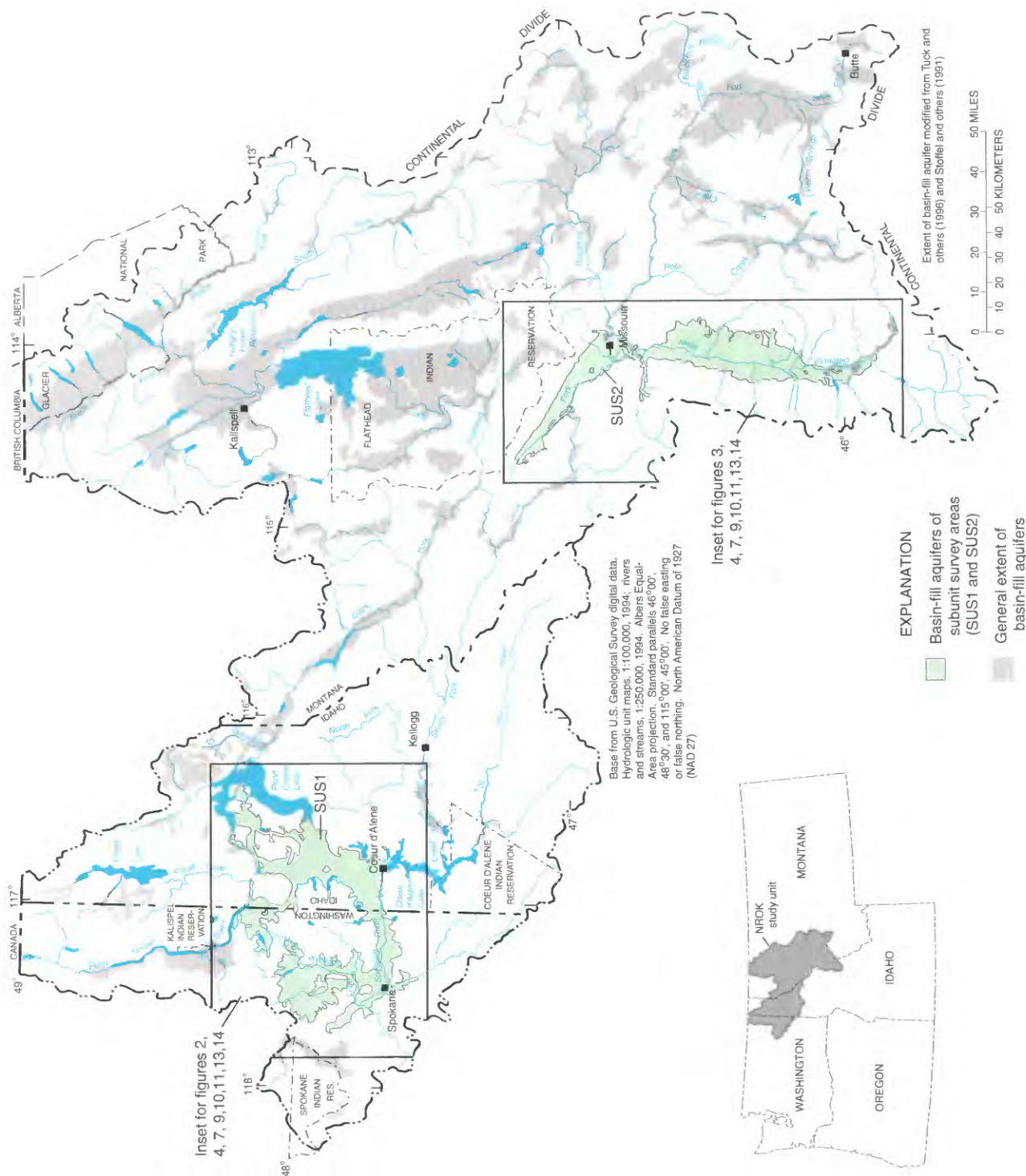


Figure 1. Location of Northern Rockies Intermontane Basins (NROK) Study Unit and subunit survey (SUS) areas, Montana, Idaho, and Washington.

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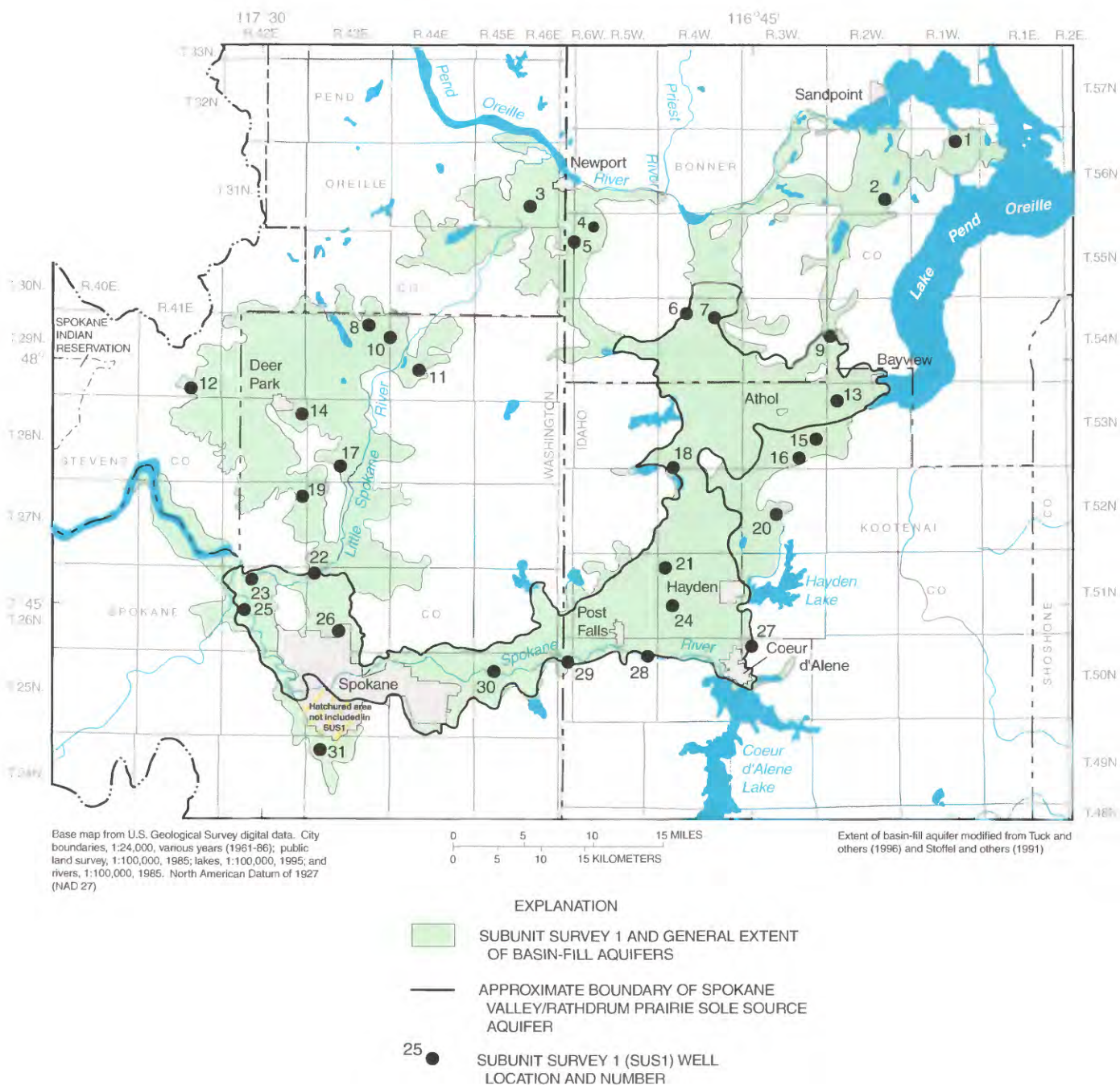


Figure 2. Location of sampled wells in subunit survey 1 of northern Idaho and eastern Washington.

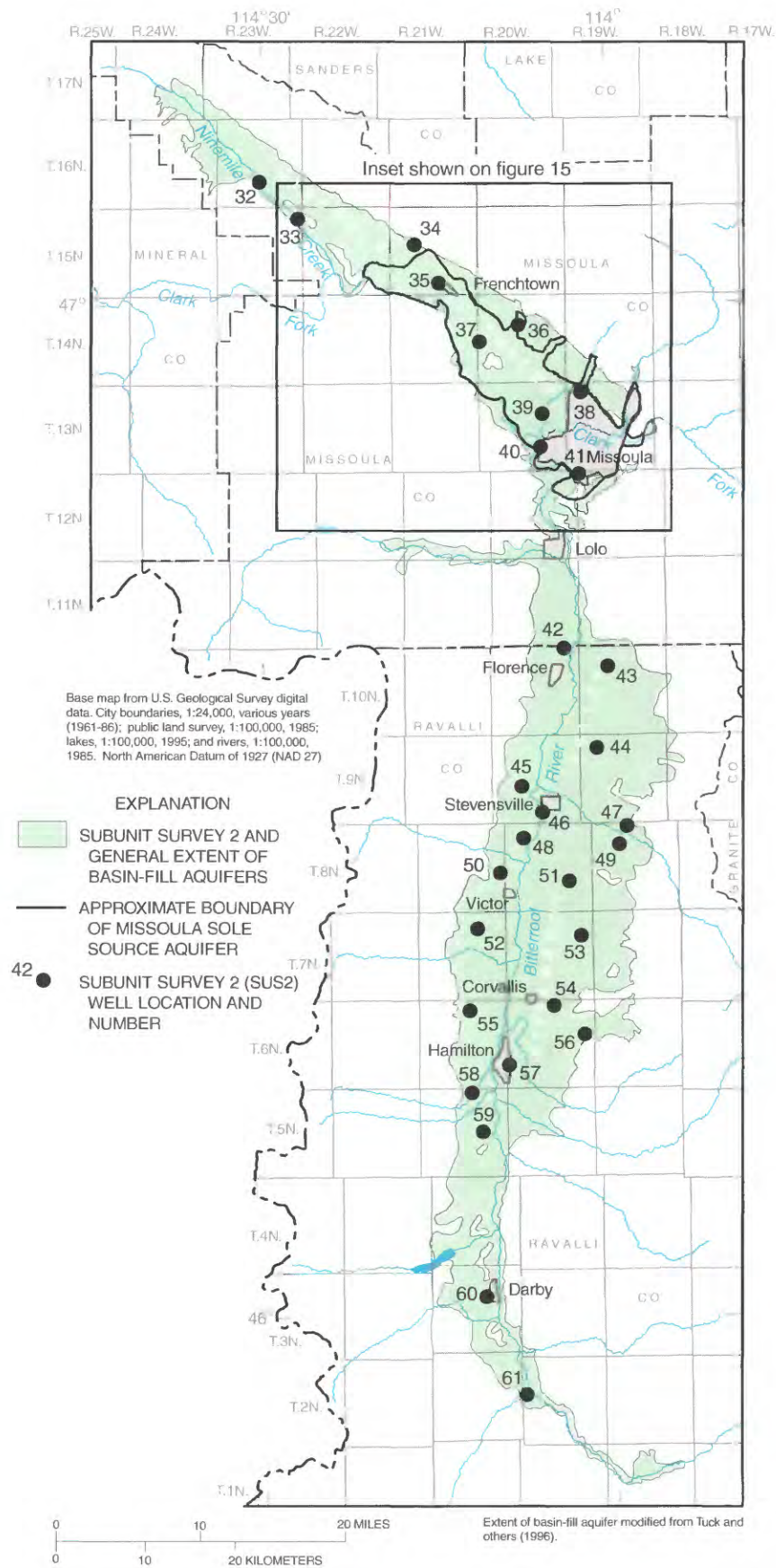


Figure 3. Location of sampled wells in subunit survey 2 of the Missoula-Bitterroot Valleys of western Montana.

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Land cover or land use within the NROK Study Unit is a mixture of forest (75 percent), rangeland (11 percent), agriculture (8 percent), urban (1 percent), and other (5 percent) (Naomi Nakagaki, Kerie Hitt, and Bernard McNamara, U.S. Geological Survey, written commun., 2001; as documented in Hitt, 1994). Land ownership is about 56 percent public, 37 percent private, and 7 percent tribal (Maret and Skinner, 2000). The 1990 population of the Study Unit was about 725,000 and includes about 255,000 in Montana, 120,000 in Idaho, and 350,000 in Washington (Price and Clawges, 1999).

The climate of the NROK Study Unit is characterized by mild summers and cold winters with most precipitation falling in the winter and spring months. Annual precipitation ranges from about 10 in. in some intermontane valleys to over 100 in. in parts of some mountain ranges in Montana. Most of the valleys receive between 10 to 30 in. of precipitation per year (Clark and Kendy, 1991). Much of the precipitation falls as snow, which contributes to streamflow and can be a source of ground-water recharge during snowmelt.

The SUS1 area (fig. 2) consists of about 836 mi² located within the counties of Bonner and Kootenai in Idaho and Spokane, Stevens, and Pend Oreille in Washington. SUS1 was delineated on the basis of the extent of sedimentary deposits of Quaternary age (Stoffel and others, 1991; Tuck and others, 1996). The subunit consists of a lowland area with land-surface altitudes ranging from 1,500 to 2,640 ft above the National Geodetic Vertical Datum of 1929 (NGVD 29) surrounded by bed-rock highlands exceeding altitudes of 5,000 ft in places. Several lakes are located along the margins of the subunit, the largest of which are Coeur d'Alene Lake and Lake Pend Oreille in Idaho. Major perennial rivers include the Spokane, Little Spokane, and Pend Oreille Rivers. Ground water is used primarily for public-supply, irrigation, commercial, industrial, and domestic purposes (U.S. Geological Survey, 2001).

Land cover or land use within SUS1 (fig. 4) includes coniferous forest (53 percent), agriculture (28 percent), urban (14 percent), rangeland (3 percent), and barren and water (2 percent) (Naomi Nakagaki, Kerie Hitt, and Bernard McNamara, written commun., 2001; as documented in Hitt, 1994). The upland areas surrounding the SUS1 area are primarily covered with coniferous forests. Land use in the coniferous forests within and surrounding SUS1 includes timber harvesting, recreation, and grazing. Agricultural land use consists predominantly of pasture and production of hay, wheat, grass seed, barley, and oats. The SUS1 area includes the cities of Coeur d'Alene, Post Falls, Sandpoint, and Bayview in Idaho, and the Spokane metropolitan area, Deer Park, and Newport in Washington. The 1990 population within the SUS1 boundary was estimated to be about 300,000 (Price and Clawges, 1999). However, population within the area is increasing as indicated by differences between the 1990 and 2000 census. The population during 1990-2000 increased by about 56 percent in Kootenai County, Idaho, and by about 16 percent in Spokane County, Washington (U.S. Census Bureau, 2002).

The SUS2 area (fig. 3) consists of about 630 mi² located within Missoula and Ravalli Counties of Montana and was delineated on the basis of the extent of sedimentary basin-fill deposits of Quaternary to Tertiary age within the Missoula and Bitterroot Valleys (Tuck and others, 1996). The subunit consists of a lowland area with land-surface altitudes ranging from about 3,000 ft above NGVD 29 where the Clark Fork flows out of the Missoula Valley to about 5,500 ft along terraces in the Bitterroot Valley. Altitudes of mountains surrounding the subunit commonly exceed 8,000 ft above NGVD 29. Major perennial rivers and creeks in SUS2 include the Clark Fork, Bitterroot River, and Ninemile Creek. The Bitterroot River originates in the southern Bitterroot Mountains and is joined by several tributaries draining from the surrounding mountains as it flows northward to its confluence with the Clark Fork in the Missoula Valley. The Missoula Valley is drained by Ninemile Creek from the northwest and the Clark Fork from the southeast. Ground water is used primarily for public-supply, industry, irrigation, and domestic purposes (U.S. Geological Survey, 2001).

Land cover or land use (fig. 4) within the SUS2 study area includes agriculture (44 percent), coniferous forest (27 percent), rangeland (21 percent), urban (5 percent), and barren and water (3 percent) (Naomi Nakagaki, Kerie Hitt, and Bernard McNamara, written commun., 2001; as documented in Hitt, 1994). Agricultural land use consists predominantly of pasture and production of hay, wheat, barley, and oats. The mountainous areas surrounding the SUS2 area are primarily covered with coniferous forests. Land use in the coniferous forests within and surrounding SUS2 includes timber harvesting, recreation, and grazing. The area includes the cities of Missoula, Corvallis, Darby, Frenchtown, Hamilton, Stevensville, and Victor. The 1990 population within the SUS2 boundary was estimated to be about 80,000 (Price and Clawges, 1999). The population in the SUS2 is increasing, with increases of about 22 percent in Missoula County and 44 percent in Ravalli County between 1990 and 2000 (U.S. Census Bureau, 2002).

Acknowledgments

The authors wish to thank the local well owners who provided access to their wells for this study. We also wish to thank officials from the Spokane County Public Works Department, Washington Department of Ecology, Idaho Department of Water Resources, Idaho Department of Environmental Quality, and the Montana Bureau of Mines and Geology for local guidance, copies of drillers' reports, and reference materials.

STUDY DESIGN AND METHODS

Wells were selected and samples were collected and analyzed according to standard NAWQA guidelines (Koterba and others, 1995; Lapham and others, 1997). The wells typically were sampled one time for this investigation. The consistent

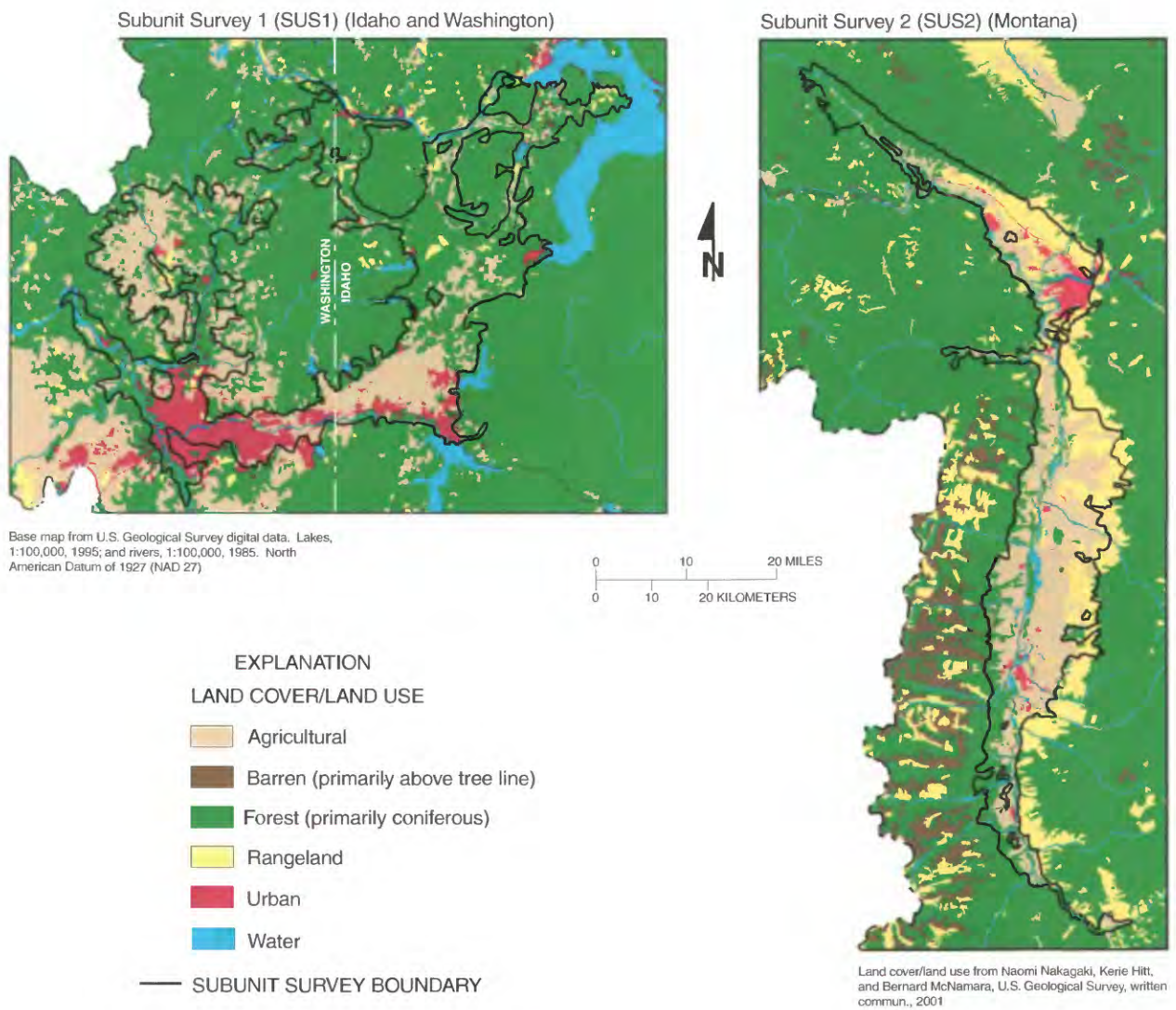


Figure 4. Generalized land cover or land use in subunit surveys 1 and 2, Montana, Idaho, and Washington.

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well-selection criteria, sampling procedures, and analytical methods of the NAWQA Program allow for the comparison of data collected as part of this Study Unit with data collected from other NAWQA Study Units throughout the Nation.

Well Selection and Description

A geographic information system (GIS)-based computer program (Scott, 1990) was used to select a random, unbiased distribution of wells to sample for this study. The program divided each subunit into 30 equal-area cells and generated areas within each cell to locate a well to sample. Field reconnaissance was conducted within equal-area cells to locate suitable wells. Wells were then selected based on construction, plumbing, and pump type that would minimally affect water chemistry. Sampling points were located as close to the well head as possible and upstream from water filters, water-treatment systems (such as chlorinators or water softeners), and water-storage tanks in the distribution system.

Data from 61 wells were used for this study: 31 wells within SUS1 and 30 wells in SUS2 (figs. 2 and 3). Physical data for these wells are presented in appendix 1. Thirty wells were initially sampled in both subunits. However, information available after sampling and analysis of water from well 16 indicated that the water passed through a large holding tank; thus, the analytical results of water from well 16 (particularly the radon-222 and VOC data) may not accurately reflect the ground-water chemistry at that location. However, information collected from well 16 is used in this report even though the water chemistry of samples from well 16 might not be representative of the water chemistry in the aquifer. A nearby well (well 15) that met the selection criteria was selected and sampled to evaluate representative water chemistry in the aquifer.

