FIELD SCREENING OF WATER QUALITY, BOTTOM SEDIMENT, AND BIOTA ASSOCIATED WITH IRRIGATION DRAINAGE IN THE HELENA VALLEY, WEST-CENTRAL MONTANA, 1995

by Eloise Kendy, U.S. Geological Survey,
and Bill Olsen and John C. Malloy, U.S. Fish and Wildlife Service

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CONVERSION FACTORS, VERTICAL DATUM, AND ACRONYMS

Multiply	By	To obtain
acre	4,047	square meter
acre-foot (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.028317	cubic meter per second
foot (ft)	0.3048	meter
foot squared per day (ft^2/d)	0.0929	meter squared per day
gallon	3.785	liter (L)
inch (in.)	25.4	millimeter (mm)
inch (in.)	25,400	micrometer (µm)
mile (mi)	1.609	kilometer
ounce	28.35	gram (g)
pint	0.4732	liter (L)
pound per day (lb/d)	0.454	kilogram per day
square mile (mi^2)	2.59	square kilometer

Degree Celsius (°C) may be converted to degree Fahrenheit (°F) by using the following equation:

$$°F = 9/5(°C)+32.$$

Degree Fahrenheit (°F) may be converted to degree Celsius (°C) by using the following equation:

$$°C = 5/9(°F-32).$$

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Chemical concentration in water is reported in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the solute mass (milligram) per unit volume (liter) of water and is about the same as parts per million unless concentrations are more than 7,000 milligrams per liter (Hem, 1989, p. 55). Chemical concentration in sediment and biological tissue is reported in micrograms per gram (µg/g), which is equal to parts per million; or in percent, which is equal to parts per hundred.

Specific conductance of water is a measure of the ability of water and dissolved constituents to conduct an electrical current and is an indication of the ionic strength of the solution. Specific conductance is expressed in microsiemens per centimeter at 25°C (µS/cm) and increases with the concentration of dissolved constituents.

SELECTED ACRONYMS USED IN THIS REPORT

AA	atomic absorption
BOR	Bureau of Reclamation of the U.S. Department of the Interior
CERCLA	Comprehensive Environmental Response Compensation and Liability Act of 1980
DOI	U.S. Department of the Interior
EPA	U.S. Environmental Protection Agency
GERG	Geochemical and Environmental Research Group, Texas A&M University, College Station, Texas
ICP	Inductively coupled plasma
MBMG	Montana Bureau of Mines and Geology
MCL	Maximum contaminant level established by the U.S. Environmental Protection Agency (1996)
NBS	National Biological Service
NWQL	U.S. Geological Survey National Water Quality Laboratory
PACF	U.S. Fish and Wildlife Service Patuxent Analytical Control Facility
PCB	Polychlorinated biphenyl
PVC	Polyvinyl chloride
SMCL	Secondary maximum contaminant level established by the U.S. Environmental Protection Agency (1996)
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WMA	Wildlife Management Area

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Abstract

This report describes the results of a field screening of water, bottom sediment, and biota associated with irrigation drainage in the Helena Valley in west-central Montana. Data were collected in 1993 and 1995 from 27 wells, 4 suction lysimeters, 13 surface-water sites, 3 bottom-sediment sites, and 8 biological sites in areas potentially affected by canal seepage and irrigation drainage from the Helena Valley Irrigation District.

The Helena Valley receives about 63,000 acre-feet of water diverted from the Missouri River annually. At the point of diversion, the concentration of naturally occurring arsenic ranges from about 22 to 34 micrograms per liter (μg/L). The Montana Department of Environmental Quality has established a human health standard of 18 μg/L arsenic for drinking water and the U.S. Environmental Protection Agency has established a maximum contaminant level of 50 μg/L arsenic for treated drinking water.

Domestic and community-supply wells in the Helena Valley are completed in shallow aquifers that are partly recharged by infiltrated irrigation water that can affect the quality of water in the aquifer. Some of the irrigation water returns as surface drainage to Lake Helena, a shallow lake used by water birds, raising concerns regarding biological risks from potentially high levels of arsenic.

Trace-element concentrations in ground water generally were low, with some exceptions. Arsenic concentrations in samples collected from 27 wells during this study ranged from less than 1 to 22 μg/L, with a median value of 2 μg/L.

In the populous, western part of the valley, drinking water typically is obtained from an alluvial aquifer. The median arsenic concentration in ground water at depths greater than 3 ft below the water table in the alluvium was 1.2 μg/L. Arsenic concentrations generally were higher in irrigation water than in soil moisture, and higher in soil moisture than in shallow ground water beneath irrigated fields. This trend suggests that arsenic is sorbed to soil particles as irrigation water percolates through the soil profile, and is diluted by ground water as it infiltrates to the underlying aquifer. Deeper in the alluvial aquifer, arsenic may continue to sorb and be diluted, or hydraulic gradients may prevent the infiltrated irrigation water from moving downward, resulting in low arsenic concentrations at depth.

The highest arsenic concentrations measured in ground water (17 and 22 μg/L) correspond to domestic wells completed in Tertiary sediments beneath the Spokane Bench in the eastern part of the Helena Valley. Potential sources of arsenic to ground water in this area are infiltrated irrigation water and dissolution of arsenic-bearing minerals. In contrast to the permeable alluvial aquifer in the western part of the valley, the Tertiary aquifer has low permeability and probably does not transmit sufficient quantities of ground water to dilute arsenic significantly.

Trace-element concentrations in surface water generally were low, with the exceptions of arsenic and zinc. Arsenic concentrations in samples from 12 irrigation-drain, natural-stream, and

lake sites ranged from 2 to 25 µg/L, with median concentrations of 5.5 µg/L during the non-irrigation season and 15 µg/L during the irrigation season. The highest concentration corresponds to water from a drain that receives direct spills from lateral canals. Samples from most surface-water sites within the Helena Valley Irrigation District had higher arsenic concentrations during irrigation season than during non-irrigation season, in contrast to a reference site not affected by irrigation drainage, at which the arsenic concentration decreased slightly during irrigation season. Moderately elevated zinc concentrations in Prickly Pear Creek probably result from historical mining and industrial activities.

National hazard levels have not been established for bottom-sediment constituents. Three samples of bottom sediment from Lake Helena had arsenic and trace-metal concentrations that are comparable to concentrations in bottom sediment from wetlands impaired by mining. For example, the maximum concentrations for the three samples were 46 µg/g for arsenic, 47 µg/g for chromium, 82 µg/g for copper, 170 µg/g for lead, and 600 µg/g for zinc. Possible sources of trace metals in the bottom sediment include irrigation drainage causing mobilization of smelter fallout on irrigated lands, and fluvial transport from upstream mining areas.

Many of the 7 aquatic-invertebrate samples, 14 fish samples, and 5 water-bird-liver samples from the Helena Valley had concentrations of the trace elements arsenic, cadmium, copper, lead, and zinc that were elevated relative to concentrations in samples from uncontaminated sites statewide and nationwide. However, few samples had concentrations that were elevated sufficiently to indicate biological risk. Trace-element concentrations in water-bird-liver samples, as well as organochlorine residues in 14 fish samples of both young and old age classes, pose no threat to the health of the organisms or to their predators in the Helena Valley. In contrast, cadmium concentrations in invertebrates may pose a threat to their predators. In addition, cadmium and lead concentrations in some fish exceeded the concentrations considered potentially harmful to predators if consumed on a sustained basis.

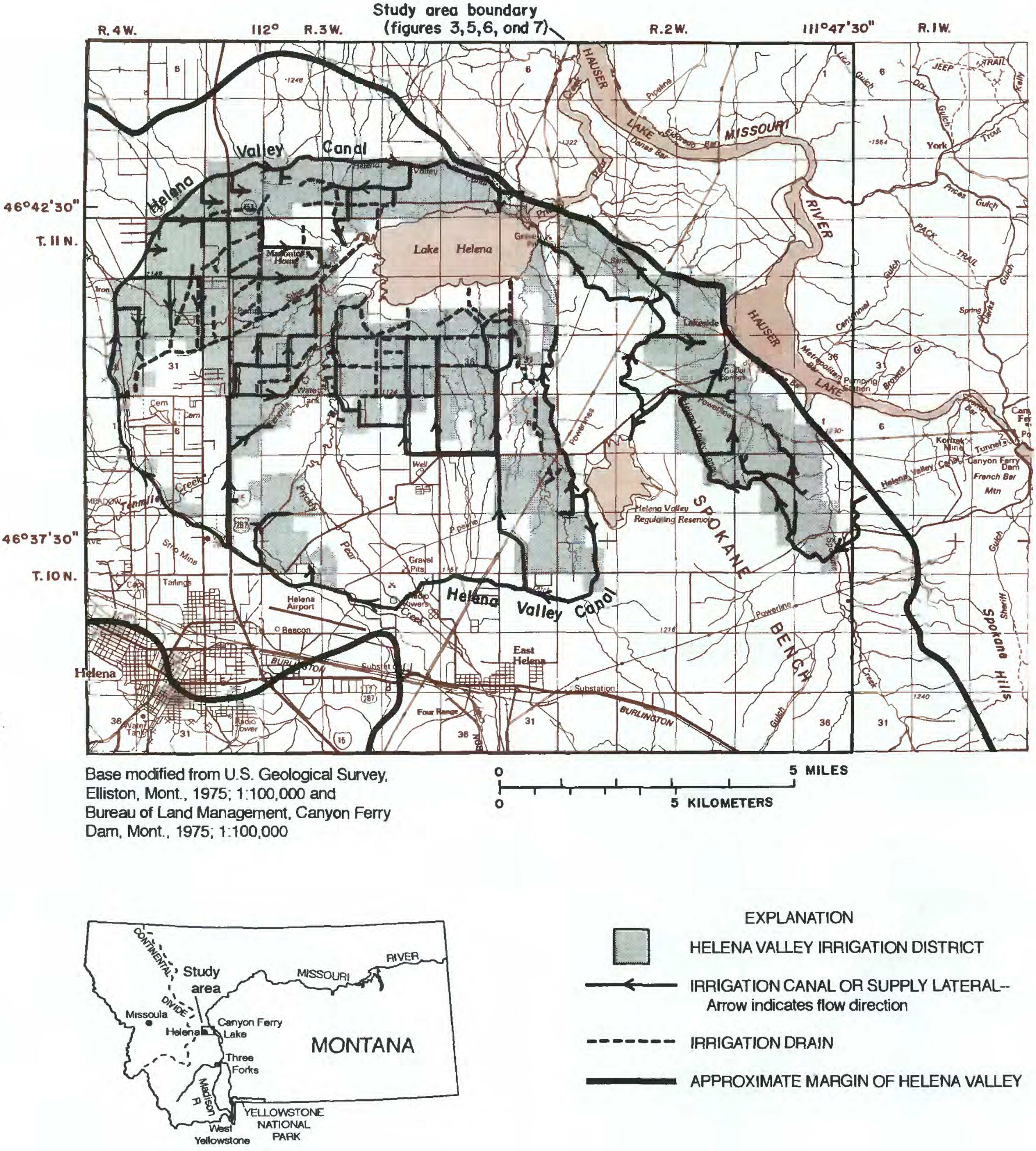
INTRODUCTION

Concerns about irrigation-related water-quality problems have arisen in recent years as a result of documented adverse biological impacts in some major irrigation project areas in the western United States (Feltz and Engberg, 1994). In response to these concerns, the U.S. Department of the Interior (DOI) was directed by Congress in 1985 to identify the nature and extent of potential problems in irrigation projects constructed or administered by the DOI. The Helena Valley Irrigation District was selected for an investigation primarily to identify potential risks to public health or wildlife as a result of infiltration of irrigation water containing arsenic into shallow aquifers and subsequent return flow into Lake Helena wetlands.

Geothermal waters from Yellowstone National Park contribute large amounts of arsenic to the Madison River, one of three rivers that converge to form the Missouri River near Three Forks, Mont. (fig. 1). Arsenic concentrations in the Madison River near West Yellowstone range from 120 to 380 µg/L; elevated arsenic concentrations persist downstream into the Missouri River, with concentrations below Canyon Ferry Dam near Helena (fig. 1) ranging from 22 to 34 µg/L (Knapton and Horpestad, 1987; Knapton and Brosten, 1987; U.S. Geological Survey, issued annually). The Montana Department of Environmental Quality (1995) has established a human health standard of 18 µg/L arsenic for drinking water and the U.S. Environmental Protection Agency (EPA) (1996) has established a maximum contaminant level (MCL) of 50 µg/L arsenic for treated drinking water.

The Helena Valley Irrigation District diverts irrigation water from the Missouri River below Canyon Ferry Dam to the Helena Valley. Some of the irrigation water returns as drainage to Lake Helena, a shallow lake used by water birds, raising concerns regarding biological risks from the potentially high levels of arsenic.

The distribution and interrelation of arsenic concentrations in surface water and ground water in the Helena Valley have not been extensively investigated. However, water in aquifers adjacent to the Madison River has been shown to contain elevated levels of arsenic, probably derived from river water, either through direct infiltration into the alluvium or from infiltration of water diverted for irrigation (Sonderegger and others, 1989; Nimick, 1994). In the Helena



Base modified from U.S. Geological Survey, Elliston, Mont., 1975; 1:100,000 and Bureau of Land Management, Canyon Ferry Dam, Mont., 1975; 1:100,000

Figure 1. Location and components of the Helena Valley Irrigation District, Montana. Modified from Bureau of Reclamation (1957).

Valley, many domestic and community-supply wells are completed in shallow aquifers that are partly recharged by arsenic-enriched irrigation water diverted from the Missouri River. Irrigation water can recharge aquifers either by seeping from irrigation canals, laterals, and drains, or by infiltrating through irrigated soils and, therefore, can affect the quality of water in the aquifers.

In addition to arsenic, trace-metal concentrations in water, bottom sediment, and biota in the Helena Valley could be affected by irrigation or other past and present activities. However, knowledge of these chemical characteristics is limited. This investigation was conducted to provide information about these chemical characteristics, particularly as related to irrigation.

PURPOSE AND SCOPE

This report describes results of an investigation conducted in 1995 of the chemical characteristics of water, bottom sediment, and biota associated with canal seepage and irrigation drainage from the Helena Valley Irrigation District. Also, in 1993, the U.S. Geological Survey (USGS) sampled ground water beneath irrigated fields in the Helena Valley. The previously unpublished results of the 1993 sampling are included in this report along with results of the 1995 work.

Data were collected from 13 surface-water sites, 4 suction lysimeters, 27 wells, 3 bottom-sediment sites, and 8 biological sites during 1993 and 1995 at locations and times selected to describe the range and spatial variability of constituent concentrations. Data-collection schedules were determined principally by hydrologic conditions related to the timing of irrigation and natural runoff, seasonal variations in biological productivity, and life-cycle stages of resident or migratory biota. The data collection was a cooperative effort by the USGS and the U.S. Fish and Wildlife Service (USFWS). In addition, previously published analyses of selected ground-water samples collected in 1989 and 1990 are presented in this report.

PREVIOUS INVESTIGATIONS

Previous investigations of water resources in the Helena Valley have focused on the hydrogeology of shallow aquifers (Lorenz and Swenson, 1951; Wilke and Coffin, 1973; Wilke and Johnson, 1978; and Moreland and Leonard, 1980). Stickney (1987) mapped surficial geological deposits of the valley. Briar and Madison (1992) described the hydrogeology of the Helena valley-fill aquifer system, focusing on the western part of the valley fill, which Stickney (1987) identified as Quaternary alluvium. Briar and Madison (1992) characterized the ground-water quality of the aquifer system on the basis of water samples from 47 wells, which were analyzed for major ions and selected trace elements. In addition, samples from 15 wells were analyzed for a suite of 15 organic compounds. One pesticide, 2,4-D, was detected in a single sample at a concentration several times lower than the MCL established by the U.S. Environmental Protection Agency (1996) for treated drinking water. A subsequent sample from the same well contained no detectable pesticides (Briar and Madison, 1992). Therefore, pesticides in ground water in the Helena Valley did not appear to be a major human-health concern.

Helena Valley surface water has not been the focus of previous investigations. Prickly Pear Creek, Silver Creek, and Tenmile Creek are the major natural tributaries to Lake Helena. Streamflow-gaging records for Prickly Pear Creek at East Helena (USGS station 06062000, which was monitored from 1908 to 1913) provide the only daily streamflow data within the study area. Additional daily streamflow data exist for two nearby stations upstream from the study area: Tenmile Creek near Helena (USGS station 06063500, with streamflow records for 1908-54 and water-quality data for 1948 and 1950-51) and Sevenmile Creek at Birdseye (USGS station 06064000, with streamflow records for 1908-13). Briar and Madison (1992) estimated monthly mean and annual mean streamflow for the major streams entering the valley. Records of monthend contents, in acre-feet, for the Helena Valley Regulating Reservoir and Lake Helena are reported in USGS Water-Data Reports (U.S. Geological Survey, issued annually). Records of diversions from the Missouri River to the Helena Valley are maintained by the Helena Valley Irrigation District and the Bureau of Reclamation (BOR) at Canyon Ferry Dam.