Generally, the selected sites were domestic wells with existing submersible pumps, and steel casing with open intervals consisting of stainless-steel screens, perforated casing, or open-ended casing. Based on information reported in drillers' logs, most of the wells were completed in unconfined aquifers. However, nine wells (appendix 1) were completed in locally confined aquifers. Well depths ranged from 29 to 443 ft below land surface with a median depth of 85 ft. Static-water levels measured at the time of sampling ranged from 4.55 ft above land surface to 381.76 ft below land surface with a median of about 32 ft below land surface. Well yields recorded on drillers' logs (commonly determined from short-duration compressed-air tests) ranged from 5 to 100 gal/min with a median yield of 25 gal/min.

Sample Collection and Analysis

Ground-water samples were collected using NAWQA sampling procedures (Koterba and others, 1995). Before samples were collected, water levels were measured to the nearest 0.01 ft with an electric or steel tape. Casing volumes were cal-

culated and pumping rates were measured to calculate purge times. A minimum of three bore volumes was purged before sample collection. Field measurements of water temperature, specific conductance, dissolved oxygen, and pH were recorded at 3- to 5-minute intervals during purging. Samples were collected when field measurements had stabilized for three consecutive measurements. Alkalinity was determined in the field using the incremental titration method (Rounds and Wilde, 2001).

Sample water was collected using polytetrafluoroethylene (Teflon) tubing, stainless-steel connections, and Teflon valves. The flow from the well was controlled using a two-valve flow manifold that diverted a continuous stream of sample water into a collection chamber. All samples were processed in the field within 1 hour of sample collection. All equipment was cleaned immediately after sampling using NAWQA protocols (Koterba and others, 1995).

Samples from each well were analyzed for major ions, nutrients, trace elements, radon, pesticides, and VOCs by the USGS National Water Quality Laboratory (NWQL) in Denver, Colo. In addition, samples from 15 wells were analyzed for tritium at the USGS Isotope Tracers Laboratory in Menlo Park, Calif., and (or) sulfur hexafluoride at the sulfur hexafluoride laboratory in Reston, Va., for age-dating analysis. A summary of analytical-method references, analyzing laboratories, and field-processing procedures is presented in Bowers and others (2003). Time-dependent samples (nutrients, radon, pesticides, and VOCs) were shipped overnight. Samples for analysis of major ions, nutrients, trace elements, and alkalinity were filtered onsite through a 0.45- μ m pore-size capsule filter. Samples for pesticide analysis were filtered through a 0.7- μ m pore-size glass-fiber filter. Samples for analysis of radon, VOCs, sulfur hexafluoride, dissolved gases, and tritium were unfiltered. Samples for analysis of major cations, trace elements, and VOCs were acidified to a pH of less than 2 immediately following sample collection.

Each of the ground-water samples were analyzed for 104 different pesticides: 47 pesticides were analyzed by gas chromatography/mass spectrometry (GC/MS) (Zaugg and others, 1995; appendix 2) and 60 pesticides were analyzed by liquid chromatography/mass spectrometry (LC/MS) (Furlong and others, 2001; appendix 3). Three analytes were analyzed by both methods. Samples collected in 1999 (wells 1-31) were analyzed when the LC/MS method was considered a new research method. These samples also exceeded the LC/MS method-specific holding time of 4 days. Potential degradation of the samples as a result of excessive holding times increases the probability that (1) a pesticide reported as not detected was present at the time of sample collection, (2) the reported concentration is less than the concentration at the time of sample collection, or (3) in the case of compounds that are degradation products of pesticides, the concentration could have increased due to degradation of the parent pesticide (Furlong and others, 2003). Because of these uncertainties, the LC/MS analytical results for water from wells 1-31 were not reported in Bowers and others

(2003). Samples from wells 32-61 (collected in 2001) were extracted within the recommended holding times and were analyzed by LC/MS after the method was approved. The LC/MS results for samples from wells 32-61 and the GC/MS results for samples from all 61 wells are included in Bowers and others (2003). All of the GC/MS and LC/MS data are discussed in this report with the understanding that the LC/MS results for water from wells 1-31 have more quantitative uncertainty than the other LC/MS (water from wells 32-61) and the GC/MS analytical results.

Data Reporting and Analysis

Water-chemistry data were reported by NWQL relative to minimum reporting levels (MRLs) or laboratory reporting levels (LRLs). The MRL is the minimum concentration at which a constituent can be reliably reported using a given analytical method (Timme, 1995). The LRL is statistically calculated by evaluating quality-control data for an analytical method on a continuing basis to determine long-term method detection levels (LT-MDLs) (Childress and others, 1999). LRLs are equal to twice the annual LT-MDLs. For brevity, MRLs and LRLs are oftentimes referred to in this report simply as reporting levels (RLs).

NWQL reports analytical results as either measured or estimated values. Estimated values are smaller than a minimum concentration reliably reported by a given analytical method, but larger than the long-term method detection level (Childress and others, 1999). Estimated concentrations also indicate quantitative uncertainty intermittently introduced by chemical interference or variable recovery efficiency; this quantitative uncertainty may result in estimated values at concentrations greater than reporting levels. Estimated values indicate that constituents have been identified in a sample, but the reported concentration has more uncertainty than concentrations not reported as estimates.

The analytical results of the samples collected for the NROK subunit surveys are described in this report through the use of statistical summaries (summary tables), maps of occurrence and concentration, and graphs (boxplots). Analytical results were compared and contrasted between the two subunits, compared to USEPA drinking-water standards and health advisories, and in some instances, compared with the analytical results from other NAWQA subunit surveys. Natural or potential human-related sources of some constituents also were investigated. The USEPA drinking-water standards (U.S. Environmental Protection Agency, 2002) include Maximum Contaminant Levels (MCLs), Alternate Maximum Contaminant Levels (AMCLs), Secondary Drinking Water Regulations (SDWRs), and Lifetime Health Advisories (LHAs). MCLs are enforceable standards that apply to public-water supplies and are defined as the highest allowable concentration of a contaminant in drinking water. An AMCL is an option to the MCL, but requires compliance with additional conditions. SDWRs are non-enforceable guidelines for constituents that may cause cos-

metic or aesthetic effects in drinking water. LHAs are non-enforceable guidelines for noncarcinogens determined for a 150-lb (70-kg) adult that consumes 0.5 gallons (2 L) of water a day over a 70-year lifetime. Data collected as part of the NAWQA Program were retrieved from the USGS National Water Information System (NWIS) database.

The Wilcoxon rank-sum test (Ott, 1993), also referred to as the Mann-Whitney or Wilcoxon-Mann-Whitney rank-sum test, was used to identify statistically significant differences between two groups of data. The Spearman's rho test, a regression analysis performed on rank-transformed data (Helsel and Hirsch, 1997), was used to determine the degree of correlation between two rank-transformed variables. A rho value of -1 represents an inverse correlation between the variables in the two data sets, whereas a rho value of 1 represents a positive correlation; a value near 0 represents no correlation. A 95-percent ($p = 0.05$) two-tailed confidence level was used for both the Wilcoxon rank-sum and the Spearman's rho tests to identify statistically significant results. A value of one-half the reporting level was used in these statistical analyses for values reported as less than the reporting level.

QUALITY-CONTROL SAMPLES AND RESULTS

Quality-control samples were collected to identify potential sample contamination and examine analytical measurement variability and bias. Quality-control samples collected for this study included blanks (field, source-solution, and trip), replicates, and spiked samples. Quality-control samples composed more than 15 percent of the samples collected for this study. Analytical data for quality-control samples are included in Bowers and others (2003). Procedures for collecting quality-control samples for NAWQA ground-water studies are described in Koterba and others (1995). In addition to the quality-control samples submitted from the field, internal quality-assurance practices at the NWQL were performed systematically to provide quality control for analytical procedures (Pritt and Raese, 1995).

Blank samples were used to determine if equipment decontamination procedures were adequate and if sampling or laboratory analysis procedures resulted in sample contamination. Water that had been certified free of inorganic or organic constituents was used for field-blank samples, which were collected immediately after environmental samples were collected and equipment was cleaned. Field blanks were analyzed for major ions, nutrients, trace elements, pesticides, and VOCs. A VOC source-solution blank was collected by pouring organic-free water into a sample bottle and was used to assess the purity of the blank water and the potential for contamination from sample bottles or laboratory analysis. A VOC trip blank consisted of a sample placed in a sample container at NWQL and shipped to the Study Unit with empty containers. The trip blank then accompanied the environmental samples from the field to

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the laboratory to determine if the sample had been contaminated during shipping, handling, and (or) storage.

Replicate samples consisted of two environmental samples considered identical in composition and were used to assess variability in sample collection procedures and laboratory analysis. In the field, the two replicate sample bottles were filled sequentially, one immediately after the other. Replicate samples were analyzed for major ions, nutrients, trace elements, radon, pesticides, and VOCs. The combined effects of sample-collection variability and precision of analytical results were evaluated by calculating the relative percent difference (RPD) of the constituent concentrations in replicate analyses. The RPD was calculated for a constituent by dividing the absolute value of the difference between the two concentrations by the mean of the two concentrations and then multiplying by 100.

Spiked samples were prepared in the field and in the laboratory to examine analytical accuracy, possible water matrix effects, and (or) possible degradation of organic constituents between sample collection and analysis. Samples were spiked by adding a volume of a spike solution with known concentrations of compounds to a replicate water sample. Spike recoveries were calculated using equations 1 and 2 at the bottom of the page. The ideal recovery is 100 percent.

Samples also were spiked in the laboratory with surrogates. A surrogate is an organic compound that has physical and chemical properties similar to at least some of the analytes being measured but that typically is not present in the environmental sample. A surrogate compound was added to each pesticide and VOC sample that was processed at the NWQL as part of the laboratory's quality-control protocols. The percent recovery of the surrogate compounds provides a qualitative check on the amount of recovery for the pesticide or VOC analytes.

Generally, detections of constituents in blank samples were infrequent, at low concentrations, and indicated that field and laboratory procedures did not cause significant bias of analytical results (table 1). A high concentration of aluminum (12 µg/L) was detected in a field blank; however, the aluminum concentration of the environmental sample collected before this blank was less than 1 µg/L. Therefore, cross-contamination from the previous sample was not the source of aluminum in this blank sample. Instead, this one high value probably represents a random occurrence. Systematic analytical problems are not indicated from the rest of the data. For samples collected in

1999, toluene was detected at estimated concentrations less than reporting levels (0.050 µg/L) in a field blank, a source-solution blank, and a trip blank (table 1). Toluene was reported in 10 environmental samples; 9 of the 10 samples had estimated concentrations of 0.017 µg/L or less. The NWQL reported toluene contamination of the glass vials used for sample collection during the summer of 1999. Therefore, systematic low-level contamination is suspected for the nine environmental samples with estimated toluene values; these values were not considered as detections for this study. The NWQL also reported analytical problems with the pesticide p,p'-DDE at estimated concentrations of about 0.002 µg/L or less. Therefore, four environmental samples with estimated p,p'-DDE values of 0.001 µg/L or less were not considered as detections for this study.

Analyses of the replicate samples indicated good agreement between the measured concentrations. The largest RPDs were for analytes with low concentrations. RPDs for major ions and nutrients were less than 10 percent or the differences in concentrations between replicate pairs were less than 0.03 mg/L. RPDs for trace elements were less than 15 percent or the differences in concentrations between replicate pairs were less than 1 µg/L, with the exception of the low aluminum concentrations in water from well 18 (concentrations of 2.7 µg/L and 1.4 µg/L with a RPD of 63 percent). RPDs for radon replicate pairs were less than 7 percent. Pesticide, pesticide-metabolite, and VOC concentrations were less than reporting levels in all replicate samples.

The recoveries of pesticide compounds in spiked samples analyzed by gas chromatography/mass spectrometry (Zaugg and others, 1995) ranged from 9 to 178 percent (fig. 5, appendix 2). The mean recovery for all pesticides analyzed by this method was 89 percent with a standard deviation of 25 percent. For most constituents, recoveries were between 64 and 111 percent (the 10th and 90th percentiles, fig. 5). The lowest recoveries were for atrazine, deethylatrazine, prometon, and simazine. The highest spike recoveries were for carbaryl, carbofuran, and linuron. The extreme highs and lows were from two spiked samples collected at site 31 during the summer of 1999. Therefore, it is possible that concentrations of these particular constituents were biased low or high, especially for samples collected during the 1999 field season. Overall, the analytical method probably was acceptable for a regional assessment of the occurrence of pesticides in ground water.

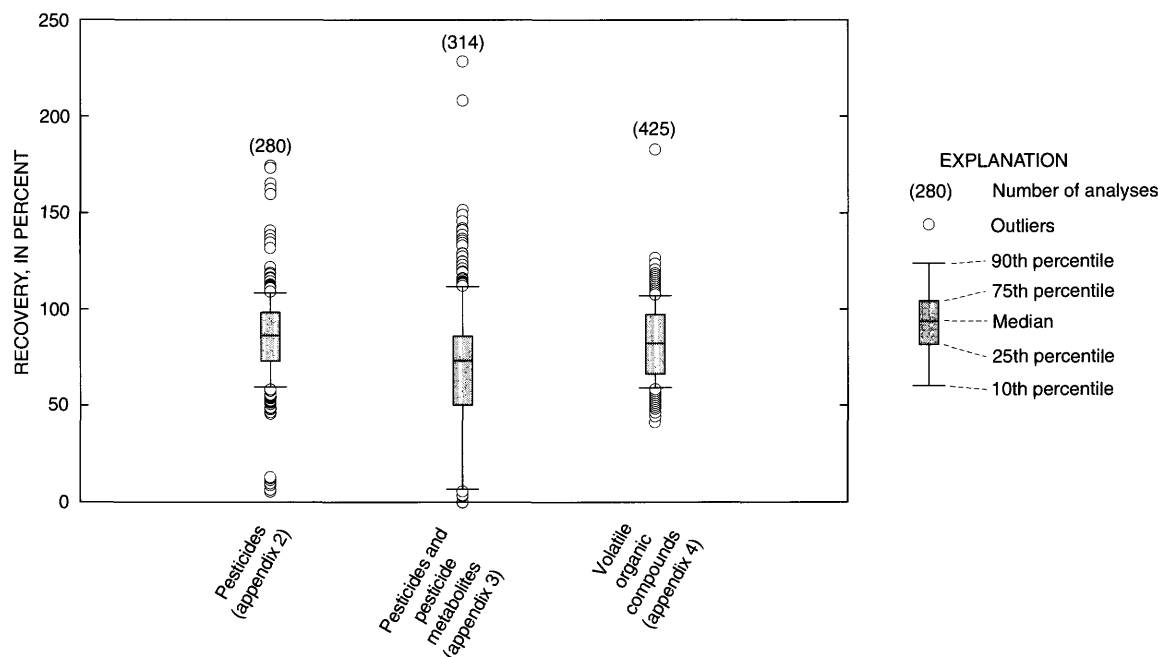
$$\text{Expected spike concentration (}\mu\text{g/L)} = \frac{\text{concentration of spike solution (}\mu\text{g/mL)} \times \text{volume of spike solution added (mL)}}{\text{sample volume in liters (L)}} \quad (1)$$

$$\text{Spike recovery, in percent} = \frac{\text{spiked sample concentration (}\mu\text{g/L)} - \text{unspiked sample concentration (}\mu\text{g/L)}}{\text{expected spike concentration (}\mu\text{g/L)}} \times 100 \quad (2)$$

Table 1. Constituents detected in blank samples collected for the Northern Rockies Intermontane Basins subunit surveys, 1999 and 2001

[Abbreviations: e, estimated; µg/L, micrograms per liter; mg/L, milligrams per liter. Symbol: <, less than]

Constituent	Number of blanks	Number of blanks with detectable concentrations	Reporting level ¹	Highest concentration in blank sample	Range of concentrations in environmental samples
Field blanks					
Potassium (mg/L)	6	1	0.09 or .10	e.08	0.18-9.2
Aluminum (µg/L)	8	1	.30 or 1.0	12	<1.0-14
Antimony (µg/L)	8	1	.05 or 1.0	e.02	<.05-.45
Cobalt (µg/L)	8	3	.02 or 1.0	.02	<.02-.10
Copper (µg/L)	8	2	.20 or 1.0	.32	<.20-4.2
Strontium (µg/L)	7	1	.08, .10, or 1.0	.26	22-433
Zinc (µg/L)	8	1	.50 or 1.0	1.5	<1.0-349
Ammonia plus organic nitrogen (mg/L as N)	6	2	.10	e.08	<10-.25
Phosphorus, orthophosphate (mg/L as P)	6	2	.01 or .02	.01	<.01-.08
Toluene (µg/L)	6	1	.050	e.013	<.050-4.31
Source-solution blank					
Toluene (µg/L)	2	1	.050	e.034	<.050-4.31
Trip blank					
Toluene (µg/L)	1	1	.050	e.025	<.050-4.31

¹Reporting level (minimum reporting levels and laboratory reporting levels) varied during the study (Timme, 1995; Childress and others, 1999).**Figure 5.** Recoveries of pesticides, pesticide metabolites, and volatile organic compounds in spiked ground-water samples collected from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001.

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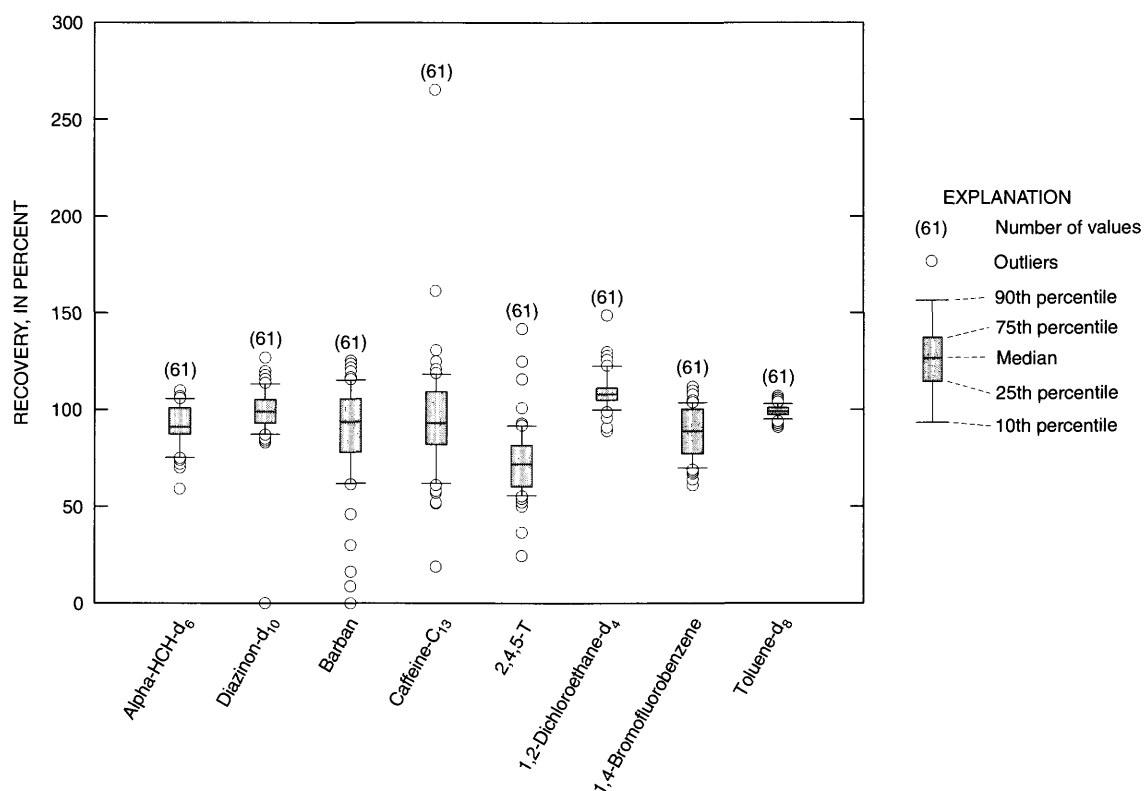


Figure 6. Recoveries of pesticide and volatile organic compound surrogates added to ground-water samples collected from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001. Includes data from Bowers and others (2003).

The recoveries of pesticide and metabolite compounds in spiked samples analyzed by high-performance liquid chromatography/mass spectrometry (Furlong and others, 2001) ranged from <2 to 231 percent (fig. 5, appendix 3). Recoveries of spiked samples analyzed by this method generally were low with an overall mean recovery of 71 percent and a standard deviation of 37 percent; recoveries were 50 percent or less for 25 percent of the spiked analytes (fig. 5). These relatively low recoveries may indicate that concentrations or the presence of these analytes may be biased low in the environmental samples from this study.

The recoveries of VOCs in individual spiked samples ranged from 45 to 186 percent (fig. 5, appendix 4). The overall mean recovery was 86 percent with an overall standard deviation of 19 percent. For most constituents, recoveries were between 63 and 110 percent (the 10th and 90th percentiles, fig. 5). A slight low bias is indicated by the overall mean recovery value, but the analytical accuracy and extent of degradation probably are acceptable for a regional study of VOCs in ground water.

Eight surrogate compounds were analyzed in conjunction with pesticide and VOC analyses (fig. 6). Median recovery values for the surrogate compounds ranged from 72 to 108 percent.

More than 80 percent of the analyses of surrogates had recoveries between 75 and 125 percent. However, the range of recoveries was quite large for some surrogate compounds (especially barban, caffeine-C₁₃, and 2,4,5-T). Therefore, the analytical methods may underestimate or overestimate concentrations of constituents in some cases. In general, the pesticide and VOC analytical methods probably were acceptable for a regional assessment of occurrence of these constituents in ground water.

GEOHYDROLOGIC SETTING

The principal aquifers within the NROK Study Unit are basin-fill deposits of Quaternary and Tertiary age (fig. 1) composed primarily of unconsolidated to consolidated gravel, sand, silt, and clay (Qal, Qg, QTd, and Ts, fig. 7) (Clark and Kendy, 1991). These alluvial fan, glacial-outburst flood, fluvial, glacial till and outwash, colluvium, and lakebed deposits are heterogeneous in nature, resulting in a large range of hydraulic properties within the subunit survey areas. The basin-fill aquifers typically have laterally discontinuous fine-grained layers that can act as leaky-confining units. Alluvial deposits of Quaternary

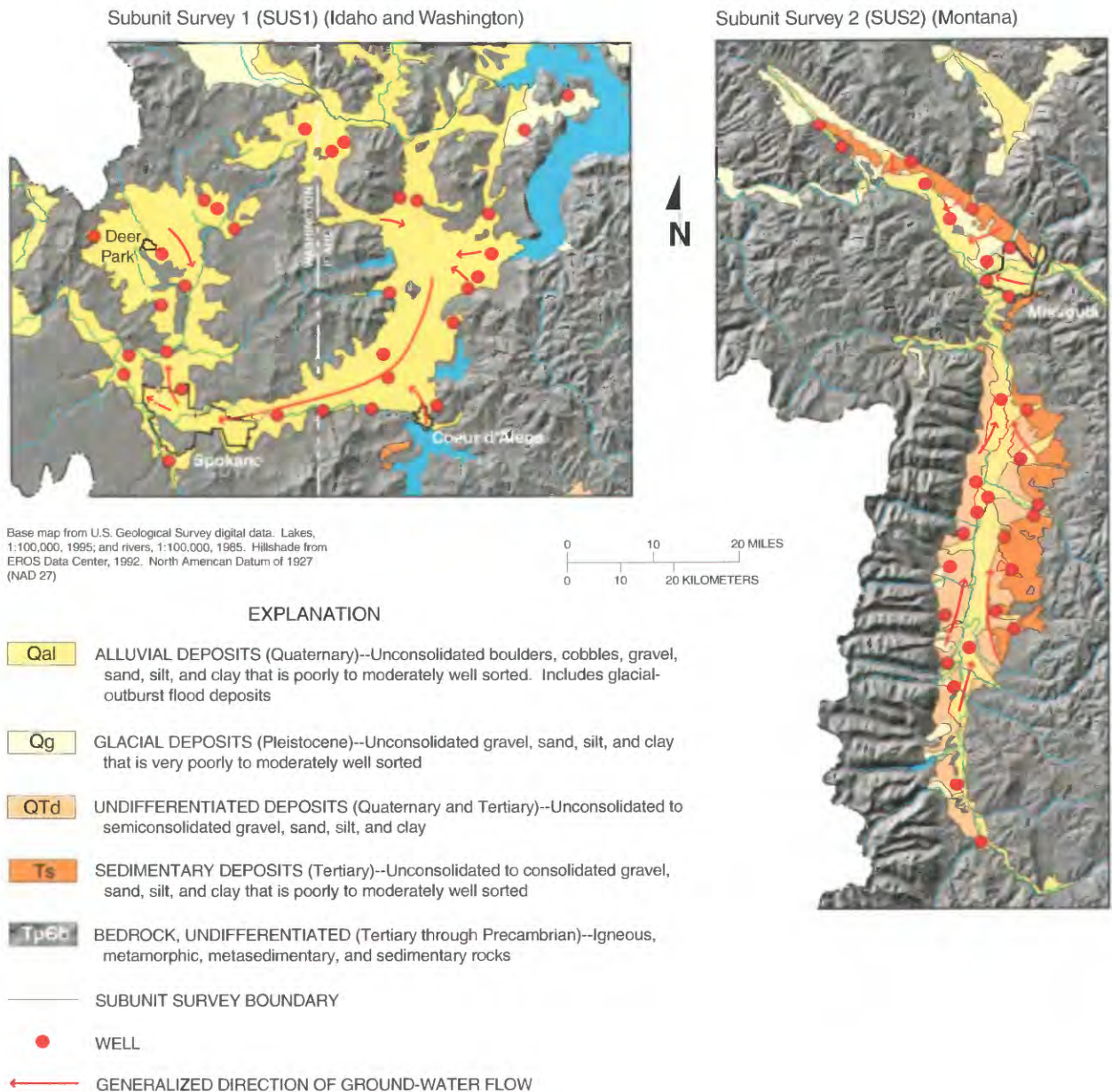


Figure 7. Generalized geology and ground-water flow direction in basin-fill aquifers of subunit surveys 1 and 2, Montana, Idaho, and Washington. (Geology modified from Stoffel and others, 1991; Tuck and others, 1996. Ground-water flow directions generalized from Drost and Seitz, 1978; Molenaar, 1988; Miller, 1991; EMCON, 1992; Briar and others, 1996.)

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age (including the Pleistocene glacial-outburst flood deposits) typically are unconfined and highly productive (Briar and others, 1996).

Ground water within the basin-fill aquifers generally flows from the basin margins down valley toward major rivers and streams (Briar and others, 1996). Basin-fill aquifers are recharged by infiltration of precipitation and snowmelt, subsurface inflow from adjoining highlands and tributary valleys, infiltration of applied irrigation water, and leakage from adjacent and overlying surface-water sources such as lakes, canals, and rivers (Molenaar, 1988; Briar and Dutton, 2000). Discharge from the basin-fill aquifers is by seepage to springs and streams, evapotranspiration, withdrawals from wells, and seepage to irrigation drains (Kendy and Tresch, 1996). Water levels in wells completed within the basin-fill aquifers ranged from nearly 5 feet above land surface to several hundred feet below land surface in some areas.

Subunit Survey 1

In SUS1, basin-fill aquifers are predominantly composed of unconsolidated coarse-grained material primarily deposited by a series of catastrophic glacial outburst floods during the Pleistocene (Molenaar, 1988). Material deposited in this high-energy environment is coarser-grained than is typical for most basin fill, resulting in extremely productive aquifers. The geologic and hydrogeologic framework of SUS1 has been extensively investigated and described in several reports (Piper and La Rocque, 1944; Walker, 1963; Hammond, 1974; Drost and Seitz, 1978; Bolke and Vaccaro, 1981; Jehn, 1988; Molenaar, 1988; and EMCON, 1992).

Gerstel and Palmer (1994) determined an aquifer thickness of 500 to 550 ft near the Idaho-Washington State line east of Spokane, Wash. However, wells completed in basin fill of SUS1 rarely extend more than 100 ft into the saturated zone. Water levels in wells completed in basin fill range from near land surface to about 500 ft below land surface (Bolke and Vaccaro, 1979; Berenbrock and others, 1995; and Stone and others, 1996). Wells completed in the coarse-grained deposits can yield several thousand gal/min (Bolke and Vaccaro, 1979; Stone and others, 1996), with several wells near Spokane reportedly yielding more than 5,000 gal/min (Bolke and Vaccaro, 1979).

Although much of the basin fill of SUS1 is highly permeable, the hydraulic characteristics of the basin fill are locally variable and may include less-permeable, fine-grained sedimentary material. Drost and Seitz (1978) reported transmissivity values calculated from aquifer tests in the basin fill ranging from 130,000 to more than 13 million ft²/d. Estimated ground-water velocities exceeded 60 ft/day in some areas.

The general direction of ground-water flow is southward from near the southern end of Lake Pend Oreille toward the city of Coeur d'Alene and then westward toward the city of Spokane (figs. 2 and 7). Ground water in the Deer Park area north of Spokane flows in a south to southeasterly direction toward the

Little Spokane River (EMCON, 1992). Most ground water either discharges to the Spokane and Little Spokane Rivers or is withdrawn by pumpage (Drost and Seitz, 1978; Molenaar, 1988).

Part of SUS1 has been designated by the USEPA as a Sole Source Aquifer (fig. 2) and is referred to as the Spokane Valley/Rathdrum Prairie (SVRP) aquifer. This aquifer supplies drinking water for more than 400,000 people (Idaho Department of Environmental Quality, 2000) and covers 320 mi² (38 percent) of the SUS1 area. Fifteen of the 31 wells sampled in the SUS1 were located within the SVRP aquifer boundary.

Subunit Survey 2

The basin-fill aquifers selected for SUS2 (fig. 7) are composed of Quaternary- to Tertiary-age unconsolidated to semi-consolidated coarse-grained material with varying amounts of silt and clay. The geology and hydrogeologic characteristics of the basin-fill deposits included within SUS2 are described in several reports (McMurtrey and others, 1965; McMurtrey and others, 1972; Noble and others, 1982; Miller, 1991; Kendy and Tresch, 1996; Tuck and others, 1996; Briar and Dutton, 2000; and Lonn and Sears, 2001). Glacial till, glacial outwash, glacial lakebed, alluvial fan, and alluvial deposits commonly overlie the Tertiary sedimentary deposits throughout the subunit.

The total thickness of the basin-fill sediments may exceed 3,000 ft in places (Noble and others, 1982). Thickness of the Quaternary alluvium averages about 40 ft in the Bitterroot Valley (McMurtrey and others, 1972). The highly productive coarse-grained Quaternary alluvial aquifer within the Missoula area generally is less than 200 ft thick (determined from aquifer base map of Miller, 1991) with an estimated average saturated thickness of about 80 feet (Miller, 1991). Test wells nearly 3,000 ft deep have been drilled into the Tertiary sedimentary deposits (Kendy and Tresch, 1996). Water levels in wells completed in the basin fill generally ranged from slightly above land surface to more than 200 ft below land surface, with the deepest water levels typically occurring in Tertiary sediments (Dutton and others, 1995). Some wells completed in the coarse-grained Quaternary alluvium reportedly yield more than 2,000 gal/min, with a median of 50 gal/min in the Bitterroot Valley to nearly 100 gal/min in the Missoula Valley (Kendy and Tresch, 1996). Reported yields were much less in wells completed in the fine-grained Tertiary sedimentary deposits with a median of about 10 gal/min (Kendy and Tresch, 1996).

The hydraulic characteristics of the basin-fill aquifers in SUS2 are variable. Transmissivity values estimated from aquifer tests in Quaternary alluvium and Tertiary sedimentary deposits in the Bitterroot Valley range from 320 to 38,000 ft²/day (McMurtrey and others, 1972). Hydraulic conductivity values estimated from aquifer tests within the sand and gravel aquifer in the Missoula Valley range from about 1,500 to more than 20,000 ft/day (Miller, 1991), resulting in transmissivity values in the hundreds of thousands to more than 1 million ft²/day. In contrast, the estimated transmissivity values for the

Tertiary sediment range from less than 1 to 1,500 ft²/day (Kendy and Tresch, 1996).

The general direction of ground-water flow within the basin fill of the Bitterroot Valley is from the mountain fronts along the basin margins toward the center of the basin and down valley (fig. 7; Briar and others, 1996). Flow directions within the Missoula Valley generally are from upland areas to the flood plain, then northwest paralleling the Clark Fork or southeast paralleling Ninemile Creek (Kendy and Tresch, 1996). Most of the ground water within the Missoula area originates as recharge from the Clark Fork and adjoining tributaries and flows west to southwest, ultimately discharging to the Bitterroot River and the Clark Fork (Miller, 1991).

The part of SUS2 underlying the city of Missoula and surrounding areas has been designated by the USEPA as the Missoula Sole Source Aquifer (fig. 3). This aquifer supplies the drinking water for more than 50,000 people (Miller, 1991) and covers 91 mi² (about 14 percent) of the SUS2 area. Seven of the 30 wells sampled in SUS2 were located within the Missoula Sole Source Aquifer boundary.

GROUND-WATER QUALITY

Statistical summaries for selected physical properties, inorganic chemistry, (major ions, nutrients, and trace elements), and radiochemistry for the water samples collected from the basin-fill aquifers are in table 2. Summaries for pesticide and pesticide metabolites are presented in table 3, and summaries for volatile organic compounds are presented in table 4. A combination of factors, including natural dissolution of minerals and anthropogenic activities, can affect ground-water quality. Nearly all of the wells were located in residential settings surrounded by forested, agricultural (pasture, grass seed, and alfalfa), and (or) urban land uses; many wells were surrounded by a mixture of land uses.

Physical Properties

Physical properties of water measured in the field at the time of sample collection included temperature, specific conductance, dissolved oxygen, pH, and alkalinity (table 2). Water temperature of samples from both subunits ranged from 5.5 to 16.5 °C with a median of 10.0 °C. The warmest water temperatures were found in wells 28 and 30 (fig. 2) located along a losing reach of the Spokane River in SUS1 and likely represent warm summertime water from the river locally recharging the aquifer. Specific conductance of water samples from both subunits ranged from 27 to 580 µS/cm with a median of 210 µS/cm. Dissolved-oxygen concentrations ranged from ¹<0.1 to 11 mg/L with a median of 6.5 mg/L. Dissolved-oxygen concentrations less than 1 mg/L generally are an indicator of reducing

conditions in the water. Under reducing conditions, ions such as arsenic, iron, and manganese can be more soluble, potentially resulting in increased concentrations in ground water. Values of pH ranged from 5.8 to 8.3 with a median of 7.2. Water from five wells had pH values that were slightly less than the USEPA SDWR acceptable range of 6.5 to 8.5.

Hardness, which can be an undesirable property of water, causes the formation of an insoluble residue when used with soap (soap scum) and causes scale in water heaters, plumbing, and appliances. The hardness of sampled waters ranged from 8.5 to 235 mg/L as CaCO₃ with a median of 95 mg/L. Water hardness becomes objectionable for domestic purposes at a concentration of about 100 mg/L as CaCO₃ (Hem, 1985). Twenty-nine of the sampled wells had hardness values greater than 100 mg/L.

Major Ions

The major-ion chemistry of the ground water in both subunits generally was similar with most samples classified as calcium-bicarbonate type water (table 2, fig. 8). Bromide and fluoride, which commonly are included with the suite of constituents considered major ions, had median concentrations of 0.01 and <0.20 mg/L, respectively. Concentrations of chloride, fluoride, and sulfate did not exceed USEPA drinking-water standards (table 2).

Dissolved solids were calculated based on the concentrations of dissolved constituents. Dissolved-solids concentrations were less than the SDWR of 500 mg/L and ranged from 32 to 369 mg/L with a median of 131 mg/L. Dissolved-solids concentrations in ground-water samples from SUS1 and SUS2 were similar with concentrations in ground-water samples from SUS1 ranging from 36 to 277 mg/L with a median of 131 mg/L, and concentrations in samples from SUS2 ranging from 32 to 369 mg/L with a median of 125 mg/L.

Nutrients

Concentrations of nutrients in ground-water samples from both subunits analyzed for this study generally were low (table 2). Ammonia concentrations ranged from <0.02 to 0.04 mg/L and ammonia plus organic nitrogen concentrations ranged from <0.10 to 0.25 mg/L. All nitrite concentrations were less than 0.01 mg/L and, therefore, all nitrite plus nitrate concentrations were dominated by nitrate. For simplicity, the reported nitrite plus nitrate concentrations are hereinafter referred to as nitrate. Nitrate concentrations ranged from <0.05 to 7.6 mg/L with a median of 0.36 mg/L. Although nitrate was detected in most samples, none of the nitrate concentrations exceeded the USEPA MCL of 10 mg/L. Nitrate concentrations in samples from SUS1 ranged from <0.05 to 7.6 mg/L with a median of 0.26 mg/L (fig. 9), whereas nitrate concentrations in samples

¹Although several dissolved-oxygen concentrations are reported as 0.0 mg/L in Bowers and others (2003), these values are censored at 0.1 mg/L for this report.

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Table 2. Summary of physical properties, inorganic chemistry, and radiochemical data for ground-water samples collected from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001

[Data from Bowers and others (2003). Samples for major-ion, nutrient, and trace-element analysis were filtered through 0.45-micrometer filter, whereas samples for radon analysis were unfiltered. Estimated values reported in Bowers and others (2003) are censored at the reporting level for this table. Abbreviations: °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25 °C; mg/L, milligrams per liter; SUS1, Subunit survey 1; SUS2, Subunit survey 2; USEPA, U.S. Environmental Protection Agency. Symbols: <, less than reporting level; --, no data]

Property or constituent	SUS1 (Idaho and Washington)		SUS2 (Montana)		SUS1 and SUS2 combined	USEPA drinking-water regulation or health advisory ²	Number of samples exceeding USEPA regulation
	Range or value	Median	Range or value	Median	Median ¹		
Physical properties							
Water temperature (°C)	7.0-16.5	9.5	5.5-14.0	10	10.0	--	--
Specific conductance (µS/cm)	50-444	210	27-580	212	210	--	--
Oxygen, dissolved (mg/L)	³ <.1-11	8.2	.2-11	5.5	6.5	--	--
pH, field	6.2-8.3	7.6	5.8-8.1	6.9	7.2	6.5-8.5 (SDWR)	5
Alkalinity (mg/L as CaCO ₃)	19-228	88	11-246	84	88	--	--
Hardness, total (mg/L as CaCO ₃)	19-235	105	8.5-226	88	95	--	--
Dissolved solids (mg/L)	36-277	131	32-369	125	131	500 (SDWR)	0
Major ions, in milligrams per liter							
Bicarbonate (as HCO ₃)	23-278	107	13-300	102	107	--	--
Bromide	<.01-.04	.01	<.01-.17	.02	.01	--	--
Calcium	3.6-71	26	2.3-71	22	25	--	--
Chloride	.34-6.6	1.4	<.08-20	2.7	1.5	250 (SDWR)	0
Fluoride	<.10-.24	<.10	<.20-1.7	<.20	<.20	4 (MCL), 2.0 (SDWR)	0
Magnesium	1.6-31	8.5	.65-22	6.4	8.2	--	--
Potassium	.18-4.1	1.5	.26-9.2	1.6	1.5	--	--
Silica	7.4-39	17	12-55	20	19	--	--
Sodium	1.6-25	3.8	2.1-43	7.3	5.2	--	--
Sulfate (as SO ₄)	.61-74	7.3	.29-24	4.2	5.6	250 (SDWR)	0
Nutrients, in milligrams per liter							
Ammonia, as N	<.02-.04	<.02	<.04-.04	<.04	<.04	30 (LHA)	0
Ammonia plus organic nitrogen, as N	<.10	<.10	<.10-.25	<.10	<.10	--	--
Nitrite, as N	<.01	<.01	<.006-.006	<.006	<.01	1 (MCL)	0
Nitrite plus nitrate, as N	<.05-7.6	.26	<.05-1.8	.40	.36	10 (MCL)	0
Orthophosphate, as P	<.01-.08	.02	<.02-.07	.02	.02	--	--
Phosphorus, as P	<.004-.093	.012	<.006-.084	.018	.017	--	--
Trace elements, in micrograms per liter							
Aluminum	<1.0-6.0	1.2	<1.0-14	<1.0	<1.0	50-200 (SDWR)	0
Antimony	<1.0	<1.0	<.05-.45	.05	<1.0	6 (MCL)	0
Arsenic	<1.0-31	2.0	<.20-5.1	.41	<1.0	10 (MCL)	3
Barium	5.9-129	31	1.3-498	42	37	2,000 (MCL)	0
Beryllium	<1.0	<1.0	<.06	<.06	<1.0	4 (MCL)	0
Boron	--	--	<7.0-95	7.8	7.8	--	--
Cadmium	<1.0	<1.0	<.04-.04	<.04	<1.0	5 (MCL)	0

Table 2. Summary of physical properties, inorganic chemistry, and radiochemical data for ground-water samples collected from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001—Continued

Property or constituent	SUS1 (Idaho and Washington)		SUS2 (Montana)		SUS1 and SUS2 combined	USEPA drinking-water regulation or health advisory ²	Number of samples exceeding USEPA regulation
	Range or value	Median	Range or value	Median	Median ¹		
Trace elements, in micrograms per liter--Continued							
Chromium	<1.0-1.4	<1.0	<.80-.83	<.80	<1.0	⁴ 100 (MCL)	0
Cobalt	<1.0	<1.0	<.02-.10	.04	<1.0	--	--
Copper	<1.0-1.5	<1.0	<.20-4.2	.58	<1.0	1,300 (AL), 1,000 (SDWR)	0
Iron	<10-604	<10	<10-486	<10	<10	300 (SDWR)	3
Lead	<1.0	<1.0	<.08-.40	<.08	<1.0	15 (AL)	0
Lithium	--	--	.38-10	3.6	3.6	--	--
Manganese	<1.0-129	<1.0	<.10-42	.48	<1.0	50 (SDWR)	3
Molybdenum	<1.0-4.7	<1.0	<.20-18	.37	<1.0	--	--
Nickel	<1.0-1.2	<1.0	<.06-.27	<.06	<1.0	--	--
Selenium	<1.0	<1.0	<.30-.36	<.30	<1.0	50 (MCL)	0
Silver	<1.0	<1.0	<1.0	<1.0	<1.0	100 (SDWR)	0
Strontium	--	--	22-433	87	87	--	--
Thallium	--	--	<.04-.11	<.04	<.04	2 (MCL)	0
Uranium	<1.0-5.8	1.3	<.02-7.9	.70	<1.0	30 (MCL)	0
Vanadium	--	--	<.20-11	.65	.65	--	--
Zinc	1.9-349	25	<1.0-143	13	19	5,000 (SDWR)	0
Radiochemical, in picocuries per liter							
Radon	376-2,943	769	253-3,047	1,270	853	⁵ 300 (proposed MCL) 4,000 (proposed AMCL)	60 0

¹For determination of the median for the combined SUS1 and SUS2 datasets, data were censored at the highest reporting level, when multiple reporting levels existed.

²USEPA drinking-water regulation or health advisory (U.S. Environmental Protection Agency, 2002): MCL—Maximum Contaminant Level is the maximum permissible level of a contaminant in water delivered to users of a public-water system. MCLs are health-based and enforceable regulations. SDWR—National Secondary Drinking Water Regulations is a guideline regarding cosmetic or aesthetic effects of drinking water. SDWRs are non-enforceable. LHA—Lifetime Health Advisory is the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects for a lifetime of exposure. Non-enforceable guidelines for noncarcinogenic effects determined for a 70-kilogram adult consuming 2 liters of water per day over a 70-year lifetime. AL—Action Level refers to the concentration which, if exceeded, requires treatment to lower the concentration. ALs for lead and copper are regulated according to treatment types and may be a MCL for these elements. AMCL—Alternate Maximum Contaminant Level.

³Although several dissolved-oxygen concentrations are reported as 0.0 mg/L in Bowers and others (2003), these values are censored at 0.1 mg/L for this report.

⁴MCL for total chromium (U.S. Environmental Protection Agency, 2002).

⁵USEPA has proposed two options for the MCL of radon. The proposed MCL is 300 picocuries per liter (pCi/L) and the proposed AMCL is 4,000 pCi/L. The AMCL applies to those States or community-water systems that develop a multimedia mitigation program to address radon in indoor air (U.S. Environmental Protection Agency, 2002).

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Table 3. Pesticides and pesticide metabolites detected in ground-water samples collected from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001

[Abbreviations: USEPA, U.S. Environmental Protection Agency; e, estimated; µg/L, micrograms per liter. Symbol: --, no data]

Constituent	Number of water samples with detections	Well number (figs. 2 and 3)	Maximum concentration (µg/L)	USEPA drinking-water regulation or health advisory (µg/L) ¹
2,4-D methyl ester ²	1	60	0.014	--
3-Hydroxycarbofuran ²	5	8, 14, 17, 22, and 23	e.005	--
Aldicarb sulfone ²	1	8	e.002	3 (MCL)
Aldicarb sulfoxide ²	1	8	e.001	4 (MCL)
Atrazine ³	2	39 and 41	.031	⁴ 3(MCL)
Carbofuran ²	3	8, 22, and 23	e.007	40 (LHA)
Carbaryl ³	2	1 and 2	e.010	700 (LHA)
Deethylatrazine ³	2	39 and 41	e.005	--
Dicamba ²	1	60	.034	200 (LHA)
Dinoseb ²	1	19	e.035	7 (MCL)
Imazethapyr ²	1	36	e.014	--
Oryzalin ²	1	43	e.012	--
Prometon ³	4	39, 41, 46, and 57	e.007	100 (LHA)
Tebuthiuron ³	1	39	.044	500 (LHA)

¹USEPA drinking-water regulation of health advisory (U.S. Environmental Protection Agency, 2002): MCL—Maximum Contaminant Level is the maximum permissible level of a contaminant in water delivered to users of a public-water system. MCLs are health-based and enforceable regulations. LHA—Lifetime Health Advisory is the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects for a lifetime of exposure. Non-enforceable guidelines for noncarcinogenic effects determined for a 70-kilogram adult consuming 2 liters of water per day over a 70-year lifetime.