Locally, the land and water resources within about a 1.5-mi radius of East Helena have been investigated under the Comprehensive Environmental Response Compensation and Liability Act of 1980 (CERCLA) because of concerns about arsenic, cadmium, lead, and other constituents resulting from lead and zinc smelting operations. As part of the investigation, streamflow and water and bottom-sediment chemistry of Prickly Pear Creek, depths and quality of ground water, and chemistry of soils were monitored intensively (Hydrometrics, Inc., 1990; ASARCO, Inc., 1995).

The USFWS examined sediment and biota from Prickly Pear Creek near East Helena and from Lake Helena in 1987, 1991, and 1992 (Olsen and others, 1997). Sediment samples were analyzed for trace-element concentrations, and biota samples were analyzed for trace-element concentrations and indices of blood-lead concentration. Blood samples from mallards (*Anas platyrhynchos*) at Lake Helena had significantly lower hemoglobin concentrations and delta-aminolevulinic acid dehydratase activity compared to reference site samples, indicating lead exposure. No consistent differences in trace-element concentrations were detected between biological samples collected upstream and downstream of East Helena.

As part of the CERCLA investigations at East Helena, brown trout collected from Prickly Pear Creek in 1987 and longnose suckers and white suckers collected from Lake Helena in 1988 were analyzed for trace-element concentrations (Hydrometrics, Inc., 1990, v. 5). Mercury concentrations in these fish were lower than concentrations reported for the same species from other sites in Montana. Arsenic, cadmium, and lead concentrations were similar to concentrations reported for the same species from other sites in Montana. Zinc concentrations were higher than concentrations reported for the same species from other sites in Montana.

Arsenic concentrations in surface water have been determined for several sites along the Madison and Missouri Rivers, including the Missouri River below Canyon Ferry Dam (USGS streamflow-gaging station 06058502), where water is diverted for the Helena Valley Irrigation District (U.S. Geological Survey, issued annually). Along the Madison River, the concentration of arsenic exceeds the MCL (U.S. Environmental Protection Agency, 1996) in some wells in the valley bottom. Sonderegger and others (1989) attributed elevated arsenic levels in the Madison Valley wells at least in part to the diversion, application, and infiltration of river-derived irrigation water.

This finding by Sonderegger and others (1989) prompted the BOR to investigate arsenic in parts of the Helena Valley that receive irrigation water from the Missouri River (Mangelson and Brummer, 1994). On the basis of soil, shallow ground-water, and surface-water samples collected from the central part of the valley, the BOR concluded that arsenic in irrigation water is largely attenuated by adsorption to irrigated soils. Mangelson and Brummer (1994) did not sample wells in the Helena Valley; rather, ground-water samples were collected at the water table from soil borings.

SITE IDENTIFICATION

In this report, ground-water and soil-moisture sites are identified according to geographic position within the rectangular grid system used for the subdivision of public land in Montana (fig. 2). The location number consists of as many as 14 characters. The first three characters specify the township and its position north (N) of the Montana Base Line. The next three characters specify the range and its position west (W) of the Montana Principal Meridian. The next two characters are the section number. The next four characters sequentially designate the quarter section (160-acre tract), quarter-quarter section (40-acre tract), quarter-quarter-quarter section (10-acre tract), and quarter-quarter-quarter-quarter section (2 1/2-acre tract), respectively, in which the well is located. The locations of subdivisions within a section are designated A, B, C, and D in a counterclockwise direction, beginning in the northeast quadrant. The final two digits are a sequence number assigned to differentiate multiple wells or suction lysimeters at a single site; for example, well 11N03W33BBAA02 (fig. 2) is the second well inventoried in the NE1/4NE1/4NW1/4NW1/4 of sec. 33, T. 11 N., R. 3 W.

Fifteen-digit site-identification numbers also are used for ground-water, soil-moisture, miscellaneous surface-water, bottom-sediment, and biological sampling sites. These numbers represent the approximate latitude and longitude of the site (first 13 digits), plus the sequence number (last 2 digits). Eight-digit station-identification numbers for routine surface-water sites represent the standard U.S. Geological Survey numbering system for streamflow-gaging stations in which numbers increase in a downstream direction according to geographic location within a drainage basin.

ACKNOWLEDGMENTS

The authors acknowledge with appreciation the many individuals who assisted in the study. Peter L. Schendel of the BOR provided valuable information regarding the history and description of the Helena Valley Irrigation District. James A. Foster of the Helena Valley Irrigation District is gratefully acknowledged for providing pertinent maps and information, which greatly assisted this project. Appreciation is extended to the landowners in the study area who allowed access to their wells for inventorying and sampling. Particular thanks are given to Les L. Pannetier for allowing access to his property for installation and monitoring of two instrument clusters. Finally, this project benefitted immensely from reviews, suggestions, and insightful

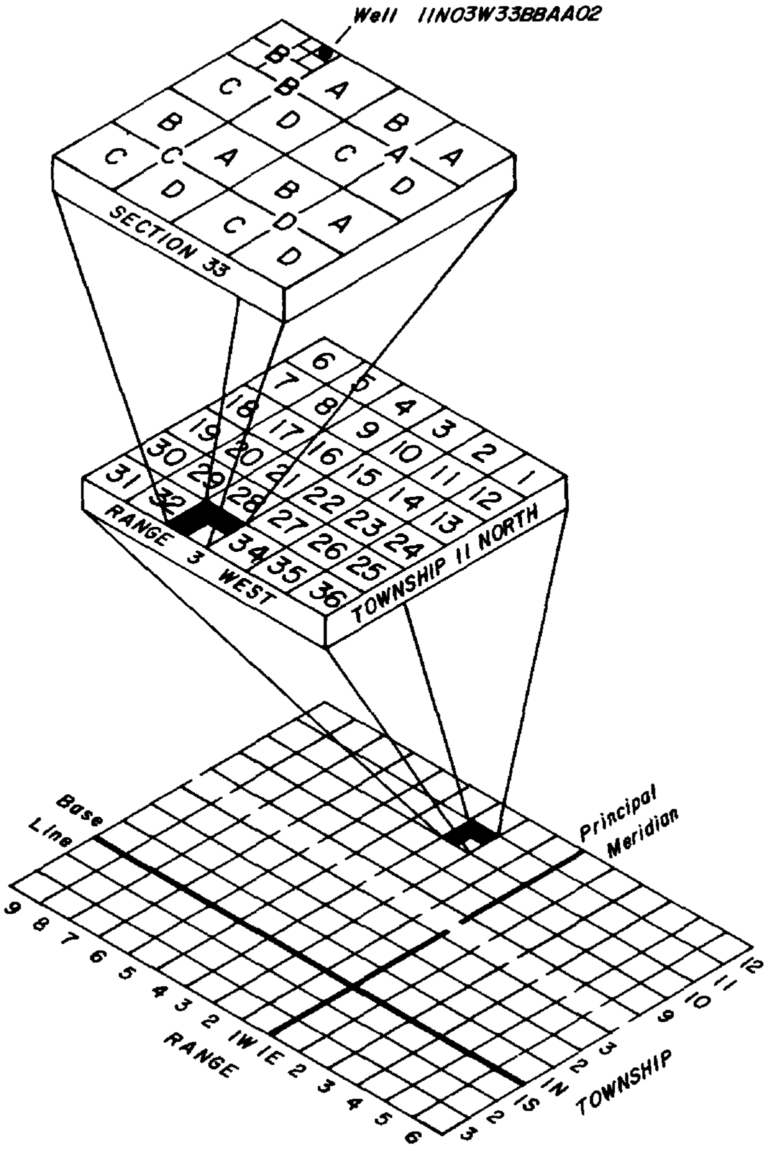


Figure 2. Site-identification system for ground-water and soil-moisture sampling sites.

discussions with David A. Nimick and John H. Lambing of the U.S. Geological Survey.

DESCRIPTION OF STUDY AREA

The study area (fig. 1) encompasses the Helena Valley Irrigation District and extends upgradient a short distance to include reference sites that are not irrigated. Land uses in the study area include irrigated hay production, small grain farming, cattle grazing, and urban and rural residential development.

The Helena Valley Irrigation District manages the distribution of water from the Missouri River to the Helena Valley. The water supply is obtained from the Missouri River below Canyon Ferry Dam, about 15 mi east of Helena (fig. 1). Turbine-driven pumps lift water to the 2.7-mi long Helena Valley Canal Tunnel, through which the water flows by gravity beneath the Spokane Hills and into the Helena Valley Canal. Water in this upland section of the canal flows 8.3 mi across the Spokane Bench to the 5,900 acre-ft Helena Valley Regulating Reservoir. The reservoir discharges water into the valley section of the Helena Valley Canal, which nearly encircles the Helena Valley alluvial plain, distributing water to the central part of the Helena Valley through an extensive network of lateral canals. The length of the Helena Valley Canal is 31.7 mi, of which 10.2 mi are lined and 21.5 mi are unlined. Of the 64.4 mi of lateral canals, 51.9 mi are lined and 12.5 mi are unlined. A 56.5-mi drainage system consisting of 26.6 mi of open drains and 29.9 mi of pipe drains prevents irrigated land from becoming saturated (Peter L. Schendel, Bureau of Reclamation, written commun., 1996). Irrigation drainage from most of the Irrigation District, plus natural discharge of ground water and streams, enter Lake Helena in the northern (downgradient) part of the valley. Drainage from the Spokane Bench flows northeastward toward Spokane Creek and Hauser Lake, which is an impoundment on the Missouri River.

PHYSICAL SETTING

The Helena Valley is a northwest-trending, 150-mi^2, oval-shaped basin just east of the Continental Divide (fig. 1). In the western part of the Helena Valley, unconsolidated alluvial sediments of Quaternary age form an approximately 65-mi^2 gently sloping plain (fig. 3). The alluvial plain is flanked on the southwest and north by gently sloping Tertiary pediments that are covered with as much as 15 ft of Pleistocene-age sandy, silty gravels. The eastern part of the Helena Valley (the Spokane Bench) is a Tertiary pediment characterized by flat-topped benches and low, rolling hills. Tertiary sediments underlying the pediment generally are finer grained and more consolidated than the Quaternary alluvium to the west. Mountains consisting of Precambrian to Cretaceous sedimentary, metamorphic, and igneous bedrock surround the valley (Stickney, 1987; Lorenz and Swenson, 1951; Knopf, 1963; Briar and Madison, 1992).

The Helena Valley Irrigation District ranges in altitude from 3,650 ft at Lake Helena to 3,860 ft at the start of the Helena Valley Canal, above the Helena Valley Regulating Reservoir. The 610-mi^2 Lake Helena watershed extends into the surrounding mountains to altitudes of more than 7,000 ft above sea level.

The climate of the Helena Valley is characterized by cold winters, mild summers, and sparse precipitation. On the basis of the 1961-90 period of record, the average annual temperature at the Helena Airport (altitude 3,830 ft) is 44.0 °F and the average annual precipitation is 11.6 in. (National Oceanic and Atmospheric Administration, 1992). The average last occurrence of 32 °F is May 18, and the average first occurrence is September 20 (Natural Resources Conservation Service, U.S. Department of Agriculture, unpub. data, 1994). Most of the precipitation occurs as winter snow and spring showers (National Oceanic and Atmospheric Administration, 1992); therefore, irrigation is required to sustain most crops through the summer growing season.

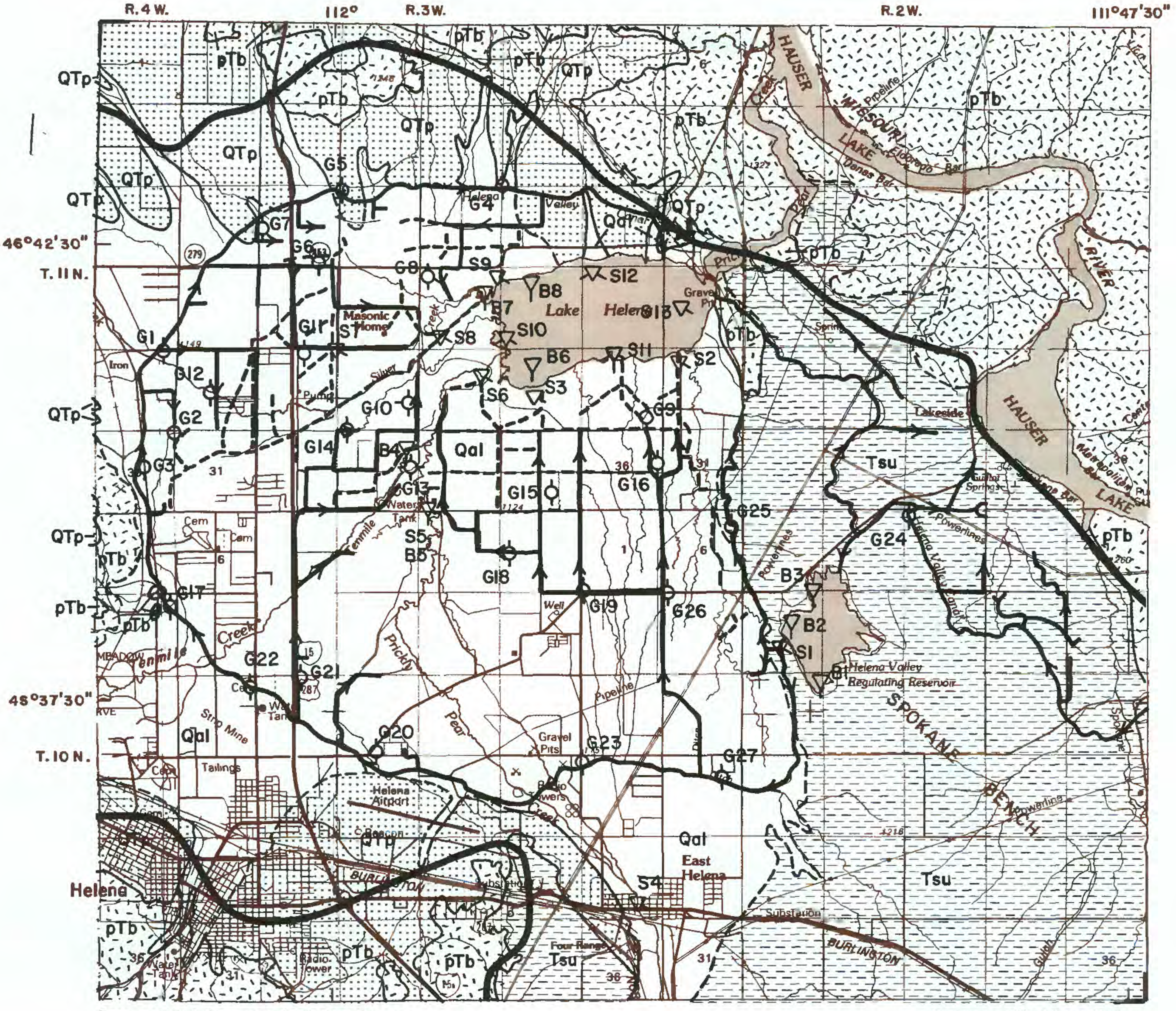
Areas surrounding and draining into the Helena Valley have a history of hard-rock mining and smelting beginning in the 1860's. Gold traditionally has been the predominant product, but silver, lead, copper, zinc, molybdenum, and other ores also were mined locally at various times. Tailings and settling ponds from abandoned mines remain prominent features within these drainages. Eleven abandoned mine sites in the Prickly Pear Creek drainage, 14 sites in the Tenmile Creek drainage, and 4 sites in the Silver Creek drainage are considered priority sites for remediation by the State of Montana (Montana Department of State Lands, 1995). Lead smelters were operated near tributaries to Prickly Pear Creek at the turn of the century (Montana Department of Health and Environmental Sciences, 1981). As recently as 1980, an underground lead mine was operated adjacent to Prickly Pear Creek, about 10 mi south of Helena.

Today, a smelter produces lead bullion and zinc oxide along Prickly Pear Creek just south of East Helena. By-products include sulfuric acid, matte (iron, copper, and lead oxides) and speiss (copper arsenides and antimonides), which are sent to other plants for further refining. Prior to the 1970's, non-contact cooling water was discharged to Prickly Pear Creek continuously at a rate of 3.3 ft^3/s. In addition, effluent from speiss washing, along with the effluent from several other process lines, was released into the creek (Montana Department of Health and Environmental Sciences, 1981). In September 1984, the EPA added the East Helena smelter site to its National Priorities List of hazardous waste sites. EPA currently is overseeing efforts to remediate soil and ground-water contamination in East Helena, and discharge practices have been modified to reduce environmental impacts.

HYDROLOGIC SETTING

Two ground-water regimes are present in the Helena Valley. In the western part of the valley, Quaternary alluvium and the upper few hundred feet of Tertiary sediments constitute the relatively permeable "valley-fill aquifer system" described by Briar and Madison (1992), referred to in this report as the "alluvial aquifer." The eastern part of the valley (the Spokane Bench) is underlain by fine-grained, poorly consolidated Tertiary sediments which constitute the only available aquifer, referred to in this report as the "Tertiary aquifer." Bedrock aquifers surround the valley and are hydraulically connected to the alluvial and Tertiary aquifers (Briar and Madison, 1992).