²Results of high-performance liquid chromatography/mass spectrometry analysis (Furlong and others, 2001). Analytical results of samples collected during 1999 were produced using a new custom method, and most of those samples exceeded recommended holding times at the National Water Quality Laboratory (Furlong and others, 2003). Therefore, pesticides sampled during 1999 (wells 1-31) and analyzed by this method could be biased low because of potential degradation during storage and these data were not included in Bowers and others (2003). These limitations need to be considered when interpreting the 1999 data. Pesticide data analyzed by this method for samples collected during 2001 (wells 32-61) are included in Bowers and other (2003).

³Data from Bowers and others (2003). Results of gas chromatography/mass spectrometry analysis (Zaugg and others, 1995).

⁴Drinking-water standard is under review by USEPA (U.S. Environmental Protection Agency, 2002).

from SUS2 ranged from <0.05 to 1.8 mg/L with a median of 0.40 mg/L (fig. 9). Nitrate concentrations were not significantly different between samples from the two subunit surveys ($p = 0.960$; Wilcoxon rank-sum test). For comparison, nitrate concentrations in samples collected during 1991-2001 from more than 2,800 subunit-survey wells in 50 NAWQA Study Units across the Nation (NWIS data base, retrieved April 23, 2002) ranged from <0.05 mg/L to 77 mg/L with a median of 0.54 mg/L.

Nutrients in ground water can originate from several sources including dissolution of geologic materials, atmospheric deposition, nitrogen-fixing plants such as alfalfa, septic-system effluent or leaky sewer lines, agricultural and domestic fertilizers, and animal manure. Nationally, the background concentration of nitrate in ground water in areas considered to be minimally affected by agricultural, urban, and associated land uses was estimated to be about 2 mg/L (U.S. Geological Survey, 1999, p. 34). Samples from seven wells within the NROK subunit surveys had nitrate concentrations of 2 mg/L or greater, which indicates the possible influence from human activities. All seven wells were located within SUS1 and six of them were located within the basin-fill aquifer north of Spokane, Wash. (fig. 9). Land-use surveys conducted during sample collection

indicated that all of these wells were located in rural areas where agriculture is the primary land use that includes pasture and crops of alfalfa and grass seed.

Although nitrate concentrations in the samples collected in the NROK subunits generally were low, elevated nitrate concentrations have been reported in the area (EMCON, 1992; Briar and Dutton, 2000; Eliopoulos and others, 2001). Nitrate concentrations as high as 250 mg/L have been measured north of Spokane in the SUS1 study area (EMCON, 1992). These high concentrations reportedly resulted from past manure disposal practices (EMCON, 1992). The Idaho Department of Agriculture (Eliopoulos and others, 2001) determined that nitrate concentrations in water from about 5 percent of the approximately 40 wells they sampled per year during 1998-2001 in the eastern part of the SUS1 area in Idaho exceeded 2 mg/L; the maximum nitrate concentration they detected was 5.5 mg/L. Although nitrate concentrations in samples collected for this study from SUS2 were all less than 2 mg/L, Briar and Dutton (2000) reported nitrate concentrations that exceeded 2 mg/L (range of <0.15 to 5.9 mg/L) in samples from about 16 percent of 239 wells sampled in the Bitterroot Valley between 1994 and 1997. Briar and Dutton (2000) also noted a seasonal variation in nitrate concentration in water from some wells.

Table 4. Volatile organic compounds detected in ground-water samples collected from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001

[Data from Bowers and others (2003). Abbreviations: e, estimated; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency. Symbol: --, no data]

Constituent	Number of water samples with detections	Well number (figs. 2 and 3)	Maximum concentration (µg/L)	Reporting limit range or value (µg/L)	Common uses or sources	USEPA drinking-water regulation or health advisory (µg/L) ¹
1,1,1-Trichloroethane	7	3, 6, 15, 26, 39, 40, 58	0.130	0.032	Adhesives, building materials, cleaning products, paints, metal degreasing	200 (MCL)
1,1-Dichloroethane	1	31	.184	.035-.066	Used to make other chemicals, degreasing	--
Bromodichloromethane	3	39, 41, 61	.165	.048	Drinking water disinfection byproduct	² 80 (MCL)
Chloroform	7	7, 30, 39, 40, 41, 57, 61	.540	.024-.052	Drinking water disinfection byproduct	² 80 (MCL)
cis-1,2-dichloroethylene	1	31	e.029	.038	Solvent	70 (MCL)
Dibromochloromethane	2	41, 61	e.062	.180	Drinking water disinfection byproduct	² 80 (MCL)
Dichlorodifluoromethane	4	2, 31, 41, 45	e1.60	.140-.270	Refrigerant	1,000 (LHA)
Dichloromethane	1	31	e.129	.160-.380	Paint remover, solvent	5 (MCL)
Tetrachloroethylene	6	1, 39, 40, 41, 45, 56	1.64	.100	Dry cleaning, metal degreasing, solvent	5 (MCL)
Tetrachloromethane	1	27	e.012	.060-.088	Manufacture of propellants and refrigerants, dry cleaning, solvent	5 (MCL)
Toluene ³	1	13	4.31	.050	Used in fuels	1,000 (MCL)
Trichlorofluoromethane	1	26	.111	.090	Refrigerant	2,000 (LHA)

¹USEPA drinking-water regulation of health advisory (U.S. Environmental Protection Agency, 2002): MCL—Maximum Contaminant Level is the maximum permissible level of a contaminant in water delivered to users of a public-water system. MCLs are health-based and enforceable regulations. LHA—Lifetime Health Advisory is the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects for a lifetime of exposure. Non-enforceable guidelines for noncarcinogenic effects determined for a 70-kilogram adult consuming 2 liters of water per day over a 70-year lifetime.

²Total trihalomethanes (TTHMs) including bromoform, bromodichloromethane, chloroform, and dibromochloromethane should not exceed 80 µg/L (U.S. Environmental Protection Agency, 2002).

³Toluene reported in samples from nine other wells at concentrations less than 0.2 µg/L are not considered as detections because of possible equipment contamination.

Nitrate concentrations in ground water can be influenced by the presence of dissolved oxygen. Nitrate generally is the principal form of nitrogen in ground water with relatively high concentrations of dissolved oxygen. The seven samples with the highest nitrate concentrations (greater than 2 mg/L) all contained dissolved-oxygen concentrations greater than 1 mg/L. Nitrate reduction (denitrification) commonly occurs in ground water with low dissolved-oxygen concentrations (U.S. Geological Survey, 1999), and all samples from SUS1 and SUS2 with nitrate concentrations less than the reporting level (0.05 mg/L) had dissolved oxygen concentrations of less than 1 mg/L.

The relation between nitrate concentrations, depth to open interval, and depth to water was examined. Nitrate concentrations do not appear to be significantly related to the depth of the open interval ($p = 0.254$, $\rho = -0.084$) or the depth to water ($p = 0.272$, $\rho = -0.078$).

Nolan and others (1998) delineated the risk of nitrate contamination in ground water based on population density, nitrogen loading from atmospheric deposition, fertilizer and manure application, and aquifer vulnerability (soil drainage characteristics and woodland to cropland ratios in agricultural areas). The highest potential for contamination of ground water from nitrate occurs in areas with high population densities, high nitrogen input, well-drained soils, and low woodland to cropland ratios. While most of the NROK Study Unit was classified as low risk by Nolan and others (1998), the western part of the SUS1 area was classified as having a moderately high to high risk for nitrate contamination. Although nitrate concentrations within SUS1 generally were low, the highest nitrate concentrations in SUS1 occurred within the areas of moderately high to high risk.

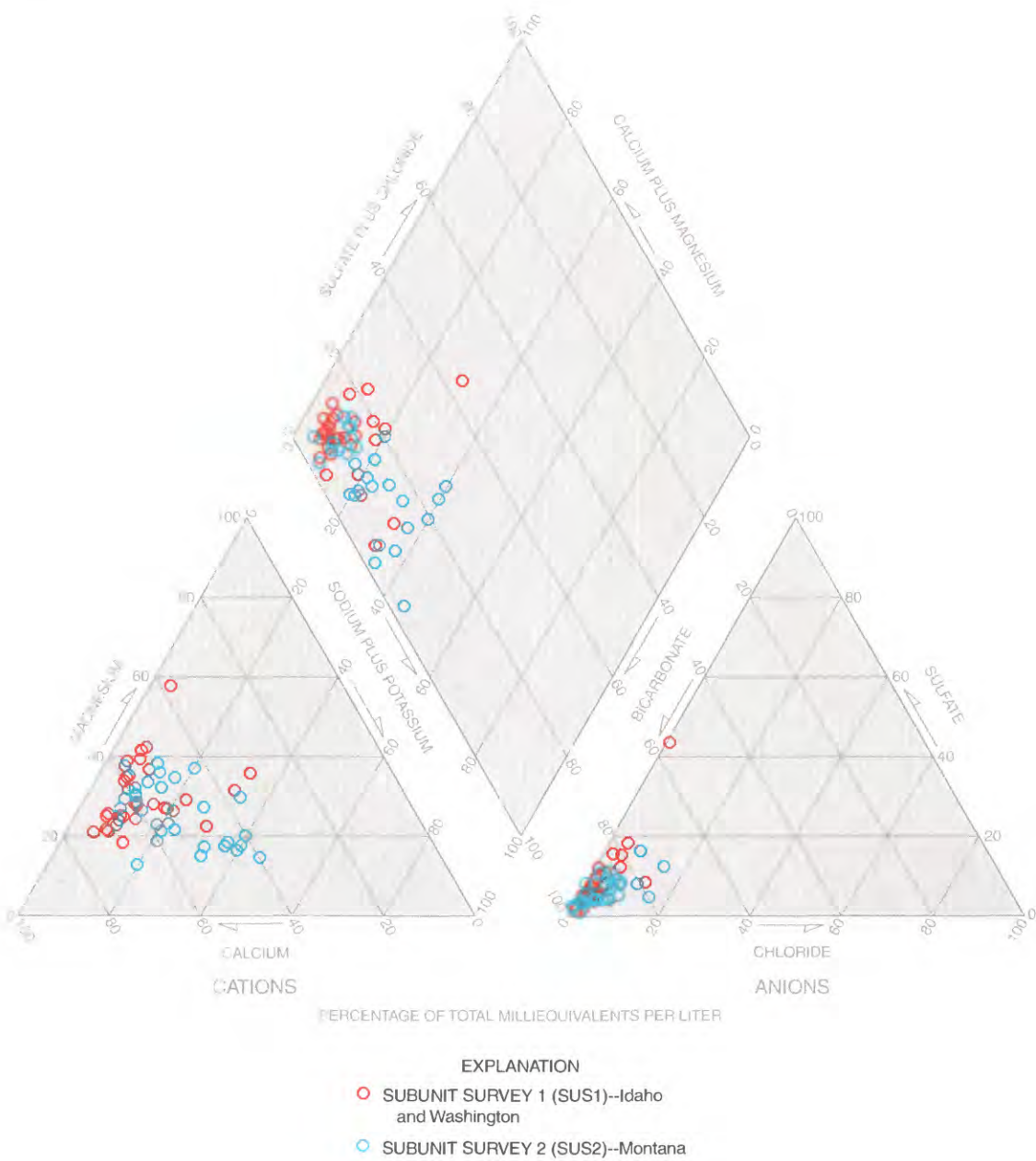


Figure 8. Modified trilinear diagram showing percentages of major cations and anions in ground-water samples from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001.

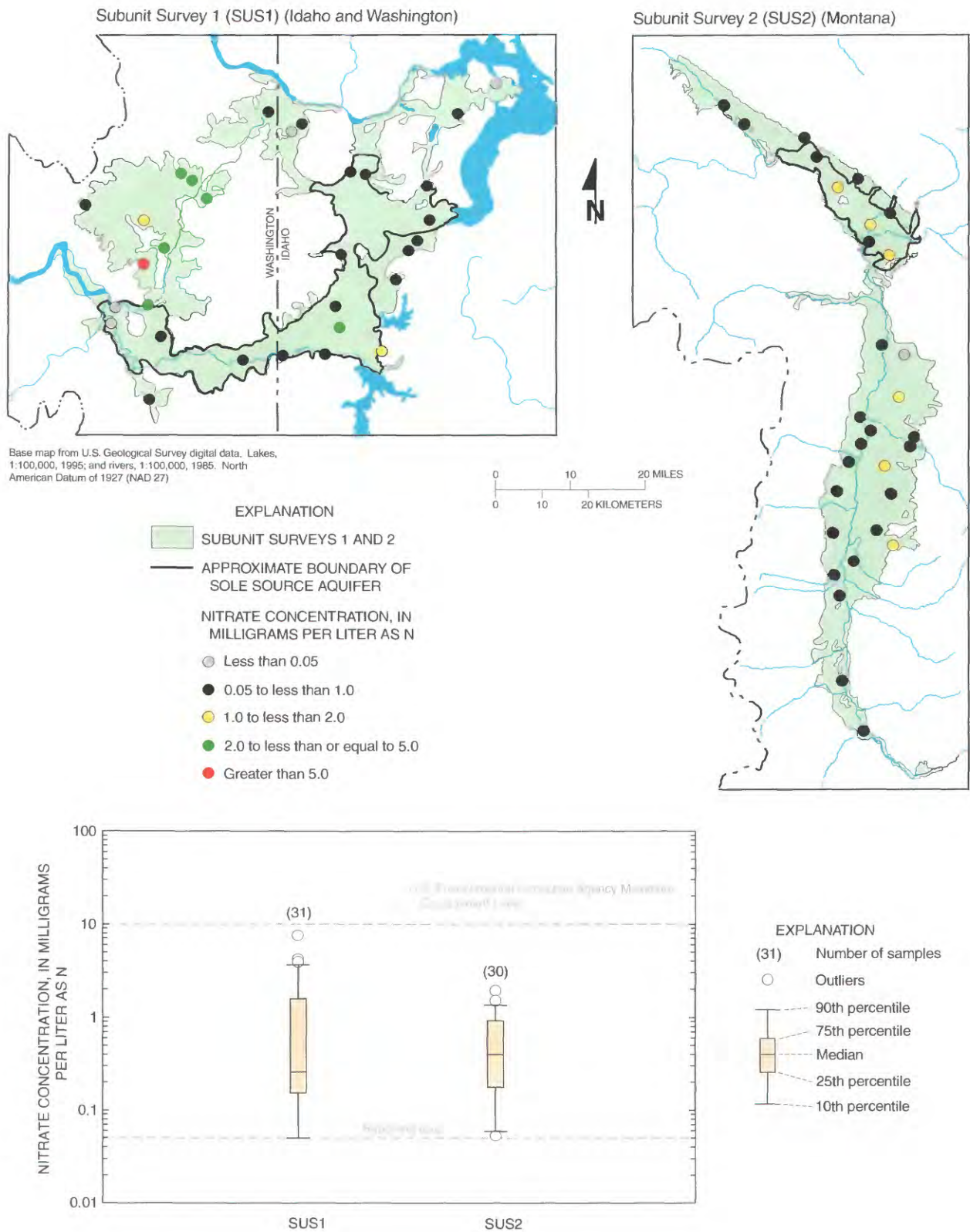


Figure 9. Sampling locations and range of nitrate concentrations in ground-water samples collected from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001. Values equal to or less than reporting level are plotted as the reporting level.

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Dissolved phosphorus concentrations generally were low, ranging from <0.004 to 0.093 mg/L with a median of 0.017 mg/L. Dissolved orthophosphate concentrations ranged from <0.01 to 0.08 mg/L with a median of 0.02 mg/L. Orthophosphate concentrations generally were similar to total phosphorus concentrations, indicating that orthophosphate probably was the prevalent form of phosphorus in ground water in the study area. Phosphorus is an essential nutrient for plants and is found naturally in igneous and sedimentary rocks and in anthropogenic sources such as manure, detergents, and fertilizers. Elevated phosphorus concentrations in surface water can stimulate the growth of algae and other aquatic plants, which can lead to an increase in eutrophication that may adversely affect aquatic life. Currently (2003), water-quality criteria have not been established for phosphorus concentrations in ground water. The USEPA recommends that the total phosphorus concentration in surface water should not exceed 0.1 mg/L (as P) for flowing water that does not discharge directly into a lake or reservoir (U.S. Environmental Protection Agency, 1986). Because ground water commonly discharges to surface water, elevated phosphorus concentrations in ground water can be of concern. None of the samples collected for this study had phosphorus concentrations that exceeded 0.1 mg/L.

Trace Elements

Concentrations of trace elements typically were low; however, concentrations of arsenic, iron, and manganese exceeded USEPA MCLs or SDWRs in a few instances (table 2). Concentrations of other trace elements were less than one-half of the applicable drinking water standard.

Arsenic is a human carcinogen and has a MCL of 10 $\mu\text{g/L}$ (U.S. Environmental Protection Agency, 2002). Arsenic concentrations in ground water ranged from <0.20 $\mu\text{g/L}$ to 31 $\mu\text{g/L}$ with a median of <1.0 $\mu\text{g/L}$ (table 2, fig. 10). Samples from three wells (5, 18, and 23) in SUS1 had arsenic concentrations greater than the MCL; the highest arsenic concentration in the samples from SUS2 was 5.1 $\mu\text{g/L}$. A comparison of arsenic concentrations in water samples from both subunits (Wilcoxon rank-sum test) indicates that concentrations in SUS1 were significantly higher ($p = 0.0003$) than concentrations in SUS2. For comparison, the median arsenic concentration in ground-water samples collected during 1991-2001 from more than 2,100 subunit-survey wells in 39 NAWQA Study Units across the Nation was <1.0 $\mu\text{g/L}$; the highest concentration was 242 $\mu\text{g/L}$ (NWIS data base, retrieved April 23, 2002).

Arsenic in most ground water is derived naturally from water-rock interactions such as desorption from iron-oxide minerals or dissolution of iron-oxide or sulfide minerals, or from geothermal water (Welch and others, 2000). Arsenic also has been associated locally with anthropogenic activities such as mining, wood preservation, agricultural application, and glass production (Welch and others, 1998; 2000). Welch and others (1988) determined that natural occurrences of high concentrations of arsenic in ground water in the western United States

were generally associated with one of four geological environments: (1) basin-fill deposits of alluvial-lacustrine origin, (2) volcanic deposits, (3) geothermal systems, and (4) uranium and gold-mining areas. All of these environments exist within the NROK Study Unit.

Welch and others (2000) reported that arsenic release from iron-oxide minerals, either by desorption or by dissolution of the iron-oxide minerals, might be the primary cause of arsenic concentrations in excess of 10 $\mu\text{g/L}$ in ground water. Water from two of the three wells with arsenic concentrations greater than 10 $\mu\text{g/L}$ had dissolved-oxygen concentrations less than 0.2 mg/L. Low dissolved-oxygen concentrations generally enhance dissolution of iron-oxide minerals. However, dissolved-oxygen concentrations were not significantly correlated with arsenic concentrations for samples collected for this study ($p = 0.13$, $\rho = 0.144$; Spearman's rank correlation). Desorption of arsenic from amorphous iron oxide or aquifer sediments can be promoted by high pH (Welch and others, 2000); the three water samples with the highest arsenic concentrations had pH values of 8.0 or higher. A statistically significant positive correlation ($p < 0.0001$, $\rho = 0.74$; Spearman's rank correlation) was found between pH and arsenic concentrations in ground-water samples from this study.

Iron concentrations ranged from <10 $\mu\text{g/L}$ to 604 $\mu\text{g/L}$ with a median of <10 $\mu\text{g/L}$ (table 2). Samples from three wells (5, 25, and 42) had iron concentrations higher than the SDWR of 300 $\mu\text{g/L}$ (U.S. Environmental Protection Agency, 2002). Dissolved-oxygen concentrations of 1.0 mg/L or less were measured at the seven sites with the highest iron concentrations (greater than or equal to 60 $\mu\text{g/L}$). A statistically significant ($p = 0.0001$) but weak negative correlation (Spearman's $\rho = -0.49$) was found between dissolved oxygen and iron concentrations. Correlations were not statistically significant for the relation between pH and iron concentration ($p = 0.1048$, $\rho = -0.162$; Spearman's rank correlation).

Manganese concentrations ranged from <0.10 to 129 $\mu\text{g/L}$ with a median of <1.0 $\mu\text{g/L}$ (table 2). Samples from three wells (5, 23, and 25) in SUS1 had manganese concentrations higher than the SDWR standard of 50 $\mu\text{g/L}$ (U.S. Environmental Protection Agency, 2002). Manganese concentrations in water from these wells ranged from 82 to 129 $\mu\text{g/L}$. Water from the three wells with manganese concentrations greater than 50 $\mu\text{g/L}$ had dissolved-oxygen concentrations of 0.3 mg/L or less. A statistically significant ($p = 0.0012$) but weak negative correlation (Spearman's $\rho = -0.393$) was found between dissolved-oxygen and manganese concentrations most likely because of the greater solubility of manganese in reducing conditions. The relation between pH and manganese ($p = 0.252$, $\rho = -0.086$; Spearman's rank correlation) was not statistically significant. A significant positive correlation was found between iron and manganese concentrations ($p < 0.0001$, $\rho = 0.665$; Spearman's rank correlation), indicating that aquifer mineralogy and reducing conditions, in part, may control concentrations of both constituents.