The general direction of ground-water flow in the alluvial aquifer is toward Lake Helena. The alluvial aquifer consists of unconsolidated, moderately sorted, complexly stratified lenses of cobbles, gravel, sand, silt, and clay. Laterally discontinuous water-yielding zones of the alluvium are very permeable, with horizontal transmissivity values of about 10,000 ft^2/d (Moreland and Leonard, 1980; Briar and Madison, 1992). Near Lake Helena, the alluvium becomes better sorted and finer grained. Most wells completed in the alluvial aquifer are less than 100 ft deep, and almost 60 percent of the domestic wells are less than 70 ft deep (Briar and Madi-



Base modified from U.S. Geological Survey, Elliston, Mont., 1975; 1:100,000 and Bureau of Land Management, Canyon Ferry Dam, Mont., 1975; 1:100,000

Irrigation canals and drains modified from Bureau of Reclamation, 1957; 1:83,380

Geology modified from Stickney (1987), Knopf (1983) and Davis and others (1963)

Figure 3. Generalized geology and location of surface-water, soil-moisture, ground-water, bottom-sediment, and biological sampling sites, Helena Valley area , Montana.

EXPLANATION FOR FIGURE 3

EXPLANATION

Qal	QUATERNARY ALLUVIUM
QTp	QUATERNARY-TERTIARY PEDIMENT DEPOSITS
Tsu	TERTIARY SEDIMENTS, UNDIFFERENTIATED
pTb	PRE-TERTIARY BEDROCK
———— — —	CONTACT--Dashed where approximately located
——←——	IRRIGATION CANAL OR SUPPLY LATERAL--Arrow indicates flow direction
- - - - - - -	IRRIGATION DRAIN
━━━━	APPROXIMATE MARGIN OF HELENA VALLEY
	SOIL-MOISTURE AND GROUND-WATER SAMPLING SITE AND SITE NUMBER
G10 -○-	Soil moisture
G5 ϕ	Ground water
	SURFACE-WATER, BOTTOM-SEDIMENT, AND BIOLOGICAL SAMPLING SITE AND SITE NUMBER
S13 ▽	Surface water
S11 ▽	Bottom sediment
B6 Y	Biota

son, 1992). Minimum depths to water in the alluvial aquifer generally are less than 10 ft within about 4 mi south and west of Lake Helena, and increase away from the lake. Depths to water typically fluctuate 2 to 15 ft annually. Water levels generally are lowest in early spring, rise during late spring and summer, and then recede through the fall and winter. The rise in water levels in late spring and summer is at least in part the result of irrigation in areas downgradient of the Helena Valley Canal (Moreland and Leonard, 1980).

The central part of the Helena Valley--including most of the Irrigation District--is a ground-water discharge area. Although previous investigators (Wilke and Coffin, 1973; Lorenz and Swenson, 1951) considered surplus irrigation water to be the major source of recharge to the alluvial aquifer, Briar and Madison (1992) concluded that subsurface flow from fractures in the surrounding bedrock mountains accounts for nearly half (46 percent) of the recharge. Recharge also enters the alluvial aquifer by infiltration from irrigated fields (31 percent), seepage from canals (8 percent), and seepage from streams (15 percent). Direct precipitation is a minor component of recharge in most years and was accounted with other terms in this estimated water budget (Briar and Madison, 1992).

The Tertiary aquifer in the eastern part of the study area consists of northeastward dipping, moderately indurated, poorly sorted, sandy siltstone and volcaniclastic sediments with laterally discontinuous sandy-pebble and gravel interbeds and lenses. Transmissivity of the Tertiary aquifer is much lower than the alluvial aquifer, owing to the low permeability of the fine-grained material and the discontinuous nature of permeable lenses (Briar and Madison, 1992; M.W. Reynolds, U.S. Geological Survey, oral commun., 1997). Potentiometric-surface contours of the alluvial aquifer (Briar and Madison, 1992; Lorenz and Swenson, 1951; Wilke and Coffin, 1973) indicate little, if any, horizontal ground-water flow between the Tertiary and alluvial aquifers. The part of the study area that is underlain by the Tertiary aquifer is relatively undeveloped and has few wells.

Surface water enters the Helena Valley principally from Prickly Pear, Tenmile, and Silver Creeks and from irrigation water that is diverted from the Missouri River (fig.1). Briar and Madison (1992) estimated annual mean flows of the three major tributaries to be about 53,000 acre-ft, 18,600 acre-ft, and 1,600 acre-ft, respectively, near the edges of the study area. Some of this water is withdrawn for irrigation upstream from the Helena Valley Irrigation District. Diversions from the Missouri River to the Helena Valley Irrigation District account for an average of about 63,000 acre-ft of inflow to the valley annually.

Most surface water in the Helena Valley flows toward Lake Helena, the stage of which is partly controlled by Hauser Lake on the Missouri River. Hauser Lake was impounded in 1907. In 1945, a dam and control works were added to separate Hauser Lake from Lake Helena, thereby allowing the two reservoirs to be regulated independently, if needed (Shields and others, 1995, p. 356). Flow between Hauser Lake and Lake Helena depends on the level of Hauser Lake, which is controlled for power generation, relative to the level of Lake Helena. Although the net flow direction is from Lake Helena to Hauser Lake, flow temporarily reverses direction almost daily.

BIOLOGIC SETTING

The Helena Valley supports many of the fish, wildlife, reptiles, and amphibians common to Montana. At least ten species of mammal, including mink (*Mustela vison*), red fox (*Vulpes vulpes*), muskrat (*Ondatra zibethicus)*, and white-tailed deer (*Odocoileus virginianus*), have been documented in the area. The Helena Valley also supports large populations of breeding and migrant birds which primarily are associated with deepwater, wetland, and riparian habitats. Two hundred thirty-five species of birds have been documented in the Helena Valley area (Robert Hazlewood, U.S. Fish and Wildlife Service, written commun., 1997).

Lakes and streams in the area produce sufficient populations of warm- and cold-water fish to support important recreational and commercial fisheries. Common fish are rainbow trout (*Oncorhynchus mykiss*), brown trout (*Salmo trutta*), kokanee salmon (*Oncorhynchus nerka*), perch (*Perca flavescens*), carp (*Cyprinus carpio*), suckers (*Catostomuss* sp.) and sculpins (*Cottus* sp.).

Federally listed species that inhabit the Helena Valley include the endangered peregrine falcon (*Falco peregrinus anatum*) and the threatened bald eagle (*Haliaeetus leucocephalus*). Peregrine falcons, which nest on cliffs adjacent to the nearby Missouri River, use the wetlands and riparian habitats of the Helena Valley as foraging sites during the breeding season. In the fall and spring, migrant peregrine falcons also may be present for brief stopovers as they move to and from winter breeding areas.

The Helena Valley provides important year-long habitat for bald eagles. The largest concentration of fall migrant bald eagles in the contiguous United States is located at Hauser Lake. The fall migrant eagles feed on kokanee salmon, which spawn below Canyon Ferry Dam and in the Helena Valley Regulating Reservoir. Eagles begin arriving in early October and depart in mid December for wintering grounds to the south. This large gathering of eagles is viewed by thousands of recreationists every year. Approximately 50 to 75 bald eagles winter in the Helena Valley and nearby Missouri River. An active bald eagle nesting territory is located near Lake Helena.

Vegetation in the Helena Valley is typical of the populated valleys in western Montana where the species composition has been heavily influenced by agriculture. The dominant species are alfalfa (*Medicago sativa*) and various grasses cultivated for pasture of hay. The riparian corridors along Prickly Pear Creek, Ten Mile Creek, and Silver Creek that are not cultivated or grazed are dominated by willows (*Salix* spp.), particularly sandbar willow (*Salix exigua*). Another shrub, water birch (*Betula occidentalis*), is present in lesser amounts. Small stands of cottonwood trees (*Populus* sp.) also can be found in some of the riparian areas, especially the lower reaches of Prickly Pear Creek. Lake Helena, the Helena Valley Regulating Reservoir, and smaller wetlands in the valley are characterized by vegetation typical of shallow lentic (standing water) systems, including cattails (*Typhus latifolia*), rushes (*Carex* sp. and *Eleocharis* sp.) and sedges (*Scirpus* sp.).

HISTORY OF IRRIGATION IN THE HELENA VALLEY

Irrigation began in the 1800's in the Helena Valley. Water from Prickly Pear, Tenmile, and Silver Creeks was diverted for irrigation purposes concurrent with the granting of land claims. Water shortages were noted as early as 1866. In 1912, the Montana Reservoir and Irrigation Company (now the Montana Power Company) erected pumping plants on the north and south shores of Lake Helena for an irrigation system to serve the Helena Valley. The company operated the pumps and delivered water until the late 1940's (Peter L. Schendel, Bureau of Reclamation, written commun., 1996).

In 1940, the BOR began investigations of the Helena Valley to improve irrigation facilities. Canyon Ferry Dam was completed in 1953. Construction of the present irrigation system began in 1957 and was completed in 1958. Features of the development include a pumping plant, tunnel, regulating reservoir, and canal system to furnish water to 16,440 acres of land and for municipal use by the City of Helena.

By about 1950, more than 8,000 acres of formerly productive land in the topographically low parts of the Helena Valley had become saturated by seepage from irrigation canals and infiltration from flood-irrigated fields (Lorenz and Swenson, 1951). The BOR installed several irrigation drains beginning in 1958, in part to drain previously saturated land and in part to accommodate the additional irrigation water imported from the Missouri River.

SAMPLE COLLECTION, PROCESSING, AND ANALYSIS

Sampling sites for surface water, soil moisture, ground water, bottom sediment, and biota are listed in tables 1-3 and shown in figure 3. All tables are at the back of the report. Sampling sites for water were chosen to determine trace-element concentrations in water delivered by the Irrigation District, infiltration from irrigated areas, shallow ground water, natural stream water, representative drains, and Lake Helena. Sites for sediment and biota sampling were selected in areas where water potentially affected by irrigation enters fish and water-bird habitats.

Samples of surface water, soil moisture, and ground water were collected and processed using standard USGS methods (Knapton, 1985; U.S. Geological Survey, 1977) and were analyzed by the USGS National Water Quality Laboratory (NWQL) in Arvada, Colo., using methods described by Fishman and Friedman (1989) and Fishman (1993). Dissolved constituents were analyzed for samples that were passed through a filter having pore sizes of 0.45 micrometer in the field (Knapton, 1985). About 10 percent of the water samples were quality-control samples consisting of blanks and replicates. Field measurements of specific conductance, pH, water temperature, dissolved oxygen, and discharge (for surface water) were made at the time water samples were collected.

SURFACE WATER

In 1995, surface water was sampled from 13 sites in the study area (table 1, fig. 3). Samples were collected from seven sites on the supply canal, irrigation drains, and natural streams over a broad area within the irrigation project. Four sites were sampled in Lake Helena, three of which are in shallow, near-shore areas near the mouths of drains. The fourth site sampled in Lake Helena (Lake Helena east) was located in deep water near the causeway between Lake Helena and Hauser Lake on the Missouri River. Reference samples unaffected by irrigation were obtained from two sites: the outlet of the Helena Valley Regulating Reservoir, where water delivered from the Missouri River enters the Helena Valley Canal; and Prickly Pear Creek at East Helena, downstream from numerous abandoned mines and an industrial area, either of which may be potential sources of several trace elements.

Surface-water samples were collected once prior to the irrigation season (March 1995) and once during the irrigation season (July 1995) to determine whether constituent concentrations differed significantly between the two hydrologic conditions. Samples from all 13 surface-water sites were analyzed for arsenic. Samples from seven of these sites also were analyzed for major ions, nutrients, and other trace elements. One sample collected from the west end of Lake Helena also was analyzed for organochlorine pesticides.

Water temperature, pH, and specific conductance were measured in the field during all samplings, and dissolved oxygen was measured in the field when samples were collected for complete chemical analysis. Field measurements of water-quality properties and field sample processing were performed as described by the U.S. Geological Survey (1977) and Knapton (1985).

Samples from streams and irrigation drains were collected either by depth integration at multiple stream verticals according to methods described by Knapton (1985), or by grab sampling at culverts and sites where streamflow was very small. Instantaneous streamflow was determined at the time of sampling by direct measurement, stage-discharge rating, or estimation when the flow was small. Samples from Lake Helena were collected near mid-depth.

Sampling equipment was nonmetallic to prevent trace-element contamination of samples. Depth-integrated samples of flowing water with sufficient depth were collected with a U.S. DH-81 hand-held sampler. Grab samples of point discharges and small flows were collected directly into either a glass or polyethylene sampling bottle, or a polyethylene churn splitter. Water samples from Lake Helena were collected in a nonmetallic Van Dorn point sampler that was lowered by rope to mid-depth and triggered to collect and seal a 10-L sample. The single pesticide sample was collected directly into a glass bottle submerged by hand about 1.5 ft beneath the lake surface.

Constituents analyzed in surface water and minimum reporting levels are listed in table 4. The analytical methods used provide minimum reporting levels sufficiently low to provide uncensored results below aquatic-life criteria for most constituents. Results of field measurements and laboratory analyses of surface-water samples are presented in table 5.

SOIL MOISTURE

Soil moisture, or pore water, from the unsaturated zone was sampled in two irrigated fields using suction lysimeters. In each field, two instrument clusters, consisting of two suction lysimeters and one very shallow well, were installed in May 1995. One cluster was located in a sprinkler-irrigated field at the site of well G10, and the other in a flood-irrigated field at the site of well G13 (fig. 3). Table 6 describes the lithology of the two sites.

Suction lysimeters, each consisting of a 1.9-in.-diameter porous ceramic cup with a 1.9-in.-diameter polyvinyl chloride (PVC) riser protecting 1/4-in. polyethylene tubing, were installed in 3-in.-diameter boreholes drilled with a hand auger. Construction diagrams for these sites are shown in figure 4. No drilling fluids were used. However, deionized water was mixed with silica flour to form a slurry into which the lysimeters were placed. To remove the deionized water, the lysimeters were evacuated repeatedly until the specific conductance of the samples stabilized. The silica pack maintained a hydraulic connection between the porous ceramic cup and the surrounding soil.

Soil-moisture samples were collected twice from most lysimeters during the irrigation season. The 1995 growing season was unusually wet, resulting in little need for irrigation. Samples from the sprinkler-irrigated site represent two separate irrigation applications. Because the flood-irrigated site was flooded only once, the two samples from that site were collected 1 day and 5 days after irrigation.

To acquire a sample, a hand pump was used to apply a vacuum to the lysimeter, which induced soil moisture to flow through the porous ceramic cup and accumulate inside the lysimeter. After a period of several hours to 2 days, the lysimeter contained about 0.4 L of sample. The sample was then evacuated from the lysimeter into a dedicated glass flask located in line between the lysimeter and the vacuum-inducing hand pump. From the flask, the homogenized sample was distributed among several bottles and sent to the NWQL for analysis. Field filtration was not necessary because the 0.446-µm pores in the ceramic cup filtered the soil water as it entered the lysimeters. Owing to the small sample volume yielded by the lysimeters, no field parameters were determined for soil-moisture samples.

Most samples were analyzed for major ions, nutrients, and selected trace elements (including arsenic). The shallow lysimeter at the sprinkler-irrigated site yielded only enough sample for one arsenic analysis. The constituents analyzed in samples of soil moisture and their minimum reporting levels are listed in table 4. Results of laboratory analyses of soil-moisture samples are presented in table 7.

GROUND WATER

In 1995, ground-water samples were collected from 18 wells in the Helena Valley (fig. 3). Most wells sampled in 1995 are positioned near the Helena Valley Canal or one of the lateral canals, where irrigation water potentially could infiltrate to ground water without passing through the soil profile. Portions of some canals in the Helena Valley are lined with PVC, compacted earth, asphalt, or concrete. Wells were sampled near reaches of canals with each type of liner, as well as near unlined reaches. Previously unpublished analyses of 1993 ground-water samples collected by USGS and analyzed by the Montana Bureau of Mines and Geology (MBMG) also are included in this report. Samples collected in 1993 were obtained from wells and boreholes located in irrigated fields in the central part of the valley. Most of the wells sampled in both 1995 and 1993 were completed several feet below the water table (table 2).

Test wells at sites G10 and G13 were installed in clusters with soil-moisture samplers in a sprinkler-irrigated field (G10) and a flood-irrigated field (G13).

Construction diagrams for these sites are shown in figure 4. The wells were installed in boreholes that were hand drilled with a 3-in. auger in May 1995. No drilling fluids were used. Table 6 describes the lithology of materials penetrated by the boreholes. The test wells were developed using a surge block, bailer, or pump until the specific conductance of the water stabilized.