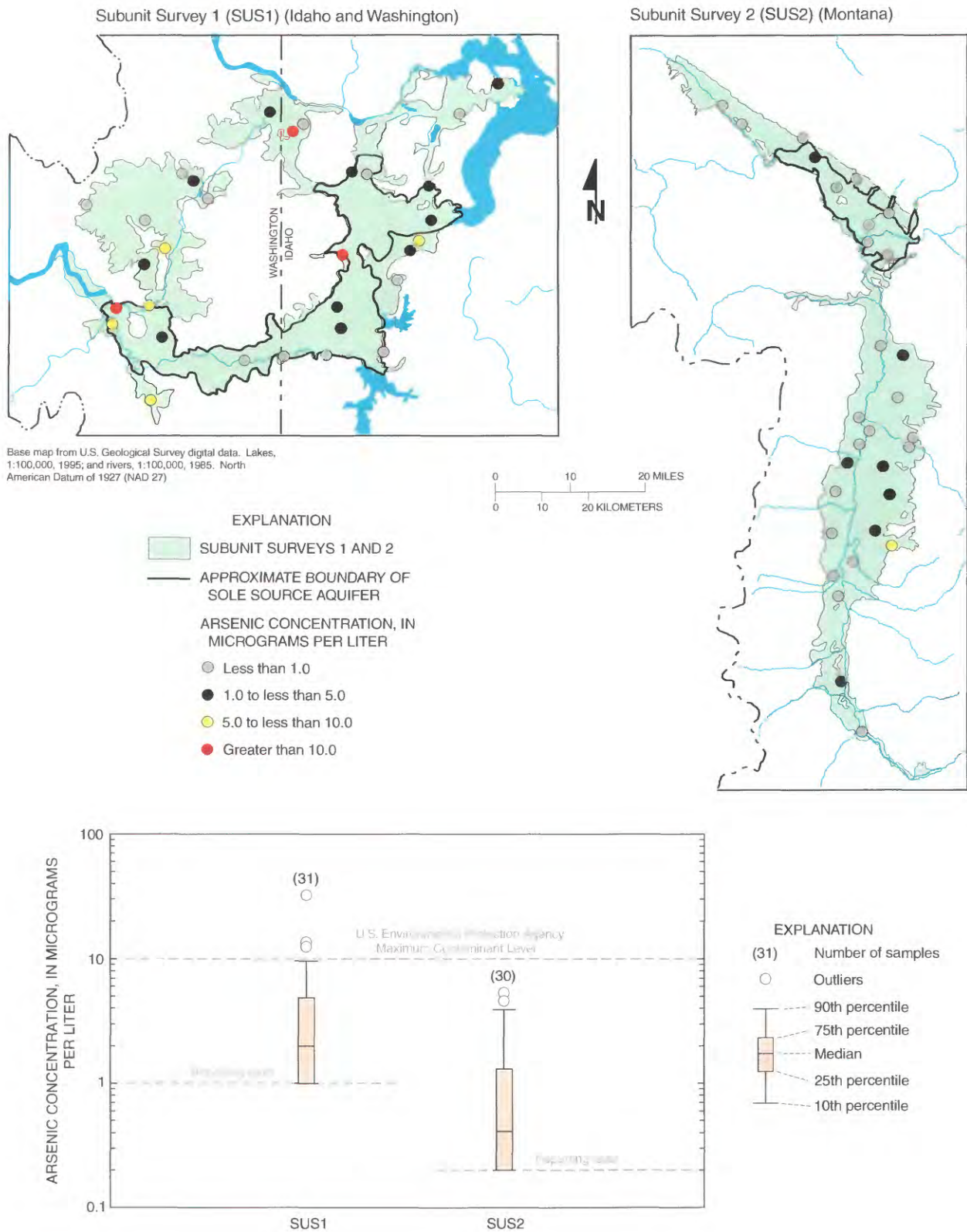


Figure 10. Sampling locations and range of arsenic concentrations in ground-water samples collected from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001. Values equal to or less than reporting level are plotted as the reporting level.

Radon

Radon is a naturally occurring, colorless, odorless, and tasteless gas derived from the radioactive decay of uranium-238 and is present to some extent in nearly all rocks and soil. Granite, light-colored volcanic rocks, dark-colored shales, sedimentary rocks that contain phosphate, and metamorphic rocks derived from these rocks generally contain the highest uranium concentrations (Otton, 1992). Granitic bedrock in parts of western Montana can contain as much as 10 parts per million of uranium (Clark and Briar, 1993). Ground water in contact with these rocks or the sediment derived from them could potentially have high concentrations of dissolved radon. Granitic bedrock is common throughout the NROK Study Unit, and the relation between granitic bedrock and high radon levels in ground water has been observed at several locations in the northwestern United States (Clark and Briar, 1993; Parlman, 1996; Clark and Eddy-Miller, 1998).

Radon exposure has been associated with increased lung-cancer risk and the USEPA recommends that the average radon concentration in indoor air should not exceed 4 pCi/L (U.S. Environmental Protection Agency, 1992). Radon gas is soluble in water and can enter homes through normal water use such as showering, flushing toilets, washing clothes, and washing dishes. Drinking water with high concentrations of radon has been linked to a slightly increased risk of stomach cancer (U.S. Environmental Protection Agency, 2000b). New regulations have been proposed to reduce public health risks from radon in drinking water (U.S. Environmental Protection Agency, 2002). The proposed standards will allow States flexibility on how to address the risk of radon in indoor air while also reducing risks from radon in drinking water. For States that do not initiate a multimedia mitigation (MMM) program to address health risks from indoor air, the proposed MCL for radon in drinking water is 300 pCi/L. For States that develop a MMM program, the proposed Alternate Maximum Contaminant Level (AMCL) is 4,000 pCi/L.

Radon was detected in water from all 61 wells sampled and concentrations ranged from 253 to 3,047 pCi/L with a median of 853 pCi/L (table 2, fig. 11). Radon concentrations in all samples were less than the proposed AMCL of 4,000 pCi/L; however, radon concentrations in 98 percent of the water samples were greater than the proposed MCL of 300 pCi/L. The ranges of concentrations in the two subunits were similar. A statistical comparison of data from both subunits indicated that radon concentrations of the two subunits were not significantly different from one another ($p = 0.0519$, Wilcoxon rank-sum test). However, the median radon concentration (769 pCi/L) in samples from SUS1 was lower than the median concentration (1,270 pCi/L) in samples from SUS2 (table 2, fig. 11). Radon concentrations from this study are similar to those reported in a previous study of the Bitterroot Valley (Briar and Dutton, 2000) in which radon concentrations in ground-water samples from 43 wells ranged from 150 to 3,700 pCi/L with a median of 810 pCi/L.

Radon concentrations in ground-water samples collected throughout the Nation from 2,500 wells during 1991-2001 as part of the NAWQA program had concentrations ranging from <80 to more than 200,000 pCi/L with a median of 417 pCi/L (NWIS data base, retrieved April 23, 2002). About 90 percent of the radon concentrations in ground-water samples collected for the NROK subunit surveys exceeded the NAWQA nationwide median radon concentration of 417 pCi/L.

Depth to water, well-construction characteristics, pH, dissolved oxygen, and uranium data were examined to evaluate their relation with radon concentrations. Significant correlations were not found between radon concentration and depth to water, or radon concentration and depth to the open interval in the well ($p = 0.105$, $\rho = -0.162$; and $p = 0.064$, $\rho = -0.197$, respectively; Spearman's rank correlation). Significant but weak negative correlations were found between radon concentration and pH, and radon concentration and dissolved oxygen concentrations ($p = 0.0195$, $\rho = -0.266$; and $p = 0.024$, $\rho = -0.254$, respectively; Spearman's rank correlation). Significant correlations were not found between radon and uranium concentrations ($p = 0.198$, $\rho = -0.110$; Spearman's rank correlation).

In the SUS1 area, the highest radon concentrations (greater than 2,000 pCi/L) in water were in samples from wells near the margins of the basin-fill aquifers (fig. 11). A source for the high radon concentrations in water from these wells may be the inflow of ground water derived from the surrounding (primarily granitic) bedrock. In SUS2, 4 of 5 wells with the highest radon concentrations (greater than 2,000 pCi/L) in water were located on the western side of the Bitterroot Valley (fig. 11). Briar and Dutton (2000) also reported relatively high radon concentrations in ground-water samples from an area on the western side of the Bitterroot Valley. The mountains to the west of the Bitterroot Valley generally are composed of igneous bedrock (primarily granitic rocks), whereas the mountains to the east are composed mostly of metasedimentary rocks (Tuck and others, 1996). The high radon concentrations in samples from wells near the western margin of the Bitterroot Valley may be influenced by the inflow of ground water from the granitic bedrock or from the basin fill that was, at least in part, derived locally from the granitic bedrock. The lowest radon concentrations (less than 500 pCi/L) in SUS2 were in samples from wells completed in either Tertiary sediment along the eastern side of the Bitterroot Valley or Quaternary alluvium in the Missoula area. The primary source of the Tertiary sediment along the eastern side of the Bitterroot Valley is metasedimentary rock. Therefore, the relatively low radon concentrations in water may be due to low uranium concentrations in these rocks and sediments. The relatively low radon concentrations in ground water from wells in the Missoula area are likely due to the occurrence of relatively young water recently recharged from the Clark Fork. Radon concentrations in surface water generally are low because radon rapidly escapes to the atmosphere.

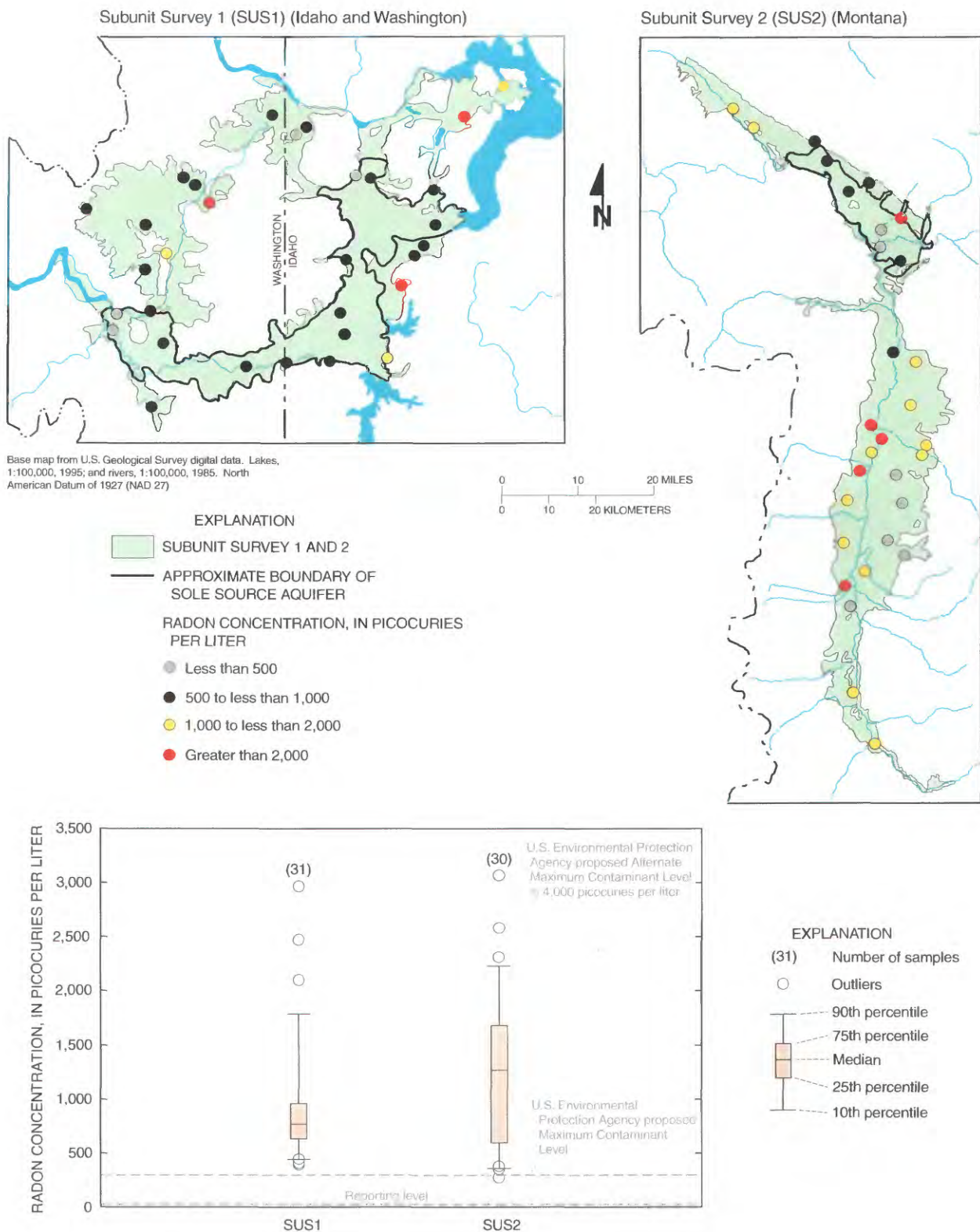


Figure 11. Sampling locations and range of radon concentrations in ground-water samples collected from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001.

Pesticides

Pesticides (including fungicides, herbicides, and insecticides) in aquatic systems can be a concern to human health and biota. Pesticides primarily are applied to croplands, but also are used in suburban and urban areas on lawns, gardens, golf courses, and roadsides. Pesticides have been detected in ground water, surface water, fish tissue, streambed sediment, and the atmosphere in many parts of the Nation (Majewski and Capel, 1995; U.S. Geological Survey, 1999). NAWQA studies have shown that the most heavily used pesticides are found most often occurring in ground water and surface water in areal and seasonal patterns that mainly correspond to distributions of land use and associated pesticide use (U.S. Geological Survey, 1999). Nationwide, where detected, the concentrations of pesticides in ground water generally are lower than concentrations in surface water. The lower concentrations in ground water are at least partially attributed to degradation and sorption of pesticides as water flows through soil and rock matrices (U.S. Geological Survey, 1999).

Agricultural land use in the NROK includes pasture and the production of hay, grass seed (predominantly in SUS1), wheat, barley, and oats. Pesticide use on these lands generally is low when compared to many agricultural areas in other parts of the Nation. Figure 12 shows the usage rates of the 20 most commonly used pesticides in the NROK Study Unit and the amount used in the Study Unit as a percentage of the total amount used nationally in 1992 (Majewski, 1997).

Ground-water samples were analyzed for 104 different pesticides and metabolites (appendixes 2 and 3). At least 1 of 14 pesticides was detected in environmental samples of water

from 15 (25 percent) of the 61 wells sampled (table 3, fig. 13). However, most pesticides identified were at estimated concentrations much less than reporting levels, and none exceeded drinking-water standards (table 3). Multiple pesticides were detected in water from six wells with a maximum of four detections in water from two of those wells. The most commonly detected pesticides were 3-hydroxycarbofuran (5 detections), prometon (4 detections), and carbofuran (3 detections); all of these detections were at low, estimated concentrations.

Samples from only three wells had pesticide concentrations that were not considered estimates. The highest concentration detected was of tebuthiuron (0.044 µg/L) in a sample from well 39 near Missoula. Tebuthiuron generally is used to control broadleaf weeds, grasses, and brush. Two wells in the Missoula area (wells 39 and 41) had detectable concentrations of atrazine. Deethylatrazine, a degradation product of atrazine, also was detected at estimated concentrations in the samples from these two wells. Atrazine is an herbicide used extensively on a variety of crops and on nonagricultural lands. Detectable concentrations of both dicamba (0.034 µg/L) and 2,4-D methyl ester (0.014 µg/L) were determined in water from well 60. Dicamba is used to control annual and perennial broadleaf weeds, brush, and vines in rangeland and other non-cropland areas. 2,4-D methyl ester is used to control a variety of weeds including Canadian thistle, dandelion, lambsquarters, and ragweed in pastures, rangeland, and a variety of agricultural crops. Well 60 is surrounded by pasture and located in a rural area of the southern Bitterroot Valley.

Carbofuran and (or) its breakdown product 3-hydroxycarbofuran were detected in ground water from five wells (table 3). Carbofuran is primarily used on fruits, vegetables, and forests

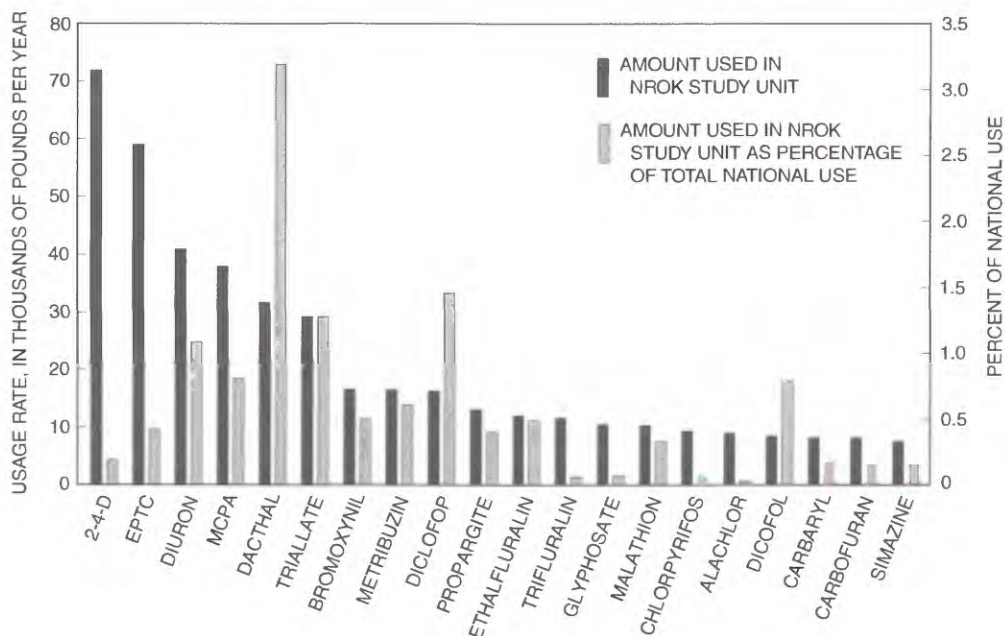


Figure 12. Usage rates of the 20 most commonly used pesticides in the Northern Rockies Intermontane Basins (NROK) Study Unit and the amount used in the Study Unit as a percentage of the total amount used nationally in 1992 (modified from Majewski, 1997).

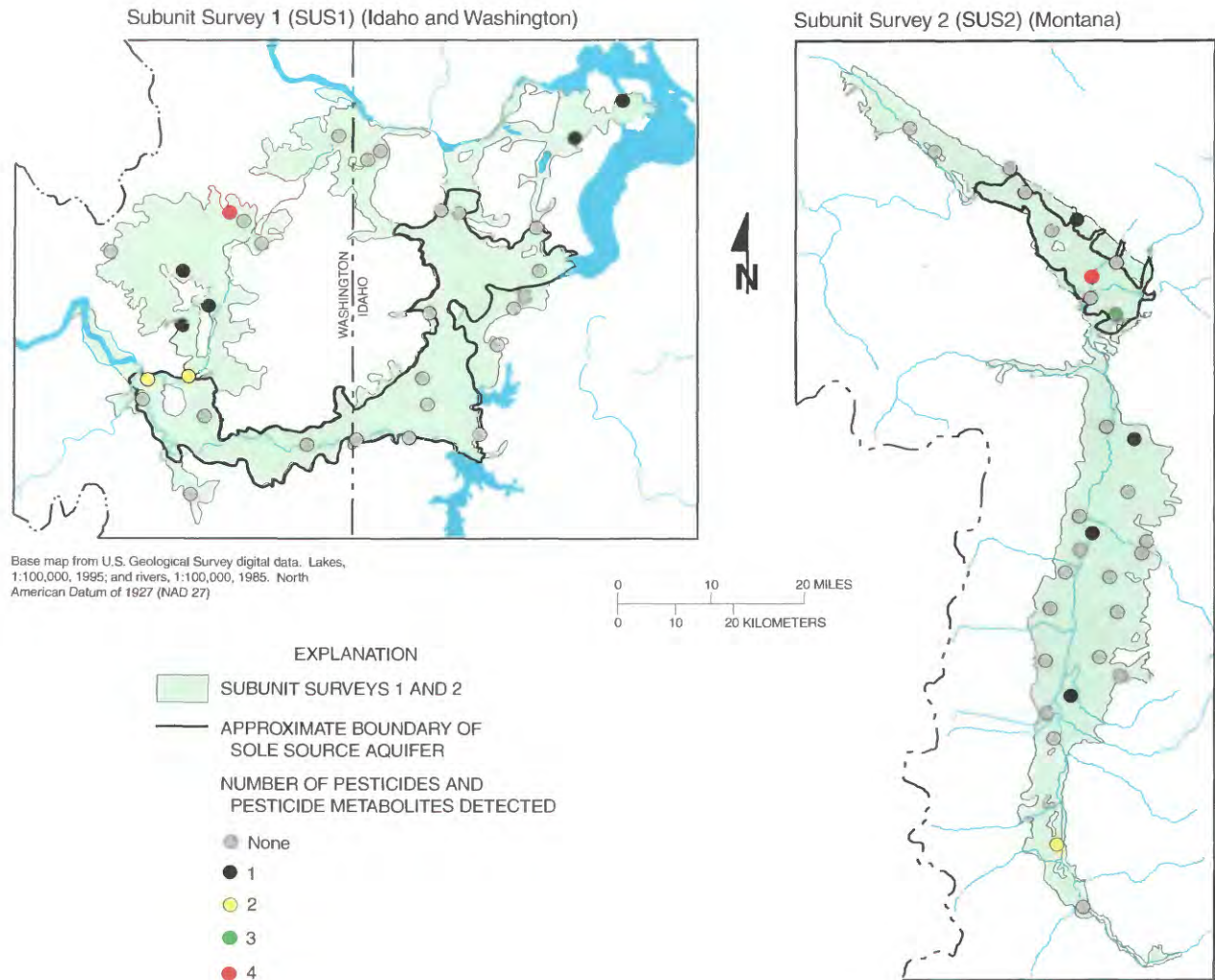


Figure 13. Sampling locations and number of pesticides and pesticide metabolites detected in ground-water samples collected from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001.

to control a variety of insects. Carbofuran and 3-hydroxycarbofuran were detected only in the Little Spokane River Valley north of Spokane, an area of relatively heavy agricultural land use. Prometon was detected in ground water from four wells (table 3). The herbicide prometon is primarily used for nonagricultural purposes such as bare-ground weed control around buildings, storage areas, fences, roadways, railroads, recreation areas, non-crop areas on farms, and right-of-ways.

Eliopulos and others (2001) determined that water from only 3 of 40 wells from the eastern part of the Spokane Valley/Rathdrum Prairie aquifer (SUS1) contained pesticides in detectable concentrations and that the occurrence and concentrations of pesticides could vary temporally. During the 1998 field season, dacthal concentrations of 0.46 and 0.61 $\mu\text{g/L}$ were detected in water from two wells and a sample from one well had a 2,4-dichlorobenzoic acid (2,4-DCBA) concentration of 0.12 $\mu\text{g/L}$ (Eliopulos and others, 2001). Pesticides were not

detected in these wells when resampled in 1999. Results from Eliopulos and others (2001) and the NROK study indicate that pesticides in ground water in SUS1 were either not detectable or were at low concentrations.

When compared to the results collected throughout the Nation as part of the NAWQA Program, the occurrence of pesticides in ground water from the NROK subunits generally is less than the occurrence of pesticides elsewhere. Using a concentration of 0.2 $\mu\text{g/L}$ as a censoring level for all pesticides and pesticide metabolites, at least 1 of the 83 pesticides analyzed was detected in 9 percent of the samples from nearly 1,500 wells collected as part of the Nationwide NAWQA program (samples collected 1992-99, Squillace and others, 2002). None of the pesticides and pesticide metabolites analyzed from the NROK subunit samples were detected at concentrations above the censoring level of 0.2 $\mu\text{g/L}$.