Ground-water samples were collected during the irrigation season using either existing submersible pumps in domestic, community, stock, and irrigation wells or a bailer or peristaltic pump in test wells. All wells were purged until at least three well volumes of water were removed prior to sampling. Purging continued until field parameters (specific conductance, pH, water temperature, and dissolved oxygen) stabilized, indicating that standing water in the casing had been removed and replaced with water withdrawn directly from the aquifer. Sample processing, filtration, and preservation were performed in the field as described by Knapton (1985). Where possible, water levels were measured both prior to and during the irrigation season (table 2) using either an electric or a steel measuring tape.

Water collected from most wells was analyzed for major ions, nutrients, and selected trace elements (including arsenic). Four of the wells (G17, G19, G20, and G26) were sampled during 1989-90 as part of another study (Briar and Madison, 1992). During that study, water was analyzed for major ions and selected trace elements (excluding arsenic). Therefore, water collected from these previously sampled wells was analyzed only for arsenic in 1995. The constituents analyzed in samples of ground water and their minimum reporting levels are listed in table 4. Results of field measurements and laboratory analyses of ground-water samples are presented in table 8.

BOTTOM SEDIMENT

Bottom sediment was sampled at three locations in Lake Helena (fig. 3). The sampling sites were located in shallow, near-shore areas along the south, west, and north shores of the lake where deposition from inflows is most likely. Deposition at these sites could be affected by a number of upstream activities, including historical mining, industrial activities, and irrigation. All bottom-sediment sampling locations correspond to surface-water sampling sites (table 1).

Bottom-sediment samples were collected once during the irrigation season (July 6, 1995). All samples were analyzed for a suite of major ions and trace elements.

A U.S. BMH-53 hand-held, stainless-steel coring device was used to collect bottom-sediment samples from the upper 4-6 in. of the lakebed surface, which represents the probable depth to which benthic organisms are routinely exposed. The brass end-plate of the internal piston was coated with epoxy paint to prevent trace-element contamination. Five replicate cores of sediment were collected at each site and composited in a plastic mixing pan. The sediment was mixed thoroughly with a plastic spoon, and about 0.5 L of material was withdrawn and placed into a 1-pint plastic carton. The bulk, unsieved samples were submitted for analysis in a wet condition.

The samples were analyzed by the USGS Branch of Geochemistry Laboratory in Denver, Colo. Samples were air dried at ambient temperature. The bulk samples were disaggregated and sieved through a 230-mesh (0.063 mm) non-metallic screen. The fraction of bulk sediment finer than 0.063-mm diameter was analyzed for selected major ions and trace elements by inductively coupled plasma (ICP) atomic emission spectrometry following digestion with a mixture of strong acids at low temperature. Analyses for arsenic were performed by hydride generation atomic absorption (AA) spectrometry following a high-temperature digestion with a mixture of strong acids. Uranium was measured by “delayed neutron counting,” a nuclear activation method used for analysis of complex geologic sample matrices without chemical processing. Detailed analytical procedures for solid-phase samples are described in Arbogast (1990). Constituents analyzed in samples of bottom sediment and their minimum reporting levels are listed in table 4. Results of laboratory analyses of bottom-sediment samples are presented in table 9.

BIOTA

Biological samples of aquatic invertebrates, fish, and bird livers were collected during 1995 from eight sites in the Helena Valley, including the Helena Valley Regulating Reservoir, Lake Helena, and reaches of Prickly Pear, Tenmile, and Silver Creeks within the Helena Valley Irrigation District (table 3, fig. 3). Biological samples of large fish were collected near the start of the irrigation season (late June 1995); all other biological samples were collected later in the growing season (mid to late August 1995), when water use for irrigation was near maximum.

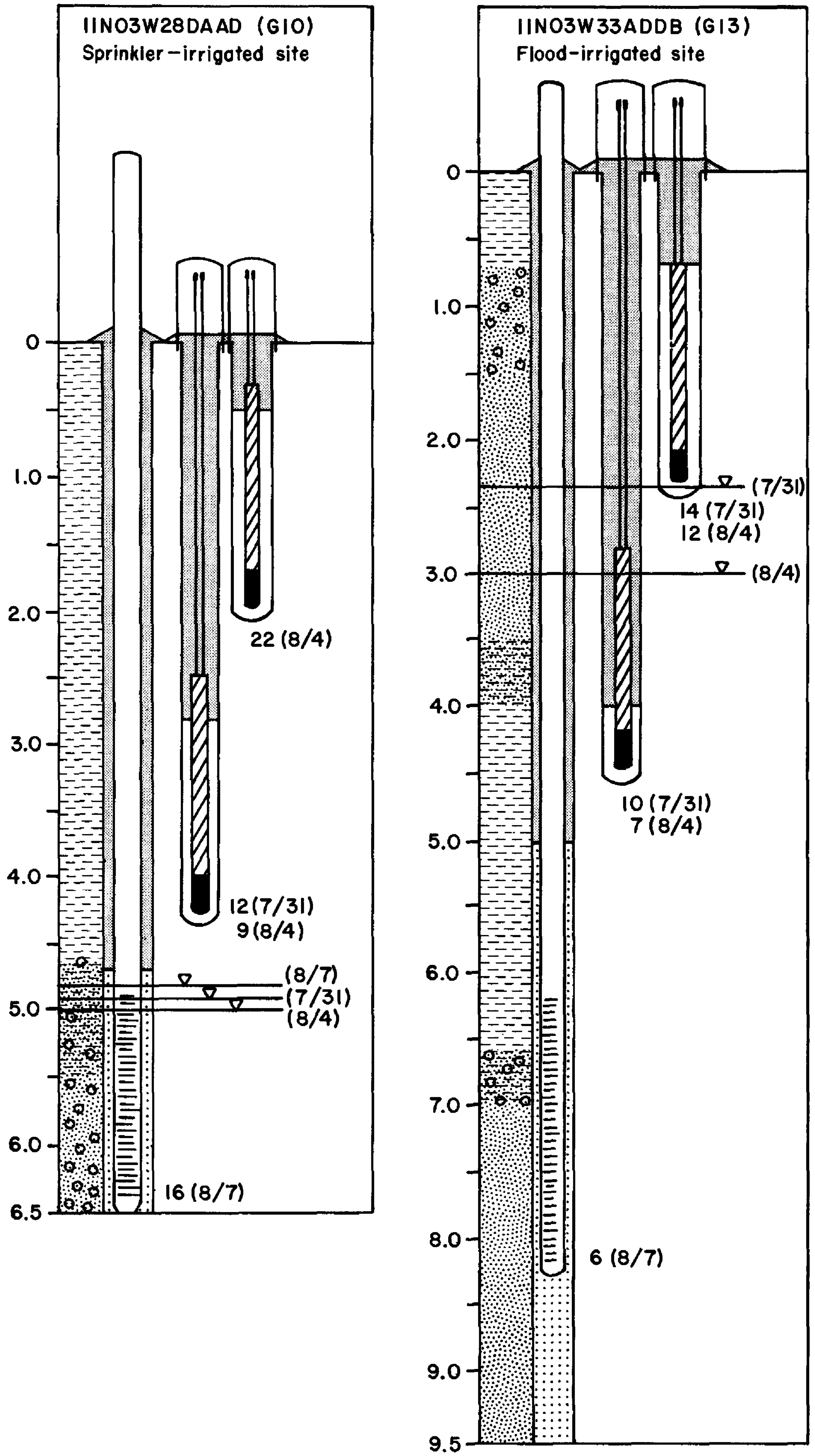


Figure 4. Profiles of clustered suction-lysimeter and monitoring-well sites indicating lithology, construction, water levels, and arsenic concentrations.

EXPLANATION FOR FIGURE 4

EXPLANATION

LITHOLOGY

▤ Clay
▩ Sand
▣ Gravel

CONSTRUCTION

▦ Bentonite
▨ Sand
□ Silica flour
▯ PVC (Polyvinyl chloride) well casing
▤ PVC (Polyvinyl chloride) well screen
▮ Suction lysimeter (porous ceramic cup)

DATA

10 (7/31) Concentration of dissolved arsenic, in micrograms per liter, with 1995 sampling date in parentheses

▽ (8/4) Water level in well with 1995 measurement date in parentheses

Composite samples of aquatic invertebrates were collected from near-shore and wetland habitats of the Helena Valley Regulating Reservoir and Lake Helena. These composite samples represent multiple species, including daphnia (Order Cladocera) and waterboatmen (Order Hemiptera). The samples were collected with light traps using methods described by Espinosa and Clark (1972). The organisms were handled with stainless steel or Teflon-coated forceps, placed in acid-cleansed glass jars, and frozen as soon as practicable. A minimum of 8.0 g of biomass was obtained for each composite sample of invertebrates.

Fish samples consisted of live, small, bottom-feeding fish, including juvenile carp (*Cyprinus carpio*) and longnose suckers (*Catostomus catostomus*) and large, adult carp carcasses. Small fish were collected with sweep nets. Dead adult carp in the early stages of decomposition were collected by hand on June 30, 1995, after a large fish kill (estimated at more than 500 carcasses, primarily in Lake Helena). Fish samples were prepared similarly to the invertebrate samples except that the large carcasses were double-wrapped in aluminum foil and then placed in clear plastic bags prior to freezing. Small, bottom-feeding fish were analyzed as specific whole-body composites (minimum of six bodies and 8.0 g of biomass) and large carp carcasses were analyzed as whole individuals.

Four mallards (*Anas platyrhynchos*) and one northern shoveler (*Anas clypeata*), all flightless, young-of-the-year birds, were collected by shooting with steel shot. The bird livers were excised, placed in acid-cleansed glass jars, and frozen as soon as practicable. All samples were kept frozen until submitted for chemical analysis. Various attempts were made to collect water-bird eggs in the spring from nest sites near the Helena Valley Regulating Reservoir and Lake Helena, but no eggs were found because of poor nesting conditions due to unusually cold and wet weather.

A total of 26 biological samples was processed and submitted for analysis. All samples were analyzed for arsenic and selenium by hydride generation AA spectrometry; for mercury by cold vapor AA spectrometry; and for all other elements by ICP atomic emission spectrometry by the Geochemical and Environmental Research Group, Texas A&M University, College Station, Texas (GERG). Prior to arsenic and metals analyses, the tissue samples were digested with concentrated, high-purity nitric acid at 129°C for 2 to 8 hours. A subset of 14 fish samples also was analyzed by GERG for organochlorine pesticides and polychlorinated biphenyls (PCBs) using a gas chromatograph equipped with a dual capillary column/dual electron-capture detector (Patricia McDonald, National Biological Service Patuxent Analytical Control Facility, written commun., 1996).

QUALITY ASSURANCE AND QUALITY CONTROL

Data-collection and analytical procedures used in this study incorporated practices designed to assure, control, verify, and assess the quality of sample data. Methods and associated quality control for collection and processing of water samples are described by Knapton (1985) and Knapton and Nimick (1991). Standard quality-assurance procedures used by the NWQL are described by Friedman and Erdmann (1982) and Jones (1987). The NWQL provided quality control of analyses performed within their facilities.

All sample bottles, standard solutions, and preservatives for water samples were provided by the NWQL. The bottles, solutions, and preservatives are systematically tested by the NWQL for conformance with criteria described in Bench-Level Protocols on file in the Quality Control Office of the laboratory.

Quality-control samples composed about 10 percent of the total number of water samples submitted for analysis. Quality-control data to document possible sample contamination and reproducibility of analytical results were provided by test samples that consisted of either a field-blank sample of deionized water or a replicate environmental sample incorporated in the sampling train. A field-blank sample is a volume of deionized water that is treated as an environmental sample in all aspects, including exposure to sampling equipment, sample containers, filtration apparatus, and chemical preservatives in the field, and to holding times and laboratory processing. A replicate environmental sample is a volume of sampled material split into subsamples in such a manner that the physical and chemical characteristics of each subsample are considered to be essentially identical in composition. Results of quality-control sample analyses are discussed below, within the context of each medium sampled.

Quality control for soil-moisture analyses consisted of one replicate sample from the deeper lysimeter at G13, the flood-irrigated site (table 7). Field blanks were not collected because the regular samples went directly from the lysimeters into clean, dedicated flasks and then into the sample bottles--a process that greatly reduces the possibility of contamination from sampling equipment. Alkalinity results for the data set may be problematic. Owing to the small sample volumes, alkalinity was determined in the laboratory, rather than in the field. Field measurement of alkalinity is preferable for ground-water and soil-moisture samples because carbon dioxide degassing and other chemical reactions that occur when subsurface water is exposed to the atmosphere can change alkalinity. The replicate analyses produced significantly different results for alkalinity, with values of 241 and 356 mg/L as $CaCO_3$. Laboratory reruns performed at a much later date resulted in values of 211 and 201 mg/L. Although these values more closely duplicate each other, they represent the sample after it achieved equilibrium with ambient atmospheric conditions, and probably do not represent conditions in the unsaturated zone when the sample was collected.

Quality control for ground-water analyses consisted of two replicate samples (G16, G23) and one field-blank sample (table 8). Results of each replicate analysis listed in table 8 follows the original analysis with which it is associated. A field blank with constituent concentrations equal to or less than the minimum reporting level for the analytical method indicates that the entire sample collection, processing, and analytical process is free of significant contamination. For the field blank collected in association with ground-water sampling (table 8), the calcium concentration of 0.2 mg/L is twice the minimum reporting level (typical measurement precision at the detection level); concentrations of all other constituents were less than or equal to minimum reporting levels (table 4). With only one sampling period, it is difficult to assess the significance of a possible bias associated with calcium concentrations reported for ground water; however, the lowest calcium concentration reported for all the routine samples was 28 mg/L, or 140 times the concentration reported for the field blank. Therefore, the influence of possible calcium contamination at a level of 0.2 mg/L is considered to be negligible.

Quality control for surface-water analyses relied primarily on internal laboratory quality-control procedures, which were supplemented by a replicate arsenic analysis (table 5). Similarly, quality control for the three bottom-sediment analyses (table 9) consisted of internal laboratory procedures.

Trace-element and organochlorine analyses of biological samples were performed by National Biological Service (NBS)[1] contract laboratories. The analyses received quality-assurance and quality-control review by the NBS Patuxent Analytical Control Facility (PACF) in Laurel, Maryland (John F. Moore, Patuxent Analytical Control Facility, written commun., 1997). Quality-assurance protocols are documented by the U.S. Fish and Wildlife Service (1992).

SOURCES AND PROCESSES CONTROLLING ARSENIC CONCENTRATIONS IN WATER

Arsenic concentrations in water are a function of the availability and type of source material and the hydrogeochemical conditions and processes that can influence arsenic mobility. The existence of multiple potential arsenic sources and few data to describe arsenic geochemistry limit a determination of the processes controlling arsenic concentrations in water in the Helena Valley. However, much is known about the geochemistry of arsenic in natural aquatic systems (Ferguson and Gavis, 1972; Mok and Wai, 1994), and potential arsenic sources in the valley have been identified.

Potential arsenic sources in the Helena Valley include irrigation water from the Missouri River, aerially deposited particulate emissions from smelter operations, naturally occurring arsenic minerals, arsenic sorbed or co-precipitated to iron oxyhydroxide coatings, and waterborne contaminants from historical mining and industrial activities. Irrigation water imported from the Missouri River contains arsenic in the dissolved form and is applied to valley farmland every year.

Aerially-deposited, arsenic-rich particulates in smelter emissions potentially can be dissolved from soils by rainfall, snowmelt, or irrigation water. Within the study area, smelter fallout has enriched surficial soils with arsenic and heavy metals; arsenic concentrations in surficial soil are highest in East Helena, but are at least slightly enriched relative to background concentrations throughout the valley (U.S. Environmental Protection Agency, 1987). However, in the areas of highest concentration in surficial soils, arsenic is not found in soils at depths greater than 32 in., and there is no evidence that arsenic from smelter fallout percolates to ground water anywhere in the valley (D. Scott Brown, U.S. Environmental Protection Agency, oral commun., 1997).

Arsenic minerals that exist naturally in geologic materials potentially could dissolve in the unsaturated or saturated zone. The arsenic minerals arsenopyrite and cuprodescloizite are present in bedrock to the south and west of the Helena Valley (Pardee and Schrader, 1933). The Tertiary aquifer underlying the Spokane Bench might be enriched with arsenic because it contains volcanic sediments which, according to Welch and others (1988), commonly are enriched in arsenic in the western United States. In contrast, significant amounts of arsenic-rich minerals are not expected to occur in the Quaternary alluvium of the western Helena Valley because the majority of the land draining to the valley is not underlain with arsenic-rich geologic materials.

Arsenic commonly is sorbed to iron oxyhydroxide coatings, which are ubiquitous in oxidized materials. The sorbed arsenic may be naturally occurring or derived from human activities.

Historical mining and related industrial practices have contributed arsenic to the local area. Drainage and erosion of tailings from historic mining areas in the headwaters of several valley streams, particularly Prickly Pear and Tenmile Creeks, may contribute dissolved and particulate arsenic to the valley. Past leakage of process water from the lead and zinc smelter in East Helena has resulted in a dissolved-arsenic plume in shallow ground water extending northward from East Helena. However, the leading edge of the plume is south of the Helena Valley Irrigation District (ASARCO, Inc., 1995, exhibit 9). Therefore, the pro-

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[1] Originally known as Research Operations (Region 8) of the USFWS, the National Biological Survey became a separate bureau within the Department of the Interior in 1993. Subsequently, the name was changed to the National Biological Service. In 1996, the NBS (with the exception of PACF) became the Biological Resources Division of the USGS and the PACF returned to the USFWS.

cess water leak is not a likely source of arsenic to ground water in the study area.

Arsenic mobility generally is controlled by sorption/desorption and dissolution/precipitation reactions. These reactions are influenced strongly by changes in pH and redox conditions. Physical processes such as dilution and evapoconcentration also can be important.

Sorption/desorption reactions typically are considered the primary geochemical processes influencing arsenic concentrations in natural waters (Farmer and Lovell, 1986; Moore and others, 1988; Gulens and others, 1979; Cherry and others, 1979). In oxic environments, arsenic typically occurs as arsenate. In most natural waters with slightly alkaline pH values, arsenate has a strong affinity for sorption sites and may be removed from solution by sorption as arsenic-rich water flows through material with suitable sorption sites, particularly those associated with iron oxyhydroxides (Gulens and others, 1979; Goldberg, 1986; Xu and others, 1988, 1991; Belzile and Tessier, 1990; Fuller and others, 1993). In a study of soils irrigated with Madison or upper Missouri River water, Keith (1995) concluded that arsenic sorbed to irrigated soils, significantly reducing dissolved-arsenic concentrations in deep-percolating irrigation water. Although Mangelson and Brummer (1994) reached a similar conclusion for several upper Missouri River basin areas, including the Helena Valley, high concentrations of water-extractable arsenic in saturated soil pastes demonstrated that not all arsenic sorbs tightly to soil. When the redox potential changes significantly, large changes in dissolved-arsenic concentration can occur. When redox conditions change from oxic to reduced, the ferric iron and sorbed arsenate in iron oxyhydroxides are reduced to ferrous iron and desorbed arsenite, both of which are relatively stable as aqueous species (Brannon and Patrick, 1987; Peterson and Carpenter, 1986; Aggett and Kriegman, 1988). Nimick (1994) attributed elevated arsenic concentrations in reduced ground water of part of the lower Madison Valley to release of sorbed arsenic. Jones and others (1996) observed that flood irrigation or a seasonally high water table can create temporary reducing conditions sufficient to mobilize sorbed arsenic, resulting in elevated arsenic concentrations in shallow ground water. Conversely, when redox conditions change from reduced to oxic, ferrous iron and arsenite become oxidized, iron oxyhydroxides precipitate, and arsenate sorbs to the oxyhydroxides.

Dissolution of solid-phase materials, such as smelter fallout, naturally occurring arsenic minerals, and volcanic sediments, potentially could mobilize arsenic in both the saturated and unsaturated zones. Precipitation of arsenic solid phases such as calcium arsenate can occur, but is unlikely at the relatively low dissolved-arsenic concentrations in the Helena Valley.

Dilution can reduce arsenic concentrations in arsenic-rich water in areas where it mixes with other water. If background arsenic concentrations in ground water are lower than in soil moisture, then arsenic in infiltrating soil moisture can become diluted upon reaching the water table. This process could be significant in the western part of the Helena Valley because the alluvial aquifer is transmissive and large volumes of ground water from upgradient parts of the alluvial aquifer and the surrounding mountains converge toward the center of the valley (Briar and Madison, 1992). However, arsenic concentrations in the upgradient alluvial and bedrock aquifers have not been determined.

Evapotranspiration can concentrate arsenic and other constituents in irrigation water as it moves through the root zone to the water table. Sonderegger and others (1989) concluded that evapoconcentration significantly increases arsenic concentrations beneath irrigated fields along the lower Madison River, although alternative processes were proposed by Nimick (1994).

WATER QUALITY

Results of the 1995 sampling of water quality are presented in tables 5, 7, and 8 and discussed below. Included with the 1995 results are previously unpublished analyses of 1993 ground-water samples collected by USGS and analyzed by MBMG. Also included are complete analyses of selected 1989 and 1990 ground-water samples from wells for which only arsenic was analyzed in 1995.

IRRIGATION WATER

Imported irrigation water from the Missouri River was sampled from the Helena Valley Canal at the outlet of the Helena Valley Regulating Reservoir (site S1) in July 1995. Physical properties and inorganic-constituent concentrations in the irrigation water are reported in table 5. The water is a calcium-sodium-magnesium bicarbonate type with a relatively small amount of dissolved solids. Irrigation water did not exceed Montana aquatic-life criteria (table 10) for any nutrient or trace element, including arsenic. However, the concentration of dissolved arsenic at this site was 31 µg/L, the highest of any site sampled, and exceeded the Montana human-health standard of 18 µg/L. Mangelson and Brummer (1994) also reported arsenic concentrations exceeding the human-health standard, ranging from 20.9 to 26.7 mg/L in irrigation water sampled from Helena Valley canals.

SOIL MOISTURE AND GROUND WATER

To help clarify the fate of arsenic in applied irrigation water, soil moisture and underlying shallow ground water were sampled at two sites--one sprinkler-irrigated (G10) and one flood-irrigated (G13). Analyses of soil moisture and shallow ground water sampled from the two clustered instrument sites are reported in table 7. At the sprinkler-irrigated site, soil moisture was a sodium sulfate to sodium-calcium sulfate type, whereas the underlying shallow ground water was a calcium bicarbonate type. At the flood-irrigated site, both soil moisture and shallow ground water were calcium bicarbonate types, although soil moisture had larger proportions of sodium and magnesium than shallow ground water.

Due to an unusually wet summer, irrigation was limited and samples were collected under relatively high water-table conditions. As a result, lysimeters sometimes collected ground water or water from the capillary fringe, rather than soil moisture. The type of water sampled was distinguished on the basis of water levels measured in the adjacent shallow test wells (table 7). Capillary-fringe water was so designated when the water table was below the lysimeter but the lysimeter filled rapidly, as it would in the saturated zone. Soil moisture (as opposed to ground water or capillary-fringe water) was collected from two different depths only during the August 4 sampling from the sprinkler-irrigated site.

Comparisons of concentrations of arsenic and chloride between soil moisture and irrigation-supply water may illustrate the relative importance of processes controlling arsenic concentrations as irrigation water percolates through soil. The table below reiterates arsenic and chloride data from tables 5 and 7.

At both sites, concentrations of chloride, a conservative species unlikely to sorb to soil, were about 2 to 5 times higher in soil moisture than in supply water. The increase in chloride concentrations indicates that irrigation water probably evaporates in the soil zone. Therefore, evapoconcentration appears to be significant in controlling concentrations of conservative constituents in soil moisture. In contrast, arsenic concentrations consistently were lower in soil moisture than in supply water. The ratio of arsenic to chloride was about 8 to 18 times lower in soil moisture (or the capillary fringe) than in supply water. Evapoconcentration does not, therefore, appear to be the only process affecting arsenic concentrations.

The decrease in arsenic concentrations in soil moisture relative to irrigation water, combined with the lower ratio of arsenic to chloride, suggests that the nonconservative species, arsenic, was removed from solu-

Site number (fig. 3)	Date	Depth of sampled interval (feet below land surface)	Depth to ground water (feet below land surface)	Sample type	Sample type		Ratio of arsenic to chloride concentrations (x 1,000)
					Arsenic (microgram per liter, as As)	Chloride (milligram per liter, as Cl)	
				Supply water			
S1	07-05-95	--	--	Canal water	31	13	2.4
				Sprinkler-irrigated site			
G10	08-04-95	1.8-2.0	5.00	Soil moisture	22	--	--
	07-31-95	4.1-4.3	4.94	Soil moisture	12	52	.23
	08-04-95		5.00	Soil moisture	9	68	.13
	08-07-95	5.0-6.5	4.85	Ground water	16	25	.64
				Flood-irrigated site			
G13	07-31-95	2.3-2.5	2.37	Ground water	14	33	.42
	08-04-95		3.00	Capillary fringe	12	38	.32
	07-31-95	4.4-4.6	2.37	Ground water	10	25	.40
	08-04-95		3.00	Ground water	7	28	.25
	08-04-95		3.00	Ground water (field replicate)	7	27	.26
	08-07-95	6.2-8.3	--	Ground water	6	17	.35

tion. One explanation might be precipitation of solid-phase arsenic. However, arsenic concentrations appear to be too low for precipitation to occur. Speciation calculations using the computer program PHREEQC (Parkhurst, 1995) with the thermodynamic database for the aqueous species and mineral phases from the program WATEQ4F (Ball and Nordstrom, 1991) confirm that soil moisture at the sites sampled is substantially undersaturated with respect to arsenate minerals. Irrigation water from site S1 was similarly undersaturated with respect to arsenate minerals. Therefore, the decrease in arsenic concentrations in soil moisture relative to irrigation water presumably is not caused by precipitation of arsenate minerals.

A more likely explanation is that arsenic sorbs to soil particles as irrigation water infiltrates through the soil profile. Negligible concentrations of dissolved iron and manganese (less than 9 µg/L) and pH values of 7.7-8.1 in soil moisture and capillary-fringe water indicate oxidizing, slightly alkaline conditions conducive to arsenate sorption in the soil zone.

If sorption were the only process controlling arsenic concentrations in the soil zone, then chloride concentrations would be expected to remain unchanged between irrigation water and soil moisture. Alternately, if evapoconcentration were the only controlling process, then arsenic-to-chloride ratios would be constant. But neither of these situations was observed. In all likelihood, both evapoconcentration and sorption control arsenic concentrations. Evapoconcentration presumably can increase concentrations of both arsenic and chloride in soil moisture, but because sorption to soil may be a predominant mechanism controlling arsenic movement, the overall effect of the two processes was a net decrease in arsenic concentrations as supply water percolated through the soil. Because this mechanism is postulated from very sparse data, it is proposed only as a conceptual model of a potential pathway for arsenic transport.

Comparing soil moisture to underlying ground water gives some insight to the processes controlling arsenic concentrations as soil moisture infiltrates to the saturated zone. At both sites, the concentration of chloride was lower in ground water than in soil moisture. At the flood-irrigated site, arsenic concentrations also were lower in ground water, and the ratio of arsenic to chloride was relatively constant. The concurrent decrease in chloride and arsenic at the flood-irrigated site indicates that ground water diluted the infiltrated soil moisture and that dilution probably was the predominant process controlling arsenic concentrations between the soil zone and the aquifer at this site.

In contrast, at the sprinkler-irrigated site, the concentration of arsenic was lower in soil moisture than in ground water. The arsenic concentration in soil moisture was 9 µg/L on August 4, whereas the concentration in ground water was 16 µg/L on August 7. The ratio of arsenic to chloride increased with depth. No mechanism is proposed for concentrating arsenic or introducing arsenic sources in shallow ground water of the alluvial aquifer. Oxidizing conditions indicated by a dissolved-oxygen concentration of 2.0 mg/L in ground water (table 8) probably prevented desorption. It seems likely that the ground-water sample collected on August 7 represents a "plug" of irrigation water that had infiltrated after being applied on August 4, and the lysimeter probably was sampled too soon after irrigation for the freshly percolated water to reach chemical equilibrium. It is unclear whether ground water diluted arsenic at the sprinkler-irrigated site.

The results of chemical analyses of other ground-water samples are reported in table 8. Most of the 27 wells sampled have calcium bicarbonate or calcium-magnesium bicarbonate type water, although water in some wells also contains a significant proportion of sodium. Arsenic concentration ranged from less than 1 to 22 µg/L, with a median value of 2 µg/L. Montana water-quality standards for human consumption of nutrients and trace elements (table 10) were not exceeded except in one sample, which exceeded the arsenic standard of 18 µg/L. MCL's established by the U.S. Environmental Protection Agency (1996) were not exceeded in any of the ground-water samples.

Compared to irrigation water (table 5, site S1), ground water in the study area generally had lower pH and higher calcium, sulfate, and dissolved-solids concentrations. Concentrations of dissolved oxygen, fluoride, and arsenic generally were lower in ground water than in irrigation water; concentrations of other constituents were similar.

Nutrient concentrations in ground water generally were low, with concentrations of nitrite plus nitrate ranging from <0.05 to 1.8 mg/L with a median value of 0.26 mg/L (table 8). Nationally, nitrate concentrations greater than 2 mg/L in ground water may indicate effects of human activity (Mueller and Helsel, 1996). In the Helena Valley, Drake (1995) estimated "background" to be about 0.1 to 0.5 mg/L. Both the MCL (U.S. Environmental Protection Agency, 1996) and the Montana Human Health Standard (Montana Department of Environmental Quality, 1995) are 10 mg/L nitrite plus nitrate as nitrogen ($NO_2 + NO_3$ as N). Drake (1995) measured nitrate concentrations in 77 water samples from Helena Valley wells and confirmed earlier findings (Wilke and Coffin, 1973; Briar and Madison, 1992) that nitrate concentrations are highest in certain parts of the valley. Some of the largest increases in concentration between 1990 and 1994 coincided with areas of highest septic-tank densities (Drake, 1995). Data reported in table 8 generally concur with nitrate distributions reported by Drake (1995).

Dissolved-solids concentrations reported in table 8 range from 161 to 1,240 mg/L, which is within the range reported for more than 200 wells sampled from 1971 to 1990 (Briar and Madison, 1992). The median dissolved-solids concentration in table 8 is 272 mg/L; the median of the 1971-90 data is 286 mg/L. The U.S. Environmental Protection Agency (1996) has established a secondary maximum contaminant level (SMCL) of 500 mg/L dissolved solids for treated drinking water. One sample from one well (G8), which is finished beneath an irrigated field, had a dissolved-solids concentration (1,240 mg/L) that exceeded the SMCL. However, samples from other wells in irrigated areas had much lower concentrations. Well G8 is located near Lake Helena, which is the end of the ground-water flow path. Dissolved-solids concentrations might be expected to be higher there than in upgradient areas owing to dissolution of aquifer material along the flow path and evapoconcentration of dissolved minerals in the ground-water discharge area.

With the exception of zinc and arsenic, trace-element concentrations were near or below minimum reporting levels in ground water. Zinc concentrations in ground water (table 8) ranged from <2 to 55 µg/L, which is well below the SMCL of 5,000 µg/L (U.S. Environmental Protection Agency, 1996).

Ground-water samples can be categorized into three groups defined by well completion: (1) samples from the upper 3 ft of water in the alluvial aquifer, (2) samples from the alluvial aquifer deeper than 3 ft below the water table, and (3) samples from other (non-alluvial) aquifers.

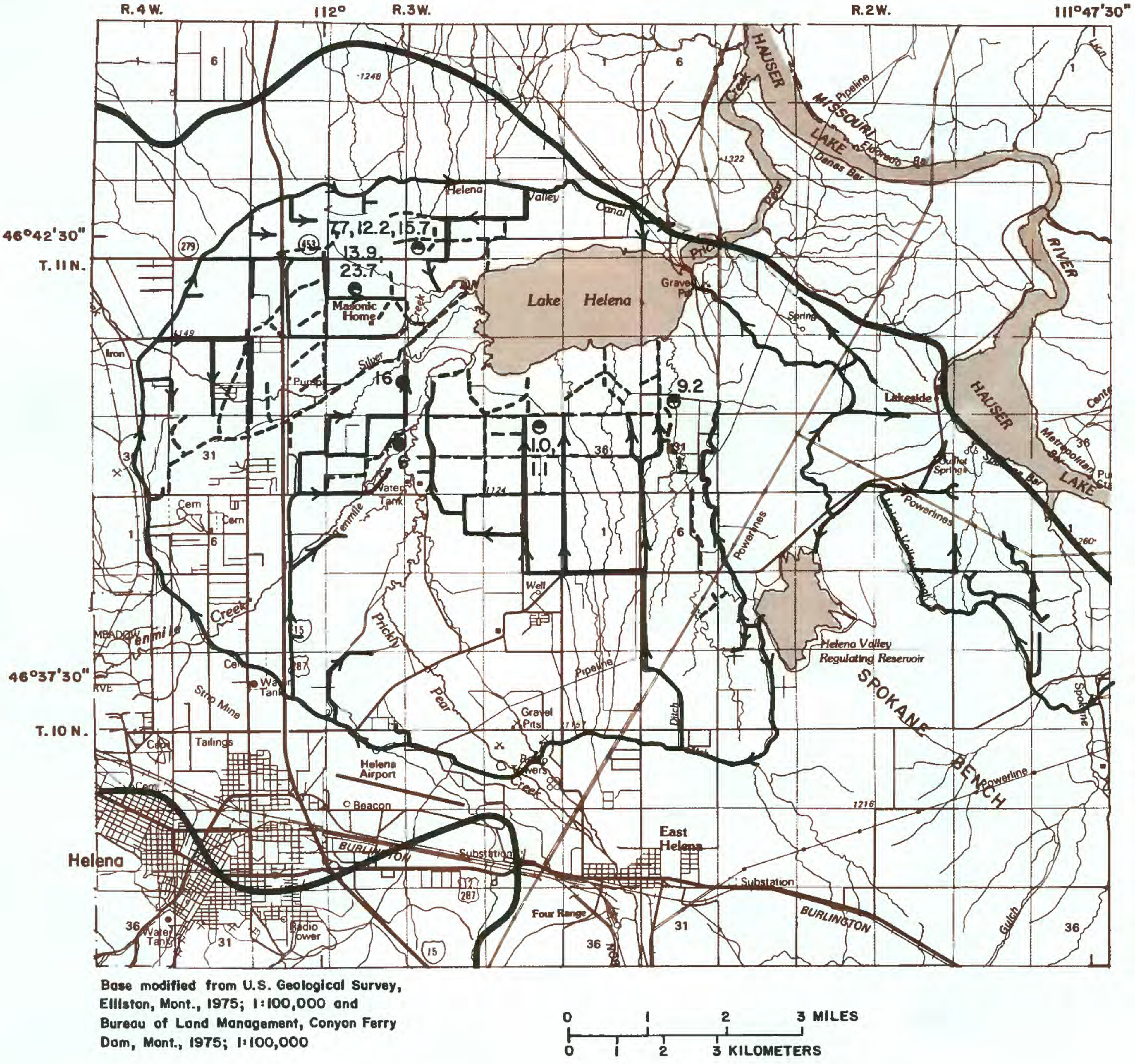
Arsenic concentrations for the first group are shown on figure 5. The group includes samples collected in 1995 from wells G10 and G13 and from four auger holes that Mangelson and Brummer (1994) bored in 1993 to the water table at depths of 1.5 to 8.5 ft below the surface of irrigated fields. Owing to the very shallow depths, ground water sampled from these sites does not represent a typical drinking-water source. This ground water most likely was derived largely from irrigation water that had recently percolated through soil. Arsenic concentrations in these water-table samples ranged from 1.0 to 23.7 µg/L, with a median value of 10.7 µg/L.