Caffeine (included with the analysis of pesticides and pesticide metabolites, appendix 3) was detected in water samples from 9 of the 61 wells sampled, but only at extremely low concentrations (estimated concentrations ranged from 0.003 to 0.02 µg/L). Caffeine is used in a variety of beverages, food, and drugs and has been detected in domestic wastewater effluent, environmental surface-water samples, and treated drinking water in the United States (Spectrum Laboratories, 2002). Because of its widespread occurrence in consumable products, caffeine is difficult to detect reliably at low concentrations. A review of nationwide field-blank data (169 samples collected as part of the Nationwide NAWQA Program from 1999-2001) indicated that caffeine was detected in about 10 percent of the blank samples and the mean detected concentration was about 0.02 µg/L (Edward T. Furlong, U.S. Geological Survey, written commun., 2002). Caffeine was not detected in the five field blanks collected for this study. However, because the detected concentrations from this study were low and within the range of concentrations found in field blanks from other NAWQA studies, caffeine data for environmental samples for this study may be suspect. Caffeine might prove to be an excellent tracer for the occurrence of effluent from septic systems within the NROK subunits; however, follow-up sampling and further investigation are warranted to better determine its presence and distribution.

Volatile Organic Compounds

VOCs are carbon-containing compounds that are used in commercially manufactured products, including adhesives, dry-cleaning agents, fertilizers, gasoline, paints, pesticides, plastics, refrigerants, and solvents. The presence of VOCs in water can be of concern because they commonly are toxic and can be mobile and persistent in ground water. Common sources of VOCs in ground water from private wells include septic systems, leaking storage tanks, gasoline and chemical spills, fertilizer and pesticide applications, pipelines, sewer lines, and chlorination (Moran and Hamilton, 2003).

Water samples from the subunit survey wells were analyzed for 85 VOCs (appendix 4), but only 12 of these compounds were detected (table 4). VOCs were detected in environmental samples of water from 19 of the 61 wells (31 percent) sampled; however, most concentrations were estimated and none exceeded MCLs or LHAs of the USEPA (U.S. Environmental Protection Agency, 2002) (table 4, fig. 14). Samples from seven of the wells had detections of two or more VOCs (a maximum of five detections in the sample from well 41). The highest measured VOC concentration was 4.31 µg/L of toluene; all other VOC concentrations were less than 2 µg/L. The detection of VOCs in ground-water samples indicates that human activities have affected water quality in some areas of the NROK basin-fill aquifers. However, VOC detections generally were uncommon and at low concentrations. The most commonly detected VOCs were 1,1,1-trichloroethane (7 detec-

tions), chloroform (7 detections), and tetrachloroethylene (6 detections).

Detected concentrations of 1,1,1-trichloroethane ranged from 0.005 µg/L (estimated) to 0.130 µg/L. All concentrations were less than the USEPA MCL of 200 µg/L. Occurrences of 1,1,1-trichloroethane generally were isolated; however, samples from two neighboring wells (39 and 40) in the Missoula area had measurable concentrations.

Trihalomethanes (THMs) are a group of VOCs that includes bromoform, bromodichloromethane, chloroform, and dibromochloromethane. Chloroform was the most frequently detected THM (7 detections), followed by bromodichloromethane (3 detections), and dibromochloromethane (2 detections). Bromoform was not detected. THMs are commonly formed along with other byproducts when chlorine or other disinfectants used to control microbial contaminants in drinking water react with naturally occurring organic and inorganic matter in water (U.S. Environmental Protection Agency, 1999). Thus, THMs commonly are found in water from wells that have been chlorinated. The current drinking-water standard for total trihalomethanes (TTHMs) is 80 µg/L. TTHM concentrations in samples collected for this study generally were low. The sample from well 61 had the highest measured TTHM concentration of 0.757 µg/L (0.540 µg/L chloroform, 0.163 µg/L bromodichloromethane, estimated 0.054 µg/L dibromochloromethane). After further investigation, it was discovered that the well had been chlorinated within 2 weeks prior to sample collection, thus indicating the plausible source of THMs in this well. Wells 39 and 41 are located in the Missoula area and reportedly had not been chlorinated or disinfected for several years. The Missoula area is supplied by public water systems and samples from these systems have had measurable concentrations of TTHMs. TTHM concentrations in water from the Missoula-area distribution system ranged from less than detection to 3 µg/L, with an estimated average concentration of 1.8 µg/L (Mountain Water and Linda Vista Water Company, 2001). Therefore, the trihalomethanes found in water from wells 39 and 41 could be from public-supply water recharging the aquifer through irrigation, septic systems, or leaky sewer lines.

Tetrachloroethylene (PERC), which is used primarily as a dry-cleaning and metal-degreasing solvent, was detected in water collected from six wells (1, 39, 40, 41, 45, and 56, table 4) at concentrations ranging from 0.020 (estimated) to 1.64 µg/L. The MCL for tetrachloroethylene is 5 µg/L. The highest concentration (1.64 µg/L) was found in water from well 1, which is located near a small rural airstrip within SUS1. Samples from wells 39, 40, and 41 (located in the Missoula area) had concentrations ranging from 0.071 (estimated) to 0.303 µg/L. Reported concentrations for Missoula's public-water supply ranged from <0.5 to 0.9 µg/L (Mountain Water and Linda Vista Water Co., 2001). Tetrachloroethylene has been detected (since 1988) in water from several public-supply wells within the Missoula area; some concentrations exceeded the USEPA MCL (Missoula County, 1999). Since detection in public-supply

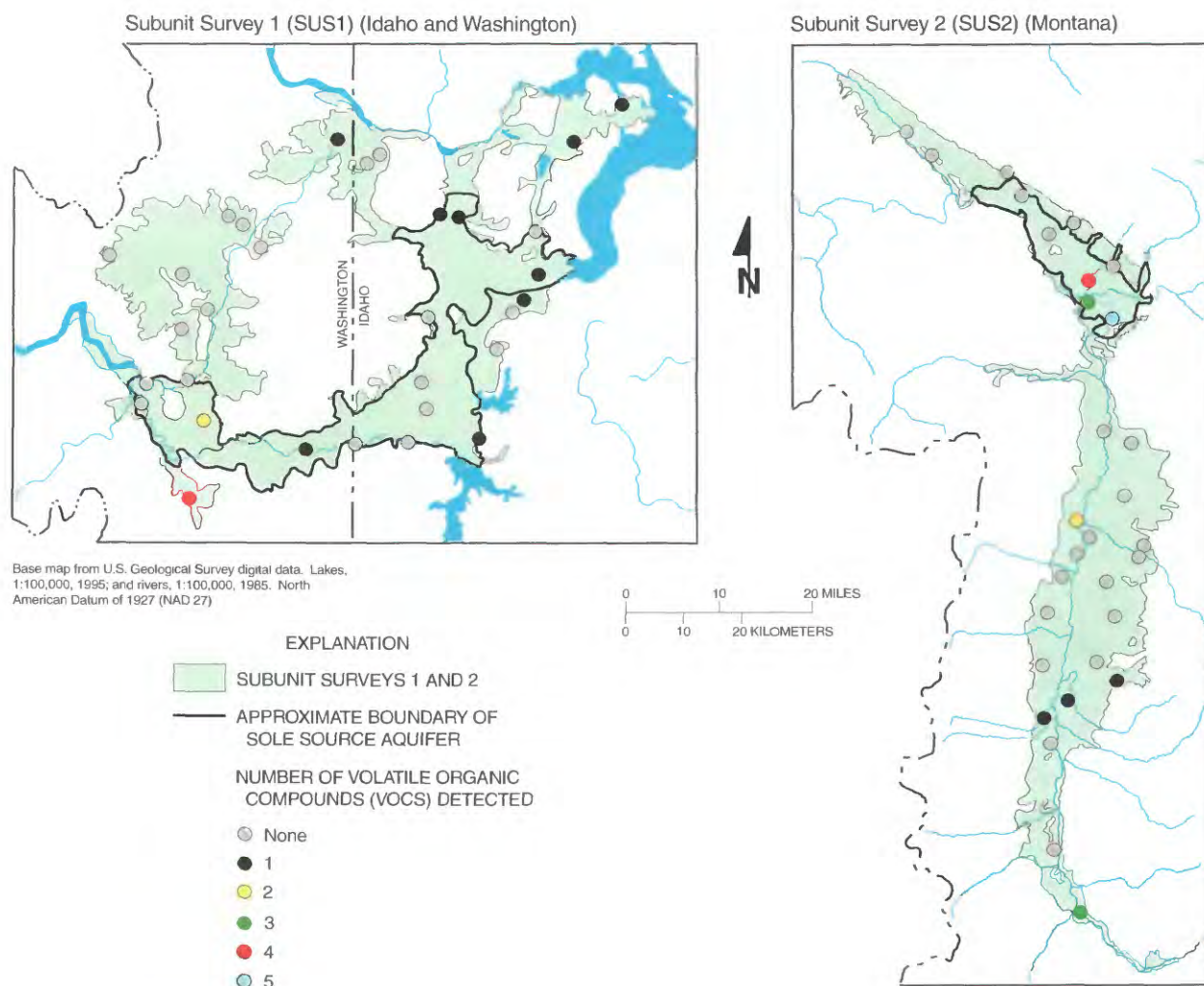


Figure 14. Sampling locations where volatile organic compounds were detected in ground-water samples collected from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001.

wells, efforts to reduce sources of tetrachloroethylene are reported to have been successful (Missoula County, 1999).

The occurrence and concentrations of VOCs in ground water of the NROK subunits appear to be lower than what has been found nationally. Using a censoring level of 0.2 $\mu\text{g/L}$, VOCs were detected in 18 percent of the samples from nearly 1,500 wells nationally (samples collected as part of the Nationwide NAWQA Program from 1992-99; Squillace and others, 2002). By applying the same censoring level (0.2 $\mu\text{g/L}$) to concentrations in samples from NROK subunits, only four VOCs (chloroform, dichlorodifluoromethane, tetrachloroethylene, and toluene) were detected. Thus, only 11 percent (7 of 61) of the wells sampled had concentrations of VOCs greater than 0.2 $\mu\text{g/L}$. Methyl tert-butyl ether (MTBE) was not detected in ground-water samples from the NROK subunits. MTBE is a

gasoline oxygenate of recent environmental concern that has been found in about 5 percent of the NAWQA ground-water samples collected throughout the Nation (Zogorski and others, 2001).

The relation between the occurrence of VOCs and well depth, depth to open interval, and depth to water was examined using Wilcoxon rank-sum tests. For statistical analysis, data for wells with and without VOC detections (censoring level at one-half the reporting level) were compared. Significant differences did not exist between VOC detections and well depths ($p = 0.064$) or VOC detections and open interval depths ($p = 0.134$). However, depth to water ($p = 0.023$) was significantly related to VOC detections; samples with detected concentrations of VOCs generally were from wells with shallower water levels.

Ground-Water Ages

Ground water within the basin-fill aquifers of the NROK subunit surveys generally is thought to be of relatively young age, particularly ground water within the high-permeability, unconsolidated sand and gravel aquifers. Environmental tracers, such as tritium (^3H) and sulfur hexafluoride (SF_6), are valuable tools for understanding ground-water flow systems by helping to determine or estimate areas of recharge and discharge, residence time, direction of flow, flow velocities, recharge rates, contamination potential, and the time needed to flush contaminants from ground-water systems (Plummer and Friedman, 1999).

Tritium and SF_6 were chosen as age-dating tools for ground water in NROK subunit surveys (table 5). These two environmental tracers have been introduced to the atmosphere through human activities at concentrations exceeding natural background concentrations; thus, these two tracers are useful for identifying relatively young ground water. The age of ground water applies to the date of introduction of the environmental tracer into the water, and not to the age of the water itself (Plummer and Friedman, 1999). Therefore, the age refers to the time elapsed since the water recharged the aquifer and was iso-

lated from the source (atmosphere) of the tracer. Age dates determined from environmental tracers may be affected by several factors including the mixing of waters of different ages, transport processes, and chemical processes. Because of these factors, ground-water ages determined through the use of environmental tracers often are qualified as "model ages" or "apparent ages" (Plummer and Friedman, 1999).

Tritium is a radioactive hydrogen isotope with an atomic weight of 3; it decays by beta emission to form helium-3 and has a half-life of 12.43 years (International Atomic Energy Agency, 1981). Tritium concentration is often reported in tritium units (TU), which is equal to one tritium atom per 1,018 hydrogen atoms or an activity of 3.24 pCi/L (Plummer and others, 1993). Although tritium is produced naturally by the interaction of cosmic rays with nitrogen and oxygen in the atmosphere, tritium concentrations in precipitation began to increase dramatically in the early 1950s as a result of thermonuclear weapons testing. Prior to weapons testing, the natural level of tritium in precipitation probably did not exceed 2 to 8 TU (Plummer and others, 1993). During the 1960s, concentrations rose to more than 1,000 TU in precipitation. If precipitation with a tritium concentration of 8 TU or less recharged ground water prior to 1950s, those waters would have tritium concentrations of less

Table 5. Tritium concentrations and calculated apparent ages determined from sulfur hexafluoride analysis of ground-water samples collected from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001

[Abbreviations: fmol/L, femtomoles per liter; TU, tritium units. Symbols: <, less than; --, no data]

Well number (figs. 2 and 3)	Date sampled	Tritium (TU)	Sulfur hexafluoride concentration (fmol/L)	Sulfur hexafluoride average age ¹ (years)
1	07/14/99	<0.3	--	--
5	07/06/99	.6	--	--
23	05/25/99	16.9	--	--
25	05/24/99	15.0	--	--
34	06/28/01	--	² 2.23	² 4.1
35	06/07/01	10.3	--	--
36	06/27/01	8.3	² 2.31	² 1.5
37	06/27/01	11.5	² 2.10	² 2.7
38	06/19/01	11.9	³ 1.92	³ 4.1
39	06/20/01	11.2	⁴ --	⁴ --
40	06/20/01	12.2	⁵ 1.90	⁵ 4.5
41	06/19/01	11.9	² 2.10	² 2.7
42	05/29/01	11.3	--	--
44	05/30/01	10.0	--	--
51	06/05/01	2.0	--	--

¹ Age calculated using an average excess air concentration of 1.5 milliliters per liter and a temperature of recharging water of 7.5 degrees Celsius.

² Based on average of two analyses.

³ Based on average of four analyses.

⁴ Contaminated sample.

⁵ Based on one analysis.

than 1 TU in 1999 and 2001 due to radioactive decay. Tritium concentrations of greater than 1 TU indicate that at least some fraction of the sampled water was recharged after the early 1950s.

The use of SF_6 appears to be a promising technique for the age determination of ground water less than 30 years old (Busenberg and Plummer, 2000). SF_6 is mainly of anthropogenic origin and commonly is used as an electrical insulator in high-voltage switches and as a cover gas in the operations of magnesium metal production. Large-scale production of SF_6 began in 1953 with the introduction of gas-filled high-voltage electrical switches (Plummer and Friedman, 1999). SF_6 is an extremely stable gas that has been accumulating in the atmosphere over the last 40 years (increasing from near zero to more than 4 parts per trillion by volume; Busenberg and Plummer, 2000). The historical concentration of SF_6 within the atmosphere is well established, which enables its use as an age-dating tool (Plummer and Friedman, 1999). Theoretically, ground water that was at equilibrium with gases in the atmosphere prior to recharge can be dated. However, age determinations can be compromised by the addition of excess air during recharge; the occurrence of naturally occurring SF_6 from igneous (particularly silicic igneous rocks), metamorphic, and sedimentary rocks and some hydrothermal fluids; or local anthropogenic point sources (Busenberg and Plummer, 2000). The calculation of SF_6 -ages also is sensitive to recharge temperature. Both excess air and recharge temperature were determined from dissolved-gas analysis during this study.

Tritium concentrations in ground-water samples collected from 14 wells ranged from <0.3 to 16.9 TU (table 5). Most of the samples (12 of 14) had tritium concentrations greater than 1 TU, indicating that at least a component of the water had been recharged since the early 1950s. Samples from the four wells in SUS1 contained the lowest and highest tritium concentrations. Two wells (1 and 5) located in the northern part of SUS1 produced samples with concentrations of less than 1 TU, which indicates the water was recharged prior to the early 1950s. Samples from two wells (23 and 25) located northwest of Spokane, Wash., near the western margin of the Spokane Valley/Rathdrum Prairie aquifer (fig. 2) had the highest concentrations (16.9 and 15.0 TU, respectively). Thus, the latter two wells produced relatively young water that was recharged after the early 1950s.

Ten wells were sampled for tritium within SUS2. Seven wells (35-41) completed within the Missoula Sole Source Aquifer or near its margins (fig. 3) produced samples with concentrations ranging from 8.3 to 12.2 TU (table 5.) These values likely represent relatively young water recharged after the 1950s. LaFave (2002) reported similar tritium concentrations in ground water and the Clark Fork (a local source of recharge) near Missoula. The other three wells (42, 44, and 51) are located in the northern and central Bitterroot Valley (fig. 3). Samples from wells 42 and 44 had tritium concentrations of 11.3 and 10.0 TU, respectively, which were similar to the concentrations found in the Missoula area. The sample from well

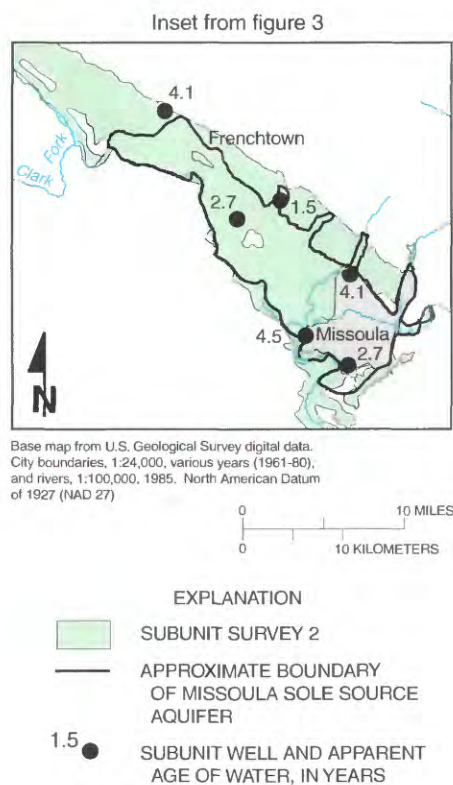


Figure 15. Apparent ground-water ages based on sulfur hexafluoride analysis of ground-water samples from the Missoula Valley, Montana.

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51 had a concentration of about 2 TU, indicative of a larger component of older water when compared to the concentrations in other samples.

Samples for SF_6 analyses were collected from wells completed in the Missoula Sole Source Aquifer or near its boundaries (table 5, fig. 15). Samples from each well were analyzed at least twice at the USGS laboratory in Reston, Va., and multiple analyses of individual samples generally were in good agreement. The results from SF_6 analyses indicate that the water was recently recharged; apparent ages (at the time of sampling in 2001) ranged from 1.5 to 4.5 years old. The apparent age of water from one well (39) could not be determined because the SF_6 concentration in the sample was greater than the atmospheric concentration at the time of sample collection, which indicates local anthropogenic point-source or natural contamination of SF_6 . The relatively young apparent SF_6 ground-water ages generally agree with the ages estimated from tritium data, the conceptual understanding of the flow system, and the occurrence of contaminants (pesticides and VOCs) resulting from human activities in the area. LaFave (2002) age dated ground-water samples in the Missoula area using the ratio of tritium and helium-3 ($^3\text{H}/^3\text{He}$) concentrations. The $^3\text{H}/^3\text{He}$ age-dating technique is based on a calculation that determines the amount of helium-3 (^3He) derived from radioactive decay of ^3H in the water (Plummer and Friedman, 1999). The apparent ages (less than 5 years old) derived from $^3\text{H}/^3\text{He}$ analysis (LaFave 2002) generally agree with the ages (1.5 to 4.5 years) derived from the SF_6 analysis for the Missoula area.

POSSIBLE WATER-QUALITY EFFECTS FROM HUMAN ACTIVITIES

The apparent young age of the ground water and the occurrence of constituents resulting from human activities in some samples indicated that water can move rapidly from land surface and (or) point sources in some areas of the basin-fill aquifers. At least a component of the water from 13 of the 15 wells (87 percent) sampled for environmental tracers (tritium and sulfur hexafluoride) had been recharged since the early 1950s. Therefore, ground water in some areas has been exposed to the effects of land-surface activities since the 1950s. Nearly all of the wells sampled were located in residential settings surrounded by forested, agricultural, or urban land-uses; several wells were surrounded by a mixture of land uses. Because of the variety of land-use activities, ground water can contain constituents that indicate the effects of agricultural and domestic application of fertilizers and pesticides, animal manure, septic-system effluent or leaky sewer lines, leaky pipelines or storage tanks, gasoline and chemical spills, and chlorination.

Although the ground water sampled generally was of good quality and acceptable for most purposes, the presence of elevated nitrate and organic compounds in some samples indicates that human activities do locally affect the quality of ground

water. Nitrate concentrations greater than or equal to the estimated background concentration of 2 mg/L were reported in water from 7 of the 61 wells sampled. These wells were located in rural areas where agriculture is the primary land use. Organic compounds were detected in samples from 29 (48 percent) of the 61 wells sampled; however, most concentrations were low and at estimated concentrations below reporting levels. Both pesticides and volatile organic compounds were found in ground-water samples from five wells. Overall, concentrations of constituents associated with human activities (nitrate concentrations greater than or equal to 2 mg/L, pesticides, and volatile organic compounds) were found in samples from 32 (52 percent) of the wells sampled. However, the concentrations of constituents associated with human activities generally were low and were less than USEPA drinking-water standards (U.S. Environmental Protection Agency, 2000).

SUMMARY

This study was conducted as part of the U.S. Geological Survey's National Water Quality Assessment Program—Northern Rockies Intermontane Basins Study Unit. Ground-water samples were collected during the late spring and summer of 1999 and 2001 from 61 wells completed in basin-fill aquifers in western Montana, northern Idaho, and eastern Washington. Basin-fill aquifers are the principal source of ground water within the Northern Rockies Intermontane Basins Study Unit and are composed of gravel, sand, silt, and clay. Two subunit surveys were conducted. The first subunit survey (SUS) was conducted during summer 1999 in eastern Washington and northern Idaho (SUS1) and the second SUS was conducted during summer 2001 in the Missoula-Bitterroot Valleys of western Montana (SUS2). About 36 percent of the sampled wells were located within U.S. Environmental Protection Agency (USEPA) designated Sole Source Aquifers.

A random unbiased distribution of wells was selected for this study. Nearly all of the wells were located in residential settings surrounded by forested, agricultural (pasture, grass seed, and alfalfa), and (or) urban land uses; many wells were surrounded by a mixture of land uses. Field measurements of water temperature, specific conductance, dissolved oxygen, pH, and alkalinity were determined. Samples were analyzed for major ions, nutrients, trace elements, radon, pesticides, volatile organic compounds, and ground-water age-dating constituents.