The second group includes samples collected in 1993 from 9 wells located in or adjacent to irrigated fields, and samples collected in 1995 from 11 wells located near canals and laterals. All wells in this group were completed more than 3 feet below the water table in the alluvial aquifer. Half of these wells are used to obtain drinking water, and the other half are observation, stock, or irrigation wells. Ground water sampled from the wells in this group probably was a mixture of ground water from upgradient areas and irrigation water that had recharged the alluvial aquifer locally. Arsenic concentrations in this group ranged from <1 to 5 µg/L (fig. 6), with a median value of 1.2 µg/L.

The third group includes samples collected in 1995 from five domestic and community wells in non-alluvial aquifers located near canals and laterals and completed at depths of 72-180 ft below land surface. These samples had arsenic concentrations ranging from 2 to 22 µg/L with a median value of 6 µg/L (fig. 6). Specifically, samples from wells G4 and G5, which were completed in Precambrian shale, had arsenic concentrations of 3 and 2 µg/L; a sample from well G3, which was completed in Cretaceous granite, had an arsenic concentration of 6 µg/L; and samples from wells G24 and G25, which were completed in Tertiary sediments, had arsenic concentrations of 22 and 17 µg/L, respectively.

The arsenic concentrations observed in ground water near the water table (group 1) demonstrate that not all arsenic sorbs to soil as water percolates though the unsaturated zone. Evapoconcentration, sorption, and some degree of dilution probably control arsenic concentrations at these sites, as described in the previous section.

Arsenic concentrations in deeper alluvial ground water (group 2) generally were low, despite the presence of numerous potential sources, including irrigation water. Due to the reconnaissance nature of this investigation, background levels of arsenic in water from Quaternary alluvium outside the Helena Valley Irrigation District were not determined. However, data from other studies indicate that arsenic concentrations in ground water within the Irrigation District are similar to, or less than, those in some local areas of the Helena Valley that are upgradient from the Irrigation District, but may be affected by mining-related activities or hydrothermal sources. Arsenic associated with historical mining in the mountains south of Helena might be present in recent alluvial deposits of Tenmile Creek; elevated arsenic concentrations have been detected in mine wastes and adit discharges from several abandoned mines in the Tenmile Creek watershed (Montana Department of State Lands, 1995). Locally, arsenic concentrations ranging from 7 to 26 µg/L have been measured in samples from wells completed in



Base modified from U.S. Geological Survey, Elliston, Mont., 1975; 1:100,000 and Bureau of Land Management, Canyon Ferry Dam, Mont., 1975; 1:100,000

Figure 5. Arsenic concentrations in ground-water samples from the upper 3 feet of water in the alluvial aquifer, Helena Valley, Montana. Data from table 8 and from Mangelson and Brummer (1994).

EXPLANATION FOR FIGURE 5

EXPLANATION

⟵	IRRIGATION CANAL OR SUPPLY LATERAL--Arrow indicates flow direction
- - - - - -	IRRIGATION DRAIN
▬	APPROXIMATE MARGIN OF HELENA VALLEY
9.2	ARSENIC CONCENTRATION, IN MICROGRAMS PER LITER

⊖	Auger hole sampled by Bureau of Reclamation (Mangelson and Brummer, 1994)
●	Monitoring well sampled by U.S. Geological Survey (this study)

The depth to water at all sites shown was less than 9 feet

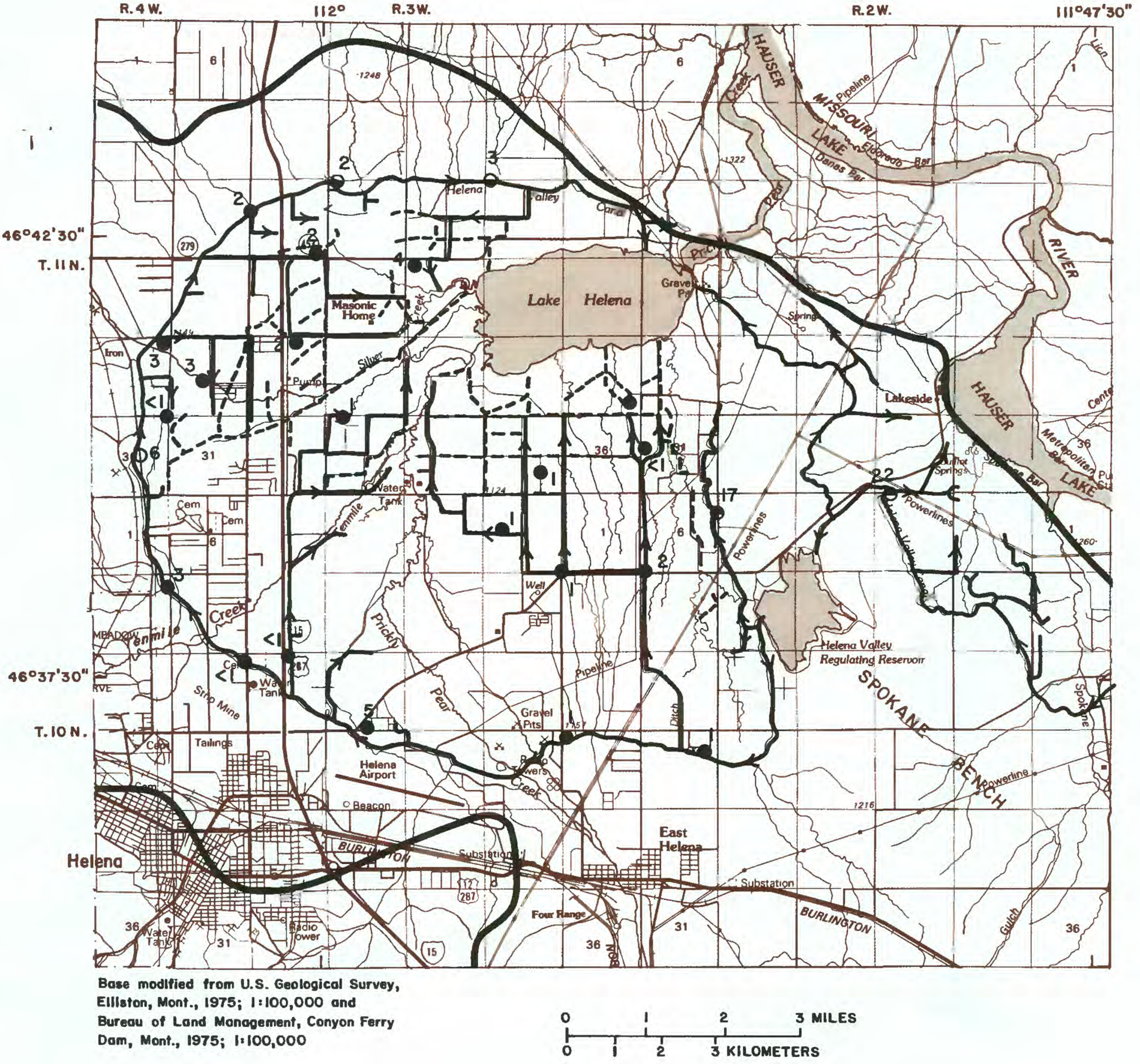
Quaternary alluvium north of Helena, in T. 10 N, R. 4 W, secs. 14 and 15 (Daniel R. Shaffer, PRC Environmental Management, Inc., written commun., 1995). High concentrations of arsenic are associated with tailings deposited in Helena about 1 mi south of these wells (Montana Department of State Lands, 1995, p. 5-143). Hydrothermal water discharging from a spring near Tenmile Creek, about 4.5 miles upstream from the Helena Valley Canal (10N04W28ACDB), had arsenic concentrations of 20-22 µg/L in 1976; water in a nearby 275-ft well had an arsenic concentration of 15 µg/L (Leonard and others, 1978). This hydrothermal water recharges the alluvial aquifer in the southwestern part of the Helena Valley.

The low arsenic concentrations in group 2 wells suggest that any arsenic added to the ground water may have been removed from solution by precipitation or sorption, or affected by dilution. Thermodynamic calculations using PHREEQC (Parkhurst, 1995) indicate that arsenate minerals would not be expected to precipitate. Dissolved-oxygen concentrations ranging from about 1 to 9 mg/L, and pH values generally above 7, indicate oxidizing, slightly alkaline conditions conducive to arsenate sorption in the aquifer. Therefore, sorption onto aquifer material might be an important process in the removal of arsenic from ground water.

Physical processes also might affect arsenic concentrations at depth in the alluvial aquifer. A large quantity of ground water flows generally northward and westward through the alluvial aquifer toward Lake Helena from recharge areas along the valley margins (Briar and Madison, 1992). Either this regional ground water, which presumably contains little or no arsenic, dilutes locally recharged water, or the strong horizontal flow gradient prevents infiltrated irrigation water from percolating deeper than the near-surface part of the aquifer. The net result of either process is that elevated arsenic concentrations were not found in the alluvial aquifer at depths greater than about 10 ft below land surface.

In contrast, arsenic concentrations in some of the non-alluvial drinking-water wells (group 3) were higher than in nearby alluvium. A sample from well G3, which is completed in granitic bedrock on the western edge of the valley, contained 6 µg/L arsenic. Cuprodescloizite, a vanadate containing arsenic, is present in the granitic bedrock in which this well is completed (Pardee and Schrader, 1933, p. 38, 58) and is a potential source of arsenic. The bedrock has low permeability and may transmit too little regional ground water to dilute or displace arsenic that either entered the aquifer as percolated irrigation water or as was dissolved from arsenic-containing minerals.

Samples from the two wells completed in Tertiary sediments beneath the Spokane Bench had arsenic concentrations of more than 16 µg/L. Sonderegger and others (1989) estimated background levels of arsenic in the Tertiary aquifer along the lower Madison River to be less than 15 µg/L. The Tertiary sediments that comprise the aquifer along the lower Madison River are derived in part from intermediate to acidic volcanic rocks (Sonderegger and others, 1989), which may be enriched in arsenic (Welch and others, 1988). Tertiary sediments in the Helena Valley also contain volcanic sediments derived from acidic volcanic rocks (Stickney, 1987). Water-level rises of 14-16 ft between April/May and August 1995 in wells G24 and G25 (table 2) indicate that the canal system probably supplies a large component of local recharge to the Tertiary aquifer. Dissolved-oxygen concentrations of more



Base modified from U.S. Geological Survey, Elliston, Mont., 1975; 1:100,000 and Bureau of Land Management, Canyon Ferry Dam, Mont., 1975; 1:100,000

Figure 6. Arsenic concentrations in ground-water samples from wells completed more than 3 feet below the water table, Helena Valley, Montana. Data from table 8.

EXPLANATION FOR FIGURE 6

EXPLANATION

—←—	IRRIGATION CANAL OR SUPPLY LATERAL--Arrow indicates flow direction
- - - - - -	IRRIGATION DRAIN
▬	APPROXIMATE MARGIN OF HELENA VALLEY
22	ARSENIC CONCENTRATION, IN 1993-95, IN MICROGRAMS PER LITER
●	Well completed in Quaternary alluvium
◓	Well completed in Tertiary sediments
○	Well completed in Cretaceous granite
◒	Well completed in Precambrian shale

than 7 mg/L in these wells support the hypothesis that water from a near-surface source has recently recharged the Tertiary aquifer. Therefore, the Tertiary sediments and applied irrigation water both are possible sources of arsenic to the ground water. Like the granitic bedrock along the western edge of the valley, the Tertiary aquifer has low permeability and probably does not transmit sufficient quantities of regional ground water to significantly dilute or displace infiltrated irrigation water.

IRRIGATION DRAINS AND NATURAL STREAMS

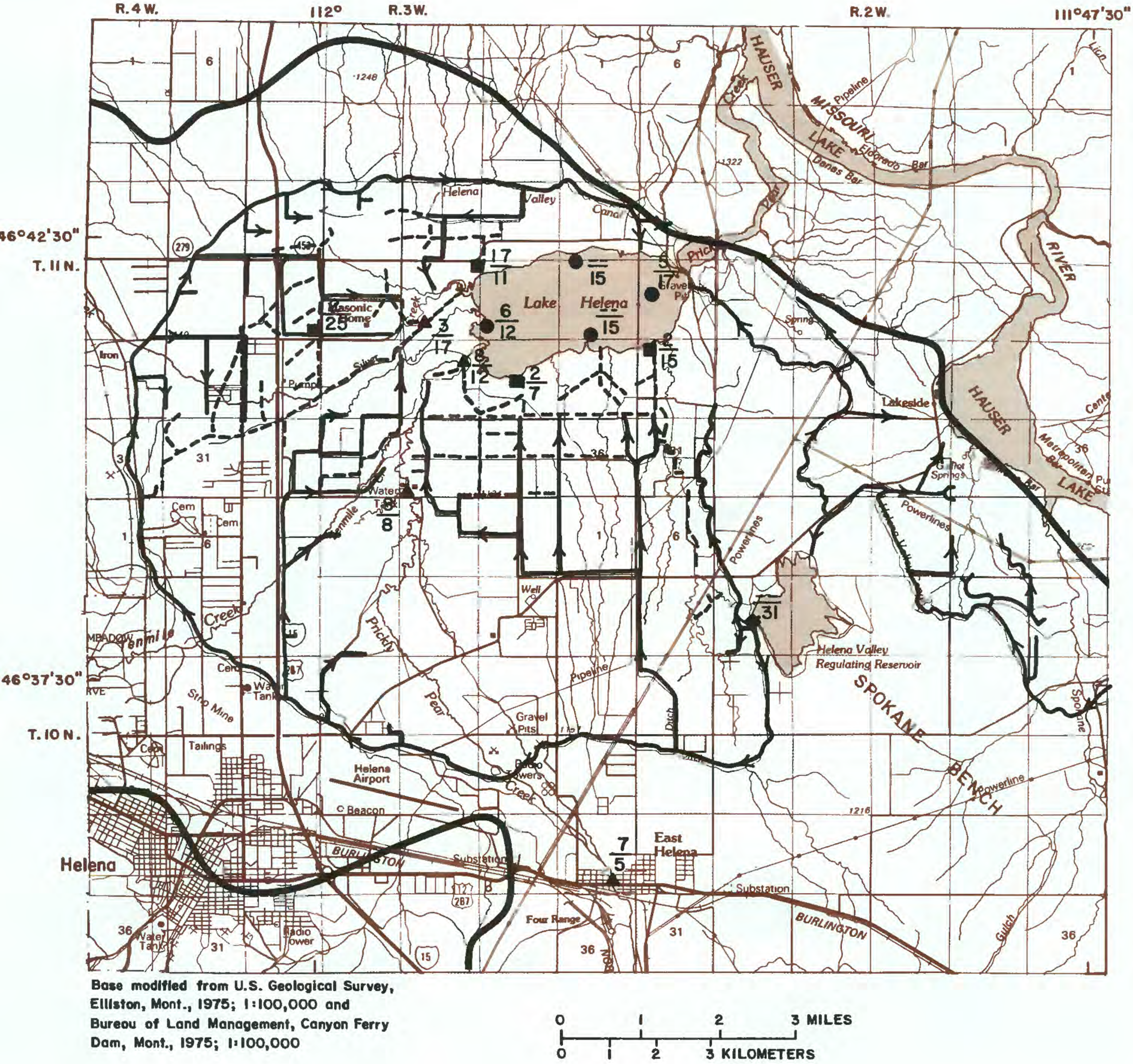
Physical properties and inorganic-constituent concentrations in samples collected from irrigation drains and streams in March and July 1995 are presented in table 5. Arsenic concentrations in surface-water samples are shown in figure 7.

Water sampled from all irrigation-drain and stream sites was a calcium bicarbonate type with varying proportions of magnesium and sodium and relatively low concentrations of dissolved solids. The Montana chronic aquatic-life criterion of 0.02 mg/L for ammonia (table 10) was equalled or exceeded in all five samples analyzed for ammonia. Montana aquatic-life criteria for other nutrients and trace elements were not exceeded, except in one sample which had a mercury concentration of 0.2 μg/L. Arsenic concentrations at all sites were lower than that of the irrigation supply water from the Missouri River (site S1) and well below the Federal (U.S. Environmental Protection Agency, 1986) and State (Montana Department of Environmental Quality, 1995) aquatic-life chronic criterion of 190 μg/L.

Irrigation drains receive inflow from shallow ground water and surface runoff derived primarily from irrigation water applied to fields, as well as from deeper ground water derived from upgradient regional recharge. Water samples collected prior to irrigation, in March 1995, from drains south and west of Lake Helena (sites S2, S3, and S7) all had arsenic concentrations of 2 μg/L.

In contrast, during the irrigation season, in July 1995, arsenic concentrations at these sites increased to 7-25 μg/L. The largest increase (from 2 to 25 μg/L) occurred at site S7 in a drain that receives some spills directly from lateral canals (James A. Foster, Helena Valley Irrigation District, oral commun., 1996). Water samples from two other drains near site S7 also exhibited large seasonal increases in arsenic in 1993 (Mangelson and Brummer, 1994). For example, samples collected in 1993 from a site 0.75 mi downstream from site S7 had arsenic concentrations of 1.1 μg/L before irrigation, and as much as 21.8 μg/L during irrigation (Mangelson and Brummer, 1994). However, not all irrigation-season increases in arsenic concentrations were due to direct spills from canals, as evidenced by increased concentrations in the other sampled drains, which received only irrigation drainage and ground-water discharge.

Water in a drain north of Lake Helena (site S9) had a higher arsenic concentration (17 μg/L) before irrigation season than water in drains to the south and west of Lake Helena. Arsenic concentrations in this



Base modified from U.S. Geological Survey, Elliston, Mont., 1975; 1:100,000 and Bureau of Land Management, Canyon Ferry Dam, Mont., 1975; 1:100,000

Figure 7. Arsenic concentrations in surface water, Helena Valley, Montana. Data from table 5.

EXPLANATION FOR FIGURE 7

EXPLANATION

—←— IRRIGATION CANAL OR SUPPLY LATERAL--Arrow indicates flow direction

------ IRRIGATION DRAIN

━━━ APPROXIMATE MARGIN OF HELENA VALLEY

$\frac{8}{12}$ ARSENIC CONCENTRATION, IN MICROGRAMS PER LITER--Upper number represents pre-irrigation-season (March 1995) sample, lower number represents irrigation-season (July 1995) sample; -- indicates no data

SAMPLING SITE

● Lake

▲ Stream

◆ Irrigation canal

■ Irrigation drain

drain north of Lake Helena apparently do not respond immediately to irrigation runoff, as do concentrations in drains sampled elsewhere in the valley. At site S9, the arsenic concentration decreased to 11 µg/L in July 1995. Mangelson and Brummer (1994) sampled this site five times in 1993, with results ranging from a maximum of 19.2 µg/L in July 1993 to a minimum of 5.2 µg/L one month later in August 1993. The pre-irrigation-season sample they collected in April 1993 had an arsenic concentration of 16.2 µg/L. The relatively high arsenic concentrations at this site might be related to the limited amount of deep ground water available to dilute the drain water. Whereas the other sites receive drainage from areas underlain by transmissive alluvium, site S9 receives drainage from areas primarily underlain by shale bedrock, which transmits relatively small quantities of ground water. Low aquifer transmissivity may also be the reason for the slow response time to irrigation inputs in this drain north of Lake Helena.

The spatial distribution of arsenic relative to zinc in samples collected from Prickly Pear Creek indicate possible effects from irrigation water. Site S4 is a reference site upstream from the Helena Valley Irrigation District on Prickly Pear Creek at East Helena. In 1995, this site had somewhat elevated concentrations of arsenic and zinc, which were likely associated with upstream abandoned mines and past and present industrial activities, including zinc-oxide production and lead and zinc smelting (D. Scott Brown, U.S. Environmental Protection Agency, oral commun., 1995). Sites S5 and S6 are located downstream on Prickly Pear Creek, within the Irrigation District. During July 5-6, 1995, streamflow decreased downstream from site S4 (207 ft^3/s) to site S6 (153 ft^3/s). Samples collected on those dates indicate that zinc concentrations (and loads) also decreased downstream from 40 µg/L (45 lb/d) at S4 to 20 µg/L (17 lb/d) at S6, indicating that most of the zinc enters the creek upstream from the Irrigation District. In contrast, arsenic concentrations (and loads) in Prickly Pear Creek increased downstream from 5 µg/L (5.6 lb/d) at site 4 to 12 µg/L (9.9 lb/d) at site 6. Decreasing flow accompanied by an increasing arsenic load indicates an intervening source of arsenic. Possible sources include irrigation drainage and unused irrigation water that may have been spilled directly to drains that discharge to Prickly Pear Creek.

As in the drains, arsenic concentrations in natural streams within the Irrigation District increased during the irrigation season. The highest arsenic concentration determined for Prickly Pear Creek was 12 µg/L at site S6 in July 1995. In Silver Creek (site S8), arsenic concentrations increased from 3 µg/L before irrigation to 17 µg/L during the irrigation season. In contrast, arsenic concentrations decreased from 7 µg/L before irrigation to 5 µg/L during the irrigation season in Prickly Pear Creek upstream from the Irrigation District (site S4).

Concentrations of other trace elements generally were low in surface water of the Helena Valley. Most concentrations were below or only slightly above minimum reporting levels. With one exception, none of the trace-element concentrations other than arsenic exceeded either MCL's for the protection of human health (U.S. Environmental Protection Agency, 1996) or aquatic-life criteria for the protection of aquatic organisms (U.S. Environmental Protection Agency, 1986). The one exception was mercury in Silver Creek (site S8), which reportedly has a history of elevated mercury in surface water and bottom sediment related to past mining and milling activities upstream (Montana Department of State Lands, 1995; Montana Department of Environmental Quality, 1996).

LAKE HELENA

The physical properties and inorganic-constituent concentrations in water samples from four sites (S10, S11, S12, S13) in Lake Helena are presented in table 5. Arsenic concentrations in lake samples ranged from 5 to 17 µg/L and are shown in figure 7. Organic-compound concentrations for Lake Helena are discussed at the end of this section.

Water sampled from Lake Helena was a calcium-sodium-magnesium bicarbonate type with relatively low concentrations of dissolved solids. Montana aquatic-life criteria for nutrients and trace elements (table 10) were not exceeded. Arsenic concentrations at all sites were lower than that of the irrigation supply water from the Missouri River (site S1) and well below the Federal (U.S. Environmental Protection Agency, 1986) and State (Montana Department of Environmental Quality, 1995) aquatic-life chronic criterion of 190 µg/L.

Lake Helena receives inflow from Prickly Pear and Silver Creeks on the west; irrigation drains on the south, west, and north; and Missouri River (Hauser Lake) backwater on the east. Pre-irrigation season samples were collected from sites S10 and S13 on the west and east sides of Lake Helena, and irrigation-season samples were collected from all four sites. Between March and July 1995, arsenic concentrations increased from 6 to 12 µg/L on the west side (site S10) and from 5 to 17 µg/L on the east side (site S13) of Lake Helena. Irrigation-season samples collected from Lake Helena at all four sites indicated an apparent spatial trend of increasing arsenic concentration, from 12 µg/L on the west to 17 µg/L on the east side of the lake. At the same time, zinc concentrations decreased from 9 µg/L on the west to less than 3 µg/L on the east. This spatial distribution of arsenic and zinc might be attributed to inflows from arsenic-enriched Missouri River backwater on the east side of the lake and zinc-enriched Prickly Pear Creek on the west side.

Although pesticides are routinely applied to farmland and residential areas in the Helena Valley watershed, the persistence of pesticides in the hydrologic system is not known. Pesticide concentrations were determined for the July 1995 water sample from the western part of Lake Helena (site S10). The sample was collected within 1 week of a large, unexplained fish kill in which more than 500 dead adult carp were observed in the southwestern part of Lake Helena. The sample was analyzed for six organochlorine herbicides: Picloram; 2,4-D; 2,4,5-T; Silvex; Dicamba; and 2,4-DP. Results indicate that 2,4-D was present at a concentration of 0.02 µg/L, well below the MCL of 70 µg/L (U.S. Environmental Protection Agency, 1996). None of the other five pesticides analyzed exceeded the minimum reporting level of 0.01 µg/L.

BOTTOM SEDIMENT

Inorganic-constituent concentrations in bottom sediment from Lake Helena are listed in table 9. National databases of bottom-sediment chemistry are sparse, and national criteria for biological risk have not been established for bottom sediment. However, comparisons to available data for soil and bottom sediment from other areas of Montana and the western United States indicate that Lake Helena bottom sediment has relatively high concentrations of some trace elements, including arsenic. Arsenic, copper, lead, and zinc concentrations in Lake Helena bottom sediment greatly exceed mean values and are near the upper end of ranges reported for more than 700 soil samples from the western United States (Shacklette and Boerngen, 1984). Cadmium, copper, lead, and zinc concentrations in Lake Helena bottom sediment exceed maximum values reported for sediment sampled from headwater flood plains in a mineralized area of western Montana (Moore and others, 1989). Arsenic concentrations in sediment from Lake Helena are similar to those of the mineralized headwater areas. Arsenic, chromium, copper, lead, mercury, and zinc concentrations in Lake Helena bottom sediment are comparable to bottom sediment sampled from seven mining-impaired wetlands and significantly greater than 73 unimpaired wetlands sampled throughout Montana (Randall S. Apfelbeck, Montana Department of Environmental Quality, oral and written commun., 1995).

Concentrations of several trace elements are higher in Lake Helena bottom sediment than in soil samples collected from the Helena Valley (table 9), indicating that some trace elements may be accumulating in Lake Helena sediment. Although the soil samples that are summarized in table 9 represent the entire valley, more than half were collected within a few miles of East Helena, where soil is affected by aerial deposition from the lead and zinc smelter. Footnotes in table 9 indicate which geometric mean values are elevated above background levels for the valley (U.S. Environmental Protection Agency, 1987).

Possible sources of trace elements in Lake Helena bottom sediment include fluvial transport from upstream mining areas and the Missouri River, and mobilization of aerially deposited smelter emissions from irrigated soils. Another potential source of arsenic is irrigation water that spills directly to the lake. However, the specific effects of each potential source cannot be differentiated on the basis of the available data.

BIOTA

Aquatic invertebrates, fish, and water-bird livers were analyzed for trace elements, and fish also were analyzed for organochlorine compounds. Enforceable criteria for maximum allowable concentrations of these compounds in biological tissue have not been established. Therefore, as guidelines for interpreting analytical results for the Helena Valley sampling, the 1995 sample data are compared to concentrations measured in samples collected in other areas of Montana and the United States (table 11) and to risk levels cited in the literature (table 12). The results of chemical analyses of biological samples collected during this study are reported in tables 13-16. In tables 11 and 12, constituent concentrations are reported on either a wet-weight or dry-weight basis, exactly as reported in the literature cited. Direct comparison between values reported in tables 13-16 with values cited in tables 11-12 may necessitate converting between dry- and wet-weight concentrations. The conversion equations, which account for sample moisture content, are given in footnotes to tables 13-16.

TRACE ELEMENTS

Concentrations of most of the 19 trace elements analyzed in biota collected in the Helena Valley were relatively low. However, concentrations of arsenic, cadmium, copper, lead, and zinc were elevated in many samples.

Invertebrates

Arsenic, copper, and zinc concentrations in some aquatic-invertebrate samples collected in the Helena Valley (table 13) were elevated compared to aquatic invertebrates collected from unimpaired sites in Montana (table 11). For samples from the Helena Valley Regulating Reservoir (site B2), the minimum arsenic concentration (3.7 μg/g) exceeded the geometric mean concentration of arsenic (1.5 μg/g) in invertebrate samples of all taxa collected elsewhere in Montana. For Lake Helena (site B8), the minimum copper (28.1 μg/g) and zinc (130 μg/g) (table 13) concentrations in invertebrates exceeded the geometric mean concentrations of copper (19 μg/g) and zinc (98 μg/g) in invertebrate samples of all taxa collected elsewhere in Montana (table 11).

Although arsenic, copper, and zinc concentrations in some invertebrate samples collected from Lake Helena and the Helena Valley Regulating Reservoir were elevated compared to those from presumably unimpaired sites, their concentrations were not elevated compared to nearby sites that are known to be impaired. For example, concentrations of those elements were considerably lower than the geometric mean concentrations of those elements in invertebrates collected from Milltown Reservoir (table 11), which is located west of the Continental Divide near Missoula (fig. 1), about 100 mi west of Helena. Milltown Reservoir has been impaired by historical mining activities (Ingersoll and others, 1993).

Dietary risk levels for arsenic and cadmium have been established for predators that consume aquatic invertebrates (table 12). According to these risk levels, the concentrations of arsenic in aquatic invertebrates from Lake Helena and the Helena Valley Regulating Reservoir do not represent a threat to the fish and birds consuming them. However, cadmium concentrations in invertebrates in the Helena Valley Regulating Reservoir (site B2) exceeded the 0.100 μg/g wet-weight dietary concentration considered by Eisler (1985) to be indicative of adverse effects on wildlife. The levels of copper, lead, and zinc in invertebrates that pose a threat to predators feeding on them are not known.

Historical aerial deposition from smelting activities in the Helena Valley might be the source of trace metals in the Regulating Reservoir. The East Helena smelter is located about 4 mi upwind from the Reservoir.

Fish

In most fish samples for which arsenic, cadmium, copper, lead, and zinc concentrations were detectable (table 14), the concentrations exceeded the geometric mean concentrations in a nationwide sample of freshwater fish (table 11). The minimum arsenic concentrations in carp from sites B2, B7, and B8 and longnose suckers from both sites from which they were collected (B4 and B5) (table 14) exceeded the geometric mean concentrations among fish of all species collected nationwide (table 11). Cadmium, copper, lead, and zinc concentrations in longnose suckers from sites B4 and B5 exceeded either the geometric mean or maximum (if mean values not calculable) concentrations of those elements among fish collected elsewhere in Montana. Zinc concentrations in all fish collected in this study exceeded the geometric mean concentration among fish of all species collected elsewhere in Montana. Zinc concentrations in two carp collected from Lake Helena at site B6 exceeded the maximum in fish collected elsewhere in Montana (table 11).

In general, the highest trace-element concentrations in fish were found in samples collected from Tenmile (site B4) and Prickly Pear (site B5) Creeks. Longnose suckers were collected from these sites, whereas carp were collected from the other biota sampling sites in the study area. Carp are known to accumulate zinc to a greater extent than other species of fish (Lowe and others, 1985), and some zinc concentrations in carp collected in this study exceeded the concentrations in longnose suckers. However, the minimum concentrations of arsenic, cadmium, copper, and lead in longnose suckers were higher than the maximum concentrations of those elements in carp. Catostomids (for example, longnose suckers) in areas having high lead concentrations are known to accumulate higher concentrations of lead in blood than do other fish (Schmitt and others, 1984). Because both species were not collected from the same sites, it is not possible to determine whether the observed differences in trace-element concentrations were due to site-specific differences in concentrations in lower trophic organisms, or due to species-specific differences in feeding habits, assimilation efficiency, or other physiological processes.

Cadmium and lead may pose a threat either to the health of fish in the Helena Valley or to the health of predators consuming them. Cadmium concentrations in longnose-sucker samples exceeded the 0.100 μg/g wet-weight concentration considered by Eisler (1985) to be potentially harmful to wildlife if consumed on a sustained basis (table 12). Lead concentrations in edible tissues of fish were not specifically determined in this study but, given the high whole-body lead concentrations in longnose suckers (mean of 1.2 μg/g wet weight) from Tenmile Creek (site B4) and Prickly Pear Creek (site B5), edible-tissue lead concentrations probably exceeded the 0.3 μg/g wet-weight concentration considered hazardous to human health (Czarneski, 1985; Eisler, 1988).