The ground water sampled generally was of good quality and acceptable for most purposes. Measured concentrations of nearly all constituents analyzed were less than USEPA drinking-water standards. Most of the samples were calcium-bicarbonate type water with dissolved-solids concentrations ranging from 32 to 369 milligrams per liter (mg/L) and a median of 131 mg/L. The median pH was 7.2 and ranged from 5.8 to 8.3. Samples from five wells had pH values slightly less than the USEPA Secondary Drinking Water Regulation (SDWR) acceptable range of 6.5 to 8.5. Dissolved-oxygen concentra-

tions ranged from less than 0.1 to 11 mg/L with a median of 6.5 mg/L. Hardness ranged from 8.5 to 235 mg/L as CaCO_3 with a median of 95 mg/L. Samples from 29 wells had hardness values greater than 100 mg/L (considered hard water).

Nutrient concentrations generally were low and all concentrations were less than USEPA drinking-water standards. Ammonia concentrations ranged from less than 0.02 to 0.04 mg/L, ammonia plus organic nitrogen concentrations ranged from less than 0.10 to 0.25 mg/L, and nitrite concentrations were all less than 0.01 mg/L. Nitrate concentrations were less than the USEPA Maximum Contaminant Level (MCL) of 10 mg/L, ranging from less than 0.05 to 7.6 mg/L with a median concentration of 0.36 mg/L. Denitrification reactions may have been reducing nitrate to nitrogen gas or ammonia in ground water with low dissolved-oxygen concentrations in some areas of SUS1 and SUS2. Denitrification is supported by data for samples with nitrate concentrations less than 0.05 mg/L and dissolved-oxygen concentrations less than 1 mg/L. Dissolved phosphorus and orthophosphorous concentrations were less than 0.1 mg/L in samples from all wells.

Concentrations of trace elements typically were low; however, concentrations of arsenic, iron, and manganese exceeded USEPA drinking-water standards in a few instances. Arsenic concentrations ranged from less than 0.20 to 31 micrograms per liter ($\mu\text{g/L}$) with a median of less than 1.0 $\mu\text{g/L}$; samples from three wells had concentrations greater than the MCL of 10 mg/L. Arsenic concentrations were significantly higher in water samples from SUS1 than SUS2. Arsenic in ground water from the NROK subunits probably is derived from the natural interaction of rocks and soils. Iron concentrations ranged from less than 10 to 604 $\mu\text{g/L}$ with a median concentration of less than 10 $\mu\text{g/L}$. Samples from three wells had iron concentrations greater than the SDWR of 300 $\mu\text{g/L}$. Manganese concentrations ranged from less than 0.10 to 129 $\mu\text{g/L}$ with a median of less than 1.0 $\mu\text{g/L}$. Samples from three wells had manganese concentrations greater than the SDWR of 50 $\mu\text{g/L}$. Statistically significant but weak negative correlations were found between dissolved-oxygen concentrations and iron and manganese concentrations, indicating a relation between reducing conditions and elevated manganese and iron concentrations. A significant positive correlation exists between the iron and manganese concentrations of the sampled waters indicating that similar geochemical processes may be controlling concentrations of both constituents.

Radon was detected in water from all 61 wells sampled and concentrations ranged from 253 to 3,047 picocuries per liter (pCi/L) with a median of 853 pCi/L. Water from 98 percent of the wells sampled had radon concentrations greater than the proposed drinking-water standard of 300 pCi/L for States that choose not to develop a multimedia mitigation program to address indoor air radon concentrations. A statistical comparison of data from both subunit surveys indicated that the radon concentrations of the two subunits were not significantly different; however, the median radon concentration in samples (769 pCi/L) from SUS1 was lower than the median concentration (1,270 pCi/L) in samples from SUS2. Radon in both areas

probably is derived from the natural decay of uranium contained in the granitic rocks present within the basin-fill aquifers and the adjacent and underlying bedrock.

At least 1 of 14 pesticides was detected in ground water from 15 (25 percent) of the 61 wells sampled, and multiple pesticides were detected in six wells. The most commonly detected pesticides were 3-hydroxycarbofuran (5 detections), prometon (4 detections), and carbofuran (3 detections). The highest pesticide concentration was 0.044 $\mu\text{g/L}$ of tebuthiuron.

Twelve volatile organic compounds (VOCs) were detected in water samples from 19 (31 percent) of the 61 sampled wells. Samples from seven wells had multiple detections of VOCs (a maximum of five detections). None of the VOC concentrations exceeded USEPA drinking-water standards. The most commonly detected VOCs were 1,1,1-trichloroethane (7 detections), chloroform (7 detections), and tetrachloroethylene (6 detections). The highest measured VOC concentration was 4.31 $\mu\text{g/L}$ of toluene; all other concentrations were less than 2 $\mu\text{g/L}$.

Tritium and sulfur hexafluoride (SF_6) concentrations were used to estimate the age of ground water in SUS1 and SUS2. The results indicate that at least some relatively young ground water (early 1950s or younger) was present in all but 2 of the 15 wells sampled. Samples from six wells within the Missoula Valley were analyzed for SF_6 with resulting apparent ages of 1.5 to 4.5 years.

Although the ground water sampled generally was of good quality and acceptable for most purposes, the presence of elevated nitrate and organic compounds in some samples indicates that human activities do locally affect the quality of ground water. Concentrations of constituents associated with human activities (nitrate concentrations greater than or equal to the estimated background concentration of 2 mg/L, pesticides, and volatile organic compounds) were found in samples from 32 (52 percent) of the wells sampled. However, concentrations generally were low with no concentrations exceeding USEPA drinking-water standards. Nitrate concentrations of 2 mg/L or greater were found in samples from seven wells. Organic constituents were identified in ground water from 29 (48 percent) of the wells sampled; both pesticides and volatile organic compounds were detected in ground water from five wells. The apparent young age and the occurrence of constituents resulting from human activities (elevated nitrate and organic compounds) in some samples indicated that water can move rapidly from land surface and (or) point sources in some areas of these basin-fill aquifers.

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APPENDIXES

38 Ground-Water Quality of Selected Basin-Fill Aquifers of the Northern Rockies Intermontane Basins in Montana, Idaho, and Washington

Appendix 1. Records of wells sampled for the Northern Rockies Intermontane Basins subunit surveys, 1999 and 2001

Well number—numbering system used for cross reference to wells plotted on figures 2 and 3; described in appendix 5.

Location number—described in appendix 5.

Well-identification number—fifteen-digit station-identification number described in appendix 5.

Latitude and longitude—horizontal coordinate information referenced to the North American Datum of 1983 (NAD 83).

Altitude—in feet above National Geodetic Vertical Datum of 1929 (NGVD 29).

Aquifer code—110ALVM, Alluvium (Quaternary); 110ALVF, Alluvial-fan deposits (Quaternary); 110TRRC, Terrace deposits (Quaternary); 112GCLO, Glacial outwash (Pleistocene); 112LKML, Glacial Lake Missoula beds (Pleistocene); 120SDMS, Sediments (Tertiary).

Aquifer type—C, confined or locally confined; U, unconfined; determined from drillers' logs.

Date drilled—date of completion.

Depth of well—in feet below land surface.

Casing diameter—in inches.

Open interval type—O, open ended; P, perforated; S, screened.

Open interval top—in feet below land surface.

Open interval bottom—in feet below land surface.

Depth to water—measured by U.S. Geological Survey at the time of water-quality sampling. Water levels in feet below or (+) above land surface.

Primary use of water—C, commercial; H, domestic; I irrigation.

Yield—in gallons per minute, as reported on drillers' logs.

Pumping period—in hours.

Pumping water level—depth, in feet below land surface.

Abbreviations—in., inch; ft, feet; gal/min, gallons per minute.

Symbol—--, no data or not applicable.

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Appendix 1. Records of wells sampled for the Northern Rockies Intermontane Basins subunit surveys, 1999 and 2001—Continued

Well number	Location number	Well-identification number	Latitude (degrees, minutes, seconds)	Longitude	Altitude of land surface (feet above NGVD 29)	Aquifer code	Aquifer type	County and State
Subunit Survey 1								
1	56N01W10BBBB01	481320116261101	481320.7	1162611.6	2,220	110ALVM	C	Bonner, Idaho
2	56N02W35BBBD01	480950116324401	480949.9	1163243.6	2,320	110ALVM	U	Bonner, Idaho
3	31N45E27DAAD01	480928117053201	480928.4	1170532.2	2,080	110ALVM	U	Pend Oreille, Wash.
4	55N05W08BABA01	480813116593701	480813.0	1165937.9	2,298	110ALVM	U	Bonner, Idaho
5	55N06W13AAAD01	480718117012501	480718.0	1170125.4	2,358	110ALVM	U	Bonner, Idaho
6	54N04W08AADA01	480249116510001	480252.2	1165103.8	2,315	110ALVM	U	Bonner, Idaho
7	54N04W10ADDD01	480235116483001	480235.9	1164830.0	2,170	110ALVM	U	Bonner, Idaho
8	29N43E02DCBC01	480203117200601	480204.6	1172019.0	2,120	110ALVM	U	Spokane, Wash.
9	54N02W18CCDD01	480128116374601	480127.6	1163746.1	2,330	110ALVM	U	Bonner, Idaho
10	29N44E07CBCD01	480119117182101	480119.0	1171821.1	2,035	110ALVM	C	Spokane, Wash.
11	29N44E21CCCB01	475925117153001	475920.9	1171544.2	2,000	110ALVM	U	Spokane, Wash.
12	29N41E34ADDB01	475825117364401	475809.8	1173638.2	2,265	110ALVM	U	Stevens, Wash.
13	53N02W07ABDD01	475731116371301	475730.6	1163713.2	2,425	110ALVM	U	Kootenai, Idaho
14	28N42E12ABDD01	475637117262501	475636.8	1172625.3	2,152	110ALVM	U	Spokane, Wash.
15	53N03W24CCCD01	475510116391201	475509.6	1163912.3	2,455	110ALVM	U	Kootenai, Idaho
16	53N03W34ADAA01	475400116404201	475400.0	1164042.0	2,455	110ALVM	U	Kootenai, Idaho
17	28N43E28CDAD01	475343117225201	475329.4	1172250.5	1,855	110ALVM	U	Spokane, Wash.
18	52N04W06AAAA01	475322116522201	475322.1	1165222.1	2,412	110ALVM	U	Kootenai, Idaho
19	27N42E12ABAA01	475130117262201	475134.3	1172619.0	2,075	110ALVM	U	Spokane, Wash.
20	52N03W21BACD01	475035116424801	475034.6	1164248.1	2,513	110ALVM	U	Kootenai, Idaho
21	51N04W06CDDD01	474718116530201	474718.4	1165302.0	2,255	110ALVM	U	Kootenai, Idaho
22	26N43E06ACBD01	474708117250501	474655.3	1172514.8	1,575	110ALVM	U	Spokane, Wash.
23	26N42E04CCDB01	474629117305101	474627.0	1173054.7	1,725	110ALVM	C	Spokane, Wash.
24	51N04W20CBCD01	474456116522001	474456.1	1165220.0	2,245	110ALVM	U	Kootenai, Idaho
25	26N42E20ABAC01	474427117312101	474434.5	1173132.5	1,630	110ALVM	U	Spokane, Wash.
26	26N43E28CABA01	474317117225301	474317.2	1172253.3	2,048	110ALVM	U	Spokane, Wash.
27	50N03W06DACC01	474218116445601	474218.4	1164456.5	2,220	110ALVM	U	Kootenai, Idaho
28	50N05W12BCAD01	474147116544001	474147.4	1165440.4	2,130	110ALVM	U	Kootenai, Idaho
29	50N06W12DBCD01	474130117015401	474129.7	1170154.4	2,050	110ALVM	U	Kootenai, Idaho
30	25N45E08BDAA01	474050117084101	474054.0	1170839.1	2,015	110ALVM	U	Spokane, Wash.
31	24N43E05CBBD01	473612117243601	473603.6	1172432.0	1,855	110ALVM	U	Spokane, Wash.
Subunit Survey 2								
32	16N23W27BBCC01	470719114301401	470714.1	1143013.7	3,270	110ALVM	U	Missoula, Mont.
33	15N23W01DCAC01	470502114265301	470502.1	1142653.1	3,110	110ALVM	C	Missoula, Mont.
34	15N21W17DBAD01	470328114164301	470327.6	1141642.6	3,570	120SDMS	U	Missoula, Mont.
35	15N21W34BACC01	470112114144001	470111.9	1141440.1	3,020	112LKML	C	Missoula, Mont.
36	14N20W16AACB01	465838114074501	465838.3	1140744.7	3,220	112GCLO	U	Missoula, Mont.
37	14N20W19BBDC01	465741114110601	465741.4	1141105.6	3,185	110ALVM	C	Missoula, Mont.
38	13N19W05CBCC01	465440114022101	465440.2	1140221.4	3,280	112GCLO	U	Missoula, Mont.
39	13N20W14BACA01	465323114054301	465322.7	1140543.2	3,175	110ALVM	U	Missoula, Mont.
40	13N20W26BCDA01	465127114055401	465127.1	1140553.8	3,110	110ALVM	U	Missoula, Mont.
41	12N19W06BBCC01	464951114023701	464951.1	1140237.4	3,150	110ALVM	U	Missoula, Mont.
42	10N20W02AADA01	463932114035901	463931.6	1140359.4	3,190	110ALVM	U	Ravalli, Mont.

Appendix 1. Records of wells sampled for the Northern Rockies Intermontane Basins subunit surveys, 1999 and 2001—Continued

Date drilled	Depth of well (ft)	Casing diameter (in.)	Open interval type	Open interval, top (ft)	Open interval, bottom (ft)	Depth to water (ft)	Date of water level measurement	Primary use of water	Yield (gal/min)	Pump-ing period (hours)	Pump-ing water level (ft)	Date yield measured	Well number
Subunit Survey 1													
03/09/1993	139	6	O	139	--	+4.55	07/14/1999	H	30	--	--	03/09/1993	1
01/21/1987	135	6	S	130	135	83.92	07/14/1999	H	12	5.5	135	01/21/1987	2
12/04/1995	56	6	S	51	56	19.85	07/07/1999	C	7	--	--	12/04/1995	3
10/17/1991	162	6	S	158	162	129.64	07/07/1999	H	5	1	145	10/17/1991	4
07/03/1997	130	6	S	125	130	94.73	07/06/1999	H	10	1	97	07/03/1997	5
12/14/1973	198	6	P	188	198	161.48	07/08/1999	H	10	--	--	12/14/1973	6
10/01/1997	80	6	O	80	--	21.17	07/13/1999	H	25	--	--	10/01/1997	7
07/22/1992	60	6	S	55	60	17.72	06/08/1999	H	20	1.5	--	07/22/1992	8
04/11/1996	76	6	S	71	76	39.71	08/04/1999	H	12	1	60	04/11/1996	9
12/12/1989	123	6	S	118	123	+0.34	06/09/1999	H	20	--	--	12/12/1989	10
07/06/1988	77	6	S	43	48	11.65	07/06/1999	H	30	--	--	07/06/1988	11
05/23/1985	67	6	S	63	67	25.24	06/09/1999	H	20	1	--	05/23/1985	12
03/21/1995	431	8	S	380	425	363.23	06/23/1999	H	30	2	--	03/21/1995	13
03/05/1987	90	6	S	85	90	32.96	06/10/1999	H	35	--	--	03/05/1987	14
06/23/1992	339	6	O	339	--	276.35	08/03/1999	H	20	--	--	06/23/1992	15
04/18/1997	237	6	O	237	--	200.11	06/22/1999	H	15	1.5	--	04/18/1997	16
03/15/1993	150	6	S	135	145	111.87	06/10/1999	H	9	1	--	03/15/1993	17
06/17/1982	443	6	O	433	--	381.76	07/12/1999	H	15	2.5	--	06/17/1982	18
10/31/1990	57	6	O	57	--	21.15	06/07/1999	H	25	1	--	10/31/1990	19
06/28/1977	338	6	O	338	--	91.00	06/22/1999	H	18	2	--	06/28/1977	20
09/20/1994	298	6	O	298	--	243.86	06/24/1999	H	35	2	--	09/20/1994	21
08/28/1984	45	6	P	37	41	5.69	06/07/1999	H	20	1	--	08/28/1984	22
05/27/1992	321	6	S	311	321	172.00	05/25/1999	H	40	1.5	--	05/27/1992	23
10/01/1997	290	6	O	290	--	242.78	06/21/1999	H	30	--	--	10/01/1997	24
05/21/1990	60	6	S	55	60	17.36	05/24/1999	H	18	--	--	05/21/1990	25
11/29/1991	260	6	S	256	260	203.88	05/27/1999	I	25	.5	--	11/29/1991	26
10/15/1984	209	6	O	209	--	138.80	07/15/1999	H	60	.5	--	10/15/1984	27
09/30/1988	200	6	S	195	200	99.58	07/26/1999	H	15	4	200	09/30/1988	28
02/21/1995	137	6	P	120	135	85.86	07/29/1999	H	40	--	--	02/21/1995	29
09/29/1982	128	6	P	115	120	63.22	07/28/1999	H	90	--	--	09/29/1982	30
09/12/1977	59	6	S	54	59	30.41	05/26/1999	H	40	--	--	09/12/1977	31
Subunit Survey 2													
10/29/1987	40	6	O	40	--	9.38	06/12/2001	H	20	1	28	10/29/1987	32
06/08/1987	60	6	O	60	--	27.52	06/12/2001	H	30	2	30	06/08/1987	33
07/05/1994	79	6	O	79	--	64.00	06/28/2001	H	30	2	68	07/05/1994	34
08/19/1995	174	6	O	174	--	18.16	06/07/2001	I	100	2	30	08/19/1995	35
07/20/1984	70	6	O	70	--	54.06	06/27/0221	H	30	1.5	61	07/20/1984	36
10/24/1991	141.5	6	O	141.5	--	39.40	06/27/2001	H	25	3	43	10/24/1991	37
11/14/1973	132	8	P	114	132	72.93	06/19/2001	H	60	15	105	11/14/1973	38
07/23/1997	119	6	S	114	119	42.50	06/20/2001	H	100	2	110	07/23/1997	39
07/28/1987	51	6	O	51	--	12.07	06/20/2001	H	100	2	20	07/28/1987	40
04/11/1975	82	6	O	82	--	30.22	06/19/2001	I	40	2	65	04/11/1975	41
09/09/1997	50	6	S	45	50	8.03	05/29/2001	H	100	2	45	09/09/1997	42

42 Ground-Water Quality of Selected Basin-Fill Aquifers of the Northern Rockies Intermontane Basins in Montana, Idaho, and Washington

Appendix 1. Records of wells sampled for the Northern Rockies Intermontane Basins subunit surveys, 1999 and 2001—Continued

Well number	Location number	Well-identification number	Latitude (degrees, minutes, seconds)	Longitude	Altitude of land surface (feet above NGVD 29)	Aquifer code	Aquifer type	County and State
Subunit Survey 2—Continued								
43	10N19W08ADAD01	463827114001201	463825.7	1140014.8	3,500	120SDMS	C	Ravalli, Mont.
44	09N19W05CCDC01	463335114011701	463334.9	1140116.7	3,405	110ALVF	U	Ravalli, Mont.
45	09N20W21CBBB01	463122114074701	463121.9	1140747.0	3,420	110ALVF	U	Ravalli, Mont.
46	09N20W34BDAB01	462948114060101	462948.3	1140601.0	3,310	110ALVF	U	Ravalli, Mont.
47	08N19W04BDAA01	462859113574401	462858.6	1135847.3	3,940	110ALVF	U	Ravalli, Mont.
48	08N20W08BAAB01	462818114074101	462817.7	1140741.1	3,320	110ALVF	U	Ravalli, Mont.
49	08N19W08ADDD01	462754113592701	462754.3	1135927.3	4,150	120SDMS	U	Ravalli, Mont.
50	08N21W24ACDB01	462616114094301	462614.3	1140945.9	3,490	120SDMS	C	Ravalli, Mont.
51	08N20W23CDDD01	462545114034301	462545.0	1140346.7	3,545	120SDMS	U	Ravalli, Mont.
52	07N21W11BBCD01	462256114114501	462256.2	1141144.7	3,675	110ALVF	U	Ravalli, Mont.
53	07N20W12CBDA01	462228114030301	462230.8	1140246.3	3,750	120SDMS	C	Ravalli, Mont.
54	06N20W03BDCC01	461823114050901	461822.8	1140512.7	3,580	120SDMS	U	Ravalli, Mont.
55	06N21W03CDAA01	461807114123001	461807.1	1141230.1	3,830	120SDMS	U	Ravalli, Mont.
56	06N20W13BDCD01	461638114023401	461638.3	1140234.0	3,985	120SDMS	U	Ravalli, Mont.
57	06N20W30CBAB01	461451114090801	461451.0	1140907.9	3,575	110TRRC	U	Ravalli, Mont.
58	05N21W03ACBA01	461320114121501	461318.2	1141218.2	3,818	110ALVF	U	Ravalli, Mont.
59	05N21W23BABB01	461055114112601	461055.1	1141125.0	3,860	120SDMS	U	Ravalli, Mont.
60	03N21W15ABDA01	460110114110901	460110.2	1141109.5	4,025	120SDMS	U	Ravalli, Mont.
61	02N20W18DBAC01	455521114074801	455520.8	1140747.6	4,060	110TRRC	U	Ravalli, Mont.

Appendix 1. Records of wells sampled for the Northern Rockies Intermontane Basins subunit surveys, 1999 and 2001—Continued

Date drilled	Depth of well (ft)	Casing diameter (in.)	Open interval type	Open interval, top (ft)	Open interval, bottom (ft)	Depth to water (ft)	Date of water level measurement	Primary use of water	Yield (gal/min)	Pump-ing period (hours)	Pump-ing water level (ft)	Date yield measured	Well number
Subunit Survey 2—Continued													
01/06/1990	340	6	P	325	335	134.63	05/29/2001	H	20	3.5	154	01/06/1990	43
03/25/1999	43	6	P	35	40	18.50	05/30/2001	H	18	1	23	03/25/1999	44
06/13/1991	60	6	S	34	39	23.04	05/30/2001	H	15	1	45	06/13/1991	45
03/21/1991	50	6	O	50	--	16.72	05/30/2001	H	30	1	35	03/21/1991	46
02/28/1985	56	6	P	51	56	11.66	06/11/2001	H	15	1	50	02/28/1985	47
03/25/1979	50	6	P	30	50	23.78	06/04/2001	H	--	--	--	--	48
10/18/1994	234	6	P	226	231	188.85	06/05/2001	H	6	1	227	10/18/1994	49
03/23/1984	49	6	P	44	49	4.67	06/05/2001	H	40	1	46	03/23/1984	50
07/20/1984	231.5	6	O	231.5	--	200.68	06/05/2001	H	10	1	231	07/20/1984	51
11/18/1978	29	6	P	21	26	2.04	06/04/2001	H	30	1	26	11/18/1978	52
03/04/1988	79	6	P	54	59	36.86	06/06/2001	H	20	2	65	03/04/1988	53
09/22/1966	53.5	6	O	53.5	--	30.39	06/06/2001	H	50	8	29	09/22/1966	54
10/10/1989	91	6	P	86	91	32.11	06/11/2001	H	50	1	80	10/10/1989	55
05/28/1997	120	6	O	120	--	67.24	06/06/2001	H	30	1	--	05/28/1997	56
05/14/1980	40	6	O	40	--	7.51	06/06/2001	H	20	1	30	05/14/1980	57
09/17/1991	55	6	S	50	55	24.61	06/05/2001	H	20	1	50	09/17/1991	58
06/26/1984	54	6	P	28	33	8.26	06/06/2001	H	5	1	32	06/26/1984	59
07/25/1996	85	--	O	85	--	28.70	06/20/2001	H	35	1	--	07/25/1996	60
11/03/1981	49	6	O	49	--	25.19	06/20/2001	H	20	1	50	11/03/1981	61

44 Ground-Water Quality of Selected Basin-Fill Aquifers of the Northern Rockies Intermontane Basins in Montana, Idaho, and Washington

Appendix 2. Reporting levels and spike recoveries for pesticides in filtered ground-water samples analyzed by gas chromatography/mass spectrometry and collected from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001

[Abbreviations: CAS number, Chemical Abstract Service Registry Number; RL, reporting level; µg/L, micrograms per liter; n, number of samples. Symbol: <, less than reporting level]

Constituent	CAS number	RL range or value (µg/L)	Spike recovery (percent) (n = 6)		
			Range	Mean	Standard deviation
2,6-Diethylaniline	579-66-8	0.002-.003	82-116	98	14
Acetochlor	34256-82-1	.002-.004	83-111	100	11
Alachlor	15972-60-8	.002	87-116	104	11
alpha-HCH	319-84-6	.002-.005	63-119	94	24
Atrazine	1912-24-9	.001-.007	14-108	71	45
Azinphos-methyl	86-50-0	.001-.050	¹ 70-101	¹ 89	¹ 13
Benfluralin	1861-40-1	.001-.002	69-101	80	15
Butylate	2008-41-5	.002	85-103	93	6.9
Carbaryl	63-25-2	.003-.041	¹ 50-178	¹ 121	¹ 52
Carbofuran	1563-66-2	.003-.020	¹ 72-163	¹ 115	¹ 39
Chlorpyrifos	2921-88-2	.004-.005	82-92	87	4.6
cis-Permethrin	54774-45-7	.005-.006	52-62	56	3.9
Cyanazine	21725-46-2	.004-.018	64-105	88	18
Dacthal	1861-32-1	.002-.003	92-115	106	8.3
Deethylatrazine	6190-65-4	.002-.006	¹ 13-59	¹ 42	¹ 23
Diazinon	333-41-5	.002-.005	87-109	101	8.2
Dieldrin	60-57-1	.001-.005	79-95	87	5.8
Disulfoton	298-04-4	.017-.021	66-94	79	11
EPTC	759-94-4	.002	86-140	104	20
Ethalfuralin	55283-68-6	.004-.009	77-122	99	20
Ethoprophos	13194-48-4	.003-.005	75-110	93	14
Fonofos	944-22-9	.003	81-105	93	9.8
Lindane	58-89-9	.004	70-109	92	16
Linuron	330-55-2	.002-.035	¹ 96-168	¹ 122	¹ 35
Malathion	121-75-5	.005-.027	49-97	77	17
Metolachlor	51218-45-2	.002-.013	89-109	99	6.9
Metribuzin	21087-64-9	.004-.006	80-109	96	11
Molinate	2212-67-1	.002-.004	83-103	92	9.0
Napropamide	15299-99-7	.003-.007	76-94	85	6.6
Parathion	56-38-2	.004-.007	71-116	90	20

Appendix 2. Reporting levels and spike recoveries for pesticides in filtered ground-water samples analyzed by gas chromatography/mass spectrometry and collected from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001—Continued

Constituent	CAS number	RL range or value (µg/L)	Spike recovery (percent) (n = 6)		
			Range	Mean	Standard deviation
Parathion-methyl	298-00-0	.006	67-112	86	20
Pebulate	1114-71-2	.002-.004	85-104	93	7.5
Pendimethalin	40487-42-1	.004-.010	55-82	69	12
Phorate	298-02-2	.002-.011	77-92	87	5.8
p,p'-DDE	72-55-9	.003-.006	66-82	71	6.2
Prometon	1610-18-0	.015-.018	¹ <16-91	¹ 59	¹ 34
Propachlor	1918-16-7	.007-.010	85-114	97	12
Propanil	709-98-8	.004-.011	73-142	103	29
Propargite	2312-35-8	.013-.023	² 62-81	² 69	² 8.5
Propyzamide	23950-58-5	.003-.004	81-110	96	11
Simazine	122-34-9	.005-.011	9-101	68	45
Tebuthiuron	34014-18-1	.010-.016	¹ 76-144	¹ 110	26
Terbacil	5902-51-2	.007-.034	¹ 56-103	¹ 74	19
Terbufos	13071-79-9	.013-.017	66-87	78	8.1
Thiobencarb	28249-77-6	.002-.005	83-107	99	10
Triallate	2303-17-5	.001-.002	81-105	92	11
Trifluralin	1582-09-8	.002-.009	54-110	78	24

¹Concentration was estimated or was less than reporting level in at least one sample. Estimated values or reporting levels were used for this calculation.

²Based on four samples.

Appendix 3. Reporting levels and spike recoveries for pesticides and metabolites in ground-water samples from basin-fill aquifers analyzed by high-performance liquid chromatography/mass spectrometry, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001

[Abbreviations: CAS number, Chemical Abstract Service Registry Number; RL, reporting level; µg/L, micrograms per liter; n, number of samples. Symbol: <, less than reporting level]

Constituent	CAS number	RL range or value (µg/L)	Spike recovery (percent) (n = 5)		
			Range	Mean	Standard deviation
2,4-D	94-75-7	0.022-.077	¹ 23-152	¹ 94	¹ 50
2,4-D methyl ester	1928-38-7	.009	67-96	78	11
2,4-DB	94-82-6	.016-.054	¹ <20-72	¹ 53	¹ 21
2-Hydroxyatrazine	2163-68-0	.008-.193	¹ 115-144	¹ 129	¹ 13
3(4-chlorophenyl)-1-methyl urea	5352-88-5	.024-.092	72-94	81	8.4
3-Hydroxycarbofuran	16655-82-6	.006-.062	65-94	80	14
3-keto-carbofuran	16709-30-1	.072-1.50	¹ 4-60	¹ 42	¹ 22
Acifluorfen	50594-66-6	.007-.062	¹ <23-142	¹ 94	¹ 47
Aldicarb	116-06-3	.040-.082	¹ <14-37	¹ 23	¹ 9.5
Aldicarb sulfone	1646-88-4	.020-.160	¹ 17-63	¹ 40	¹ 21
Aldicarb sulfoxide	1646-87-3	.008-.027	¹ 3-33	¹ 15	¹ 11
Bendiocarb	22781-23-3	.025-.061	61-89	72	13
Benomyl	17804-35-2	.004-.022	¹ 54-99	¹ 76	¹ 19
Bensulfuron-methyl	83055-99-6	.016-.048	75-112	89	16
Bentazon	25057-89-0	.011-.019	¹ <7-88	¹ 46	¹ 38
Bromacil	314-40-9	.033-.081	¹ 52-83	¹ 62	¹ 13
Bromoxynil	1689-84-5	.017-.057	¹ <21-110	¹ 66	¹ 39
Caffeine	58-08-2	.010-.080	¹ 77-115	¹ 95	¹ 17
Carbaryl	63-25-2	.028-.063	73-93	83	7.9
Carbofuran	1563-66-2	.006	74-91	82	7.2
Chloramben methyl ester	7286-84-2	.018-.114	¹ 56-77	¹ 64	¹ 9.1
Chlorimuron-ethyl	90982-32-4	.010-.037	¹ 15-116	¹ 69	¹ 49
Chlorothalonil	1897-45-6	.035-.048	¹ <18-37	¹ 27	¹ 7.0
Clopyralid	1702-17-6	.014-.041	<15-92	63	¹ 31
Cycloate	1134-23-2	.013-.054	¹ 49-75	¹ 62	¹ 12
Dacthal monoacid	887-54-7	.012-.072	¹ <26-145	¹ 95	¹ 49
Deethyl deisoprophyl atrazine	3397-62-4	.001-.060	¹ 1-60	¹ 35	¹ 31
Deisopropylatrazine	1007-28-9	.044-.074	¹ 14-45	¹ 27	¹ 12
Dicamba	1918-00-9	.013-.096	¹ <35-132	¹ 96	¹ 38
Dichlorprop	120-36-5	.014-.050	<18-104	¹ 76	¹ 34
Dinoseb	88-85-7	.012-.043	<16-99	¹ 73	¹ 34
Diphenamid	957-51-7	.026-.058	76-85	80	3.5
Diuron	330-54-1	.001-.079	76-96	85	8.0
Fenuron	101-42-8	.032-.074	58-76	71	7.6
Flumetsulam	98967-40-9	.011-.087	¹ 103-123	¹ 115	¹ 7.4
Fluometuron	2164-17-2	.031-.062	80-89	84	3.9
Imazaquin	81335-37-7	.016-.103	¹ 11-155	¹ 137	¹ 15
Imazethapyr	81335-77-5	.017-.088	¹ 92-231	¹ 150	¹ 66

Appendix 3. Reporting levels and spike recoveries for pesticides and metabolites in ground-water samples from basin-fill aquifers analyzed by high-performance liquid chromatography/mass spectrometry, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001—Continued

Constituent	CAS number	RL range or value (µg/L)	Spike recovery (percent) (n = 5)		
			Range	Mean	Standard deviation
Imidacloprid	138261-41-3	.007-.106	¹ 78-144	¹ 107	¹ 29
Linuron	330-55-2	.014-.070	68-97	80	11
MCPA	94-74-6	.016-.058	<2-99	¹ 74	¹ 31
MCPB	94-81-5	.015-.062	¹ 23-70	¹ 54	¹ 19
Metalaxyl	57837-19-1	.020-.057	73-81	78	3.1
Methiocarb	2032-65-7	.008-.080	¹ 55-80	¹ 72	¹ 9.7
Methomyl	16752-77-5	.004-.077	¹ 46-86	¹ 66	¹ 17
Metsulfuron methyl	74223-64-6	.025-.114	¹ <9-61	¹ 33	¹ 23
Neburon	555-37-3	.012-.075	79-88	82	3.8
Nicosulfuron	111991-09-4	.013-.065	¹ 44-136	¹ 91	¹ 44
Norflurazon	27314-13-2	.016-.077	¹ 60-85	¹ 77	¹ 10
Oryzalin	19044-88-3	.018-.071	54-81	73	11
Oxamyl	23135-22-0	.012-.016	48-88	73	15
Picloram	1918-02-1	.020-.071	¹ <26-123	¹ 82	² 39
Propham	122-42-9	.010-.072	63-99	80	¹ 15
Propiconazole	60207-90-1	.021-.064	78-91	83	6.4
Propoxur	114-26-1	.008-.059	68-95	79	12
Siduron	1982-49-6	.017-.093	² 75-91	² 85	² 7.1
Sulfometuron-methyl	74222-97-2	.009-.039	38-109	73	34
Terbacil	5902-51-2	.010-.095	¹ 46-87	¹ 63	¹ 15
Tribenuron-methyl	101200-48-0	.009-.068	¹ <3-35	¹ 17	¹ 14
Triclopyr	55335-06-3	.022-.101	<37-114	¹ 86	¹ 30

¹Concentration was estimated or was less than reporting level in at least one sample. Estimated values or reporting levels were used for this calculation.

²Based on four samples.

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Appendix 4. Reporting levels and spike recoveries for volatile organic compounds in ground-water samples collected from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001

[Abbreviations: CAS number, Chemical Abstract Service Registry Number; RL, reporting level; µg/L micrograms per liter; n, number of samples]

Constituent	CAS number	RL range or value (µg/L)	Spike recovery (percent) (n = 5)		
			Range	Mean	Standard deviation
1,1,1,2-Tetrachloroethane	630-20-6	0.030-0.044	63-106	78	17
1,1,1-Trichloroethane	71-55-6	.032	61-102	82	18
1,1,2,2-Tetrachloroethane	79-34-5	.090-.130	79-112	92	14
1,1,2-Trichloroethane	79-00-5	.060-.064	76-118	96	19
1,1,2-Trichlorotrifluoroethane	76-13-1	.032-.060	¹ 57-122	¹ 88	¹ 26
1,1-Dichloroethane	75-34-3	.035-.066	63-103	85	18
1,1-Dichloroethylene	75-35-4	.040-.044	¹ 57-95	¹ 77	¹ 16
1,1-Dichloropropene	563-58-6	.026	61-113	88	22
1,2,3,4-Tetramethylbenzene	488-23-3	.230	69-117	87	19
1,2,3,5-Tetramethylbenzene	527-53-7	.200	64-115	80	20
1,2,3-Trichlorobenzene	87-61-6	.270	65-103	83	16
1,2,3-Trichloropropane	96-18-4	.160	66-99	83	16
1,2,3-Trimethylbenzene	526-73-8	.120	71-130	93	23
1,2,4-Trichlorobenzene	120-82-1	.190	63-104	79	16
1,2,4-Trimethylbenzene	95-63-6	.056	59-122	84	25
1,2-Dibromo-3-chloropropane	96-12-8	.210	63-106	84	18
1,2-Dibromoethane	106-93-4	.036	73-108	89	16
1,2-Dichlorobenzene	95-50-1	.031-.048	62-112	84	21
1,2-Dichloroethane	107-06-2	.130	72-102	88	13
1,2-Dichloropropane	78-87-5	.029-.068	68-107	84	16
1,3-Dichlorobenzene	541-73-1	.030-.054	56-108	80	22
1,3-Dichloropropane	142-28-9	.120	72-108	89	16
1,3,5-Trimethylbenzene	108-67-8	.044	58-109	79	21
1,4-Dichlorobenzene	106-46-7	.050	56-112	81	23
2,2-Dichloropropane	594-20-7	.050-.078	54-99	74	19
2-Butanone	78-93-3	1.60	86-118	104	16
2-Chlorotoluene	95-49-8	.026-.042	56-111	78	22
2-Hexanone	591-78-6	.700	86-102	96	7.2
3-Chloropropene	107-05-1	.070-.200	63-114	85	20
4-Chlorotoluene	106-43-4	.056-.060	59-114	81	22
4-Isopropyl-1-methylbenzene	99-87-6	.070-.110	52-115	80	26
4-Methyl-2-pentanone	108-10-1	.370	73-94	85	9.7
Acetone	67-64-1	5.00-7.00	77-103	93	13
Acrylonitrile	107-13-1	1.20	85-106	98	9.6
Benzene	71-43-2	.035-.100	61-103	83	18
Bromobenzene	108-86-1	.036	59-111	82	21
Bromochloromethane	74-97-5	.044	65-112	90	23
Bromodichloromethane	75-27-4	.048	73-108	91	¹ 16
Bromoethene	593-60-2	.100	64-107	86	18
Bromoform	75-25-2	.060-.100	73-101	86	13
Bromomethane	74-83-9	.150-.260	¹ 48-92	¹ 67	16
Butylbenzene	104-51-8	.190	50-104	78	24

Appendix 4. Reporting levels and spike recoveries for volatile organic compounds in ground-water samples collected from basin-fill aquifers, Northern Rockies Intermontane Basins Study Unit, 1999 and 2001—Continued

Constituent	CAS number	RL range or value (µg/L)	Spike recovery (percent) (n = 5)		
			Range	Mean	Standard deviation
Carbon disulfide	75-15-0	.070-.370	63-114	86	20
Chlorobenzene	108-90-7	.028	59-107	81	20
Chloroethane	75-00-3	.120	64-107	86	18
Chloroform	67-66-3	.024-.052	68-110	88	17
Chloromethane	74-87-3	.250	¹ 66-124	¹ 89	¹ 22
cis-1,2-Dichloroethylene	156-59-2	.038	65-105	87	18
cis-1,3-Dichloropropene	10061-01-5	.090	61-104	95	21
Dibromochloromethane	124-48-1	.180	69-106	88	16
Dibromomethane	74-95-3	.050	69-104	87	16
Dichlorodifluoromethane	75-71-8	.140-.270	¹ 86-186	¹ 117	¹ 41
Dichloromethane	75-09-2	.160-.380	72-112	94	18
Diethyl ether	60-29-7	.170	81-109	89	12
Diisopropyl ether	108-20-3	.098-.100	71-108	90	16
Ethyl methacrylate	97-63-2	.180-.280	79-108	88	12
Ethyl tert-butyl ether	637-92-3	.054	72-100	86	12
Ethylbenzene	100-41-4	.030	59-106	80	20
Hexachlorobutadiene	87-68-3	.140	57-120	89	29
Hexachloroethane	67-72-1	.190-.360	¹ 60-111	¹ 86	¹ 22
Isopropylbenzene	98-82-8	.032	57-110	78	21
m- and p-Xylene	108-38-3 and 106-42-3	.060	61-113	84	21
Methyl acrylate	96-33-3	1.40	86-112	95	10
Methyl acrylonitrile	126-98-7	.570-.600	83-113	96	12
Methyl iodide	74-88-4	.120-.210	¹ 45-127	¹ 78	¹ 33
Methyl methacrylate	80-62-6	.350	87-113	96	10
Naphthalene	91-20-3	.250	68-108	80	16
n-Propylbenzene	103-65-1	.042	53-108	78	23
o-Ethyl toluene	611-14-3	.060-.100	58-113	83	23
o-Xylene	95-47-6	.038-.060	61-108	78	19
sec-Butylbenzene	135-98-8	.032-.048	55-110	81	23
Styrene	100-42-5	.042	64-121	86	23
Methyl tert-butyl ether	1634-04-4	.170	72-98	82	11
tert-Butylbenzene	98-06-6	.060-.100	57-109	85	24
tert-Pentyl methyl ether	994-05-8	.110	79-109	90	12
Tetrachloroethylene	127-18-4	.100	60-112	87	23
Tetrachloromethane	56-23-5	.060-.088	¹ 59-106	¹ 83	¹ 20
Tetrahydrofuran	109-99-9	2.2-9.0	84-111	99	12
Toluene	108-88-3	.050	59-104	81	20
trans-1,2-Dichloroethylene	156-60-5	.032	62-111	88	21
trans-1,3-Dichloropropene	10061-02-6	.090-.130	65-107	86	20
trans-1,4-Dichloro-2-butene	110-57-6	.700	88-120	102	13
Trichloroethylene	79-01-6	.038	64-112	85	19
Trichlorofluoromethane	75-69-4	.090	¹ 63-113	¹ 88	22
Vinyl chloride	75-01-4	.110	68-121	92	20

¹Calculation based on estimated values.

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Appendix 5. Well-numbering system

Wells are assigned well numbers (1-61; figs. 2 and 3; appendix 1), location numbers (appendix 1), and well-identification numbers (appendix 1). The well numbers (1-61) are used for cross reference for the sampled wells shown in figures 2 and 3 and listed in tables 3-5 and appendix 1. The location numbers describe the geographic position within the rectangular grid system used for the subdivision of public lands. The location-numbering system consists of 14 characters. The first three characters specify the township and its position north (N) of the Willamette baseline in Washington, the Boise baseline in Idaho, or the baseline in Montana. The next three characters specify the range and its position west (W) or east (E) of the Willamette meridian in Washington, the Boise meridian in Idaho, or the principal meridian in Montana. The next two numbers represent the section number. The next four characters sequentially designate the quarter (160-acre tract), quarter-quarter (40-acre tract), quarter-quarter-quarter (10-acre tract), and the quarter-quarter-quarter-quarter (2 1/2-acre tract). The locations of quarter subdivisions within a section are designated A, B, C, D in a counterclockwise direction, beginning in the northeast quadrant. The final two characters are a sequence number assigned to differentiate multiple wells within a single quarter-quarter-quarter-quarter section. For example, as shown in figure 16, 26N43E06ACBD01 was the first well inventoried in the SE1/4NW1/4 SW1/4NE1/4 sec. 6, T. 26 N., R. 43 E. Wells also are assigned 15-digit well-identification numbers (appendix 1). These numbers represent the approximate latitude and longitude of each well (first 13 digits) plus the sequence number (last 2 digits). However, some well-identification numbers differ (appendix 1) from the latitude and longitude where wells were recently field checked and latitudes and longitudes were determined with greater accuracy.

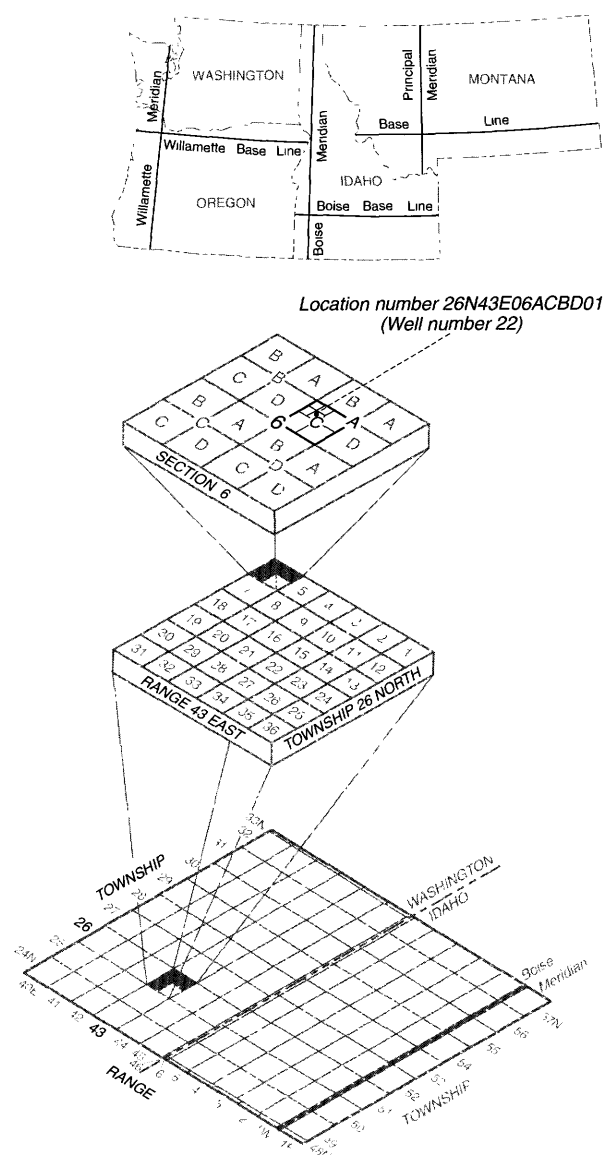


Figure 16. Well-numbering system.



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