Carp from the southwestern part of Lake Helena (site B6) had whole-body lead concentrations (mean of 0.5 μg/g wet weight) that may indicate a likelihood of elevated concentrations in edible tissue. In contrast, carp in the northwestern part of Lake Helena (site B8) did not have elevated lead concentrations, possibly indicating a localized lead source in bottom sediment near the southwestern part of the lake, or an influence from Prickly Pear Creek. The single surface-water sample collected from Prickly Pear Creek at Lake Helena (site S6) during low flow did not have a high lead concentration; the lead concentration at site S6 during high-flow runoff conditions is unknown.

Arsenic, copper, and zinc concentrations in fish collected from the Helena Valley may not pose a risk. Arsenic concentrations in all fish were below the 1.3 μg/g wet-weight concentration reported by Eisler (1994) to cause diminished growth and survival in immature bluegills (*Lepomis macrochirus*). Dietary risk levels for copper and zinc are not established, but zinc concentrations did not exceed the 700 μg/g dry weight concentration cited by Eisler (1993) as the maximum concentration commonly found in fish tissue.

Water-Bird Livers

Arsenic and copper concentrations were elevated in mallard livers collected from the Helena Valley Regulating Reservoir (table 15). Arsenic concentrations in the livers of three of the four mallards collected from site B1 (fig. 3) exceeded the maximum concentration in livers of seven mallards collected elsewhere in Montana (table 11). Copper concentrations in all four mallard livers were elevated; the geometric mean copper concentration of 150 μg/g dry weight in the mallard livers collected from site B1 equals the maximum recorded among mallards collected elsewhere in Montana (table 11). Cadmium, lead, and zinc concentrations in the mallard-liver samples did not exceed the maximum or (if calculable) geometric mean concentrations of those metals in mallard-liver samples collected elsewhere in Montana (table 11).

The arsenic, cadmium, copper, lead, and zinc concentrations in the single northern-shoveler liver from the Helena Valley Regulating Reservoir (site B3) (table 15) were not elevated compared to the maximum concentrations in northern-shoveler livers collected elsewhere in Montana, but cadmium and zinc concentrations did exceed the geometric mean concentrations for those metals in other Montana northern-shoveler livers (table 11). Again, it is not known if the differing results between the few mallard and northern-shoveler samples collected in the Helena Valley resulted from site-specific differences in arsenic and copper concentrations in water-bird food organisms, or from species-specific feeding methods, or from assimilation characteristics unique to the few individuals sampled.

Arsenic, cadmium, lead, and zinc concentrations in the livers of water birds sampled from the Helena Valley Regulating Reservoir do not indicate a threat to water-bird health. The maximum arsenic concentration in water-bird livers sampled was below the 2-10 µg/g wet-weight concentration considered by Eisler (1994) to be elevated (table 12). Cadmium concentrations in water-bird livers were well below the 10.0 µg/g wet-weight level considered by Eisler (1985) to be evidence of cadmium poisoning. Lead concentrations in water-bird livers did not exceed the 8 µg/g wet-weight concentration considered by Eisler (1988) to be evidence of lead poisoning. Zinc concentrations in water-bird livers were much lower than the 2,100 µg/g dry weight suggested by Eisler (1993) as an indicator of zinc poisoning. Threats to water-bird health due to elevated copper concentrations could not be determined because risk levels have not been established for copper concentrations in water-bird livers.

ORGANOCHLORINE COMPOUNDS IN FISH

On June 30, 1995, more than 500 dead adult carp were observed in the southwestern part of Lake Helena (site B6, fig. 3). Five carp carcasses were collected for whole-body organochlorine residue and trace-element analyses to evaluate potential cause(s) of the mortality. Organochlorine compounds include pesticides (for example, p,p'-DDT), their decomposition products (for example, p,p'-DDE) and industrial chemicals (for example, PCB's). Many of these compounds are highly toxic, persistent contaminants in aquatic environments and historically have been responsible for some population declines in migratory birds (Fleming and others, 1983).

Organochlorine concentrations in fish samples from the Helena Valley (table 16) were not elevated compared to samples collected nationwide (table 11). Therefore, it is unlikely that the observed carp mortality was caused by organochlorine-compound toxicity. Schmitt and others (1990) reported a geometric mean p,p'-DDE concentration of 0.19 µg/g wet weight in freshwater fish collected nationwide. Concentrations in samples from the Helena Valley did not exceed those levels. Schmitt and others (1990) also reported a nationwide geometric mean p,p'-DDD concentration of 0.06 µg/g wet weight in freshwater fish. None of the Helena Valley samples exceeded that concentration. Two of the carp samples from site B6 exceeded the nationwide geometric mean PCB concentration of 0.39 µg/g, but not the nationwide maximum PCB concentration of 6.7 µg/g wet weight in freshwater fish. The geometric mean PCB concentration from site B6 did not exceed the nationwide geometric mean.

The percentage of fish from the Helena Valley in which organochlorine compounds were detected was comparable to, or less than, the percentage of detections in a nationwide study (Schmitt and others, 1990). In that study, the minimum reporting levels were 0.01 µg/g wet weight for p,p'-DDE and p,p'-DDD and 0.1 µg/g wet weight for PCB's. Residues of both p,p'-DDE and p,p'-DDD were detected at concentrations greater than 0.01 µg/g wet weight at 17 percent of the fish-sampling sites in the Helena Valley, compared to 98.2 percent and 97.3 percent of 112 sites sampled nationwide by Schmitt and others (1990). Residues of total PCB's were detected at concentrations greater than 0.1 µg/g wet weight at 33 percent of the fish-sampling sites in the Helena Valley, compared to 91.1 percent of 112 sites sampled nationwide by Schmitt and others (1990). For all three compounds, carp from Lake Helena at site B6 had by far the highest concentrations (table 16).

The differences in organochlorine concentrations in fish sampled from the various sites probably represent differences in fish ages, rather than differences in organochlorine concentrations in the water or in the foods of carp and longnose suckers at those sites. The carp collected from site B6 were large (greater than 1,000 g) adult fish, whereas fish of both species collected from the other sites were small (less than 20 g) and immature. Older fish are expected to have accumulated higher concentrations of organochlorine compounds than younger fish (Fabrizio and others, 1994).

Organochlorine concentrations in fish samples from the Helena Valley do not represent a threat to the fish or to their predators, including humans. Martin and Hartman (1985) considered their reported total DDE concentrations of less than 0.512 µg/g wet weight in fish to indicate little organochlorine pesticide contamination. PCB concentrations in fish from the Helena Valley are well below the 5.0 µg/g wet-weight concentration action level stipulated by the U.S. Food and Drug Administration for human consumption (Eisler, 1986). Therefore, although the cause of the fishkill is unknown, it is unlikely that the observed carp mortality was caused by organochlorine-compound toxicity.

POTENTIAL RISKS TO HUMAN AND BIOLOGICAL HEALTH

Some of the arsenic in irrigation water sorbs to soil; however, some arsenic remains in solution and percolates through soil horizons into ground water. In the western part of the Helena Valley Irrigation District, where the alluvial aquifer is the primary source of drinking water, infiltrated water containing arsenic apparently is either diluted by regional ground water, or hydraulically prevented from moving downward. In addition, some arsenic may sorb to aquifer material. The net result of these various processes is that arsenic concentrations in typical domestic wells completed in the Helena Valley alluvial aquifer are much lower than drinking-water standards. Therefore, in the western part of the District, domestic ground-water supplies that are partly recharged by irrigation water do not pose a public-health risk.

In the eastern part of the District, where Tertiary sediments compose the aquifer, the two deep (100-ft and 180-ft) wells sampled had arsenic concentrations of 22 and 17 μg/L, respectively. The Montana Department of Environmental Quality (1995) has established a human health standard of 18 μg/L for arsenic, a potential carcinogen. The EPA has established an MCL of 50 μg/L arsenic for treated drinking water (U.S. Environmental Protection Agency, 1996) and is developing a proposal to lower the MCL to the 2 to 20 μg/L range (Reid, 1994). Because only two wells were sampled in this area, the risk to humans is unclear. Sampling of additional wells, both within and upgradient from the Irrigation District, would clarify the risk and help identify the source of arsenic in the Tertiary aquifer. Relatively few wells are completed in Tertiary sediments within the District, although residential development is underway. If infiltrated irrigation water is the source of arsenic in the ground water, then reducing irrigation as agriculture is displaced by residential development would result in decreased arsenic loading to the aquifer. However, eliminating ground-water recharge from the irrigation system could cause existing wells to become dry. Under current conditions of irrigation recharge, a more practical remedy might be to treat drinking water at individual taps or wellheads. Properly maintained stills and reverse-osmosis purifying systems reportedly are capable of removing 99 percent of arsenic from domestic well water with elevated arsenic concentrations in the Madison River valley (Sonderegger and others, 1989).

Trace-element concentrations in water-bird-liver samples and organochlorine residues in fish samples of both young and old age classes do not appear to pose a threat to the health of these organisms or their predators in the Lake Helena area. However, this conclusion is based on an extremely small sample size of a limited number of species from few sample sites. Cadmium concentrations in invertebrates from the Helena Valley Regulating Reservoir may pose a threat to predators that feed on invertebrates. Cadmium and lead concentrations in some fish also may be potentially harmful to predators if consumed on a sustained basis.

For this study, fish were analyzed as whole-body samples rather than separating the edible tissue for specific analysis. Therefore, results of this study do not provide definitive conclusions regarding potential human-health risks due to fish consumption.

SUMMARY AND CONCLUSIONS

The Helena Valley receives about 63,000 acre-ft of irrigation water diverted from the Missouri River annually. At the point of diversion, the concentration of naturally occurring arsenic ranges from about 22 to 34 μg/L, compared to the MCL of 50 μg/L established by the U.S. Environmental Protection Agency and the Montana human health standard of 18 μg/L. Domestic and community-supply wells in the Helena Valley are completed in alluvial aquifers that are partly recharged by this irrigation water. To address concerns regarding potential public health and biological risks, the USGS and USFWS conducted a field screening of the physical and chemical conditions of water, bottom sediment, and biota associated with canal seepage and irrigation drainage from the Helena Valley Irrigation District.

Two ground-water regimes are present in the Helena Valley. A permeable alluvial aquifer consisting primarily of Quaternary alluvium underlies the western part of the valley, and a much less permeable Tertiary aquifer consisting of Tertiary sediments underlies the Spokane Bench in the eastern part of the valley. Bedrock aquifers surround the valley and are hydraulically connected to both valley aquifers.

Potential arsenic sources in the Helena Valley include irrigation water from the Missouri River, aerially deposited particulate emissions from smelter operations, naturally occurring arsenic minerals, arsenic sorbed or coprecipitated to iron oxyhydroxide coatings, and waterborne contaminants from historical mining and industrial activities. Arsenic mobility generally is controlled by sorption/desorption and dissolution/precipitation reactions. Physical processes such as dilution and evapoconcentration can also control arsenic concentrations in water.

Arsenic concentrations in samples collected from 27 wells during this study ranged from less than 1 to 22 μg/L, with a median of 2 μg/L. Data from two instrument clusters, each consisting of two suction lysimeters and one shallow test well, indicate that arsenic sorbed to soil particles as irrigation water percolated through the soil zone, and was diluted by ground water as it infiltrated to the underlying aquifer. As a result, soil moisture at these sites had lower arsenic concentrations than irrigation water, and very shallow ground water generally had lower concentrations than soil moisture. Deeper in the alluvial aquifer, at depths more representative of drinking-water sources, arsenic concentrations were lower still (<1 to 5 μg/L, with a median value of 1.2 μg/L for 20 samples), possibly as a result of sorption to aquifer materials and dilution. Alternately, hydraulic gradients might prevent arsenic-enriched shallow ground water from moving downward in the aquifer.

Two drinking-water wells completed in the Tertiary aquifer in the eastern part of the valley, beneath the Spokane Bench, had the highest arsenic concentrations in the study area (17 and 22 μg/L). Potential sources of arsenic in the ground water are in infiltrated irrigation water and dissolution of arsenic-bearing minerals in the Tertiary aquifer. In contrast to the alluvial aquifer, the Tertiary aquifer has low permeability and probably does not transmit sufficient quantities of ground water to dilute arsenic significantly.

Trace-element concentrations in surface water generally were low, with the exceptions of arsenic and zinc. Arsenic concentrations in samples from 12 irrigation-drain, natural-stream, and lake sites ranged from 2 to 25 μg/L, with median concentrations of 5.5 μg/L during the non-irrigation season and 15 μg/L during the irrigation season. The highest concentration was measured in water from a drain that receives direct spills from the Helena Valley Canal. Samples from most sites within the Helena Valley Irrigation District had higher arsenic concentrations during the irrigation season than during the non-irrigation season; a reference site not affected by irrigation drainage did not display this trend. Moderately elevated zinc concentrations in Prickly Pear Creek probably result from historical mining and industrial activities upstream from the Irrigation District.

Three samples of bottom sediment from Lake Helena had arsenic and trace-element concentrations that are comparable to or higher than those in a broad range of soils from the western United States and sediment from a mineralized headwaters area in western Montana. Trace-element concentrations in Lake Helena bottom sediment are comparable to concentrations in bottom sediment from seven mining-impaired wetlands in Montana. Possible sources of trace elements in the bottom sediment include fluvial transport from upstream mining areas and mobilization of aerially deposited smelter emissions from irrigated soils.

Concentrations of arsenic, cadmium, copper, lead, and zinc were elevated in many biological samples from the Helena Valley relative to geometric mean concentrations of samples from uncontaminated sites statewide and nationwide. However, not all trace-element concentrations were sufficiently elevated to indicate biological risk. In invertebrates, only cadmium concentrations exceeded the concentrations considered potentially harmful to predators if consumed on a sustained basis. In fish, cadmium concentrations may pose a risk to predators. In addition, whole-body lead concentrations in some fish, based on the comparison to guideline concentrations for edible fish tissues, very likely exceeded the concentrations considered potentially harmful to humans if consumed on a sustained basis. Trace-element concentrations in water-bird liver samples and organochlorine residues in fish samples indicate no threat to the health of the organisms or to their predators in the Helena Valley. The elevated trace-element concentrations measured in biota at most sites may result from historical metals mining and smelting operations in the Helena Valley and surrounding areas. However, these conclusions are based on very small sample sizes.

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DATA

Table 1. Surface-water and bottom-sediment sampling sites in the Helena Valley, Montana

[Site number: Letter preceding number indicates medium type (S, surface water). Site type: DR, irrigation drain; LK, lake; ST1, natural stream that receives irrigation drainage; ST2, stream or canal that receives no irrigation drainage (reference site). Data type: BS, bottom sediment analyzed for trace elements including arsenic; WA, water analyzed for arsenic; WC, water analyzed for full chemistry (major ions, nutrients, and trace elements including arsenic)]

Site number (fig. 3)	U.S. Geological Survey site-identification number[1]	Site name	Site type	Data type
		HELENA VALLEY IRRIGATION DISTRICT		
S1	463816111525601	Helena Valley Regulating Reservoir outlet	ST2	WC
S2[2]	464122111543501	Helena Valley Field Drain No. 1 at mouth	DR	WA
S3[2]	464045111564401	Helena Valley Field Drain No. 2 near mouth	DR	WA
S4	06062000	Prickly Pear Creek at East Helena	ST2	WC
S5	463939111582801	Prickly Pear Creek above Tenmile Creek	ST1	WA
S6	464107111573701	Prickly Pear Creek at Lake Helena	ST1	WC
S7[2]	464124111595801	Silver Creek Drain at Masonic Home Road	DR	WC
S8	464140111580901	Silver Creek Diversion Canal near mouth	ST1	WC
S9	464210111572401	Helena Valley Drain above Lake Helena	DR	WA
		LAKE HELENA		
S10	464139111571201	Lake Helena (west)	LK	WC, BS
S11	464120111555001	Lake Helena (south)	LK	WA, BS
S12	464220111555001	Lake Helena (north)	LK	WA, BS
S13	464155111544101	Lake Helena (east)	LK	WC

[1] Fifteen-digit station identification number represents the approximate latitude and longitude location of the site (first 13 digits), plus the sequence number (last 2 digits). Eight-digit station identification number represents the standard USGS streamflow-gaging station numbering system wherein numbers increase in a downstream direction according to geographic location within the drainage basin.

[2] Site (or nearby location) was also sampled by Mangelson and Brummer (1994).

Table 2. Water levels and well-construction data for soil-moisture and ground-water sampling sites in the Helena Valley, Montana

[Site number: Letter preceding number indicates medium type (G, ground water). Geologic unit: p€s, Precambrian shale; Kg, Cretaceous granite; Ts, Tertiary sediments; Qal, Quaternary alluvium. Use of water: C, community; D, domestic; I, irrigation; S, stock; U, unused. Abbreviations: ft, feet below land surface; in., inches. Symbol: --, no data; >, greater than]

Site number (fig. 3)	U.S. Geological Survey site-identification number[1]	Location number[2]	Geologic unit	Use of water	Date water level measured	Depth to water (ft)	Depth of well (ft)	Top of open intervel (ft)	Bottom of open interval (ft)	Diameter of casing (in.)	Date of well construction
G1	464121112024401	11N04W25AABA01	Qal	D	--	--	74	64	74	6	03-05-86
G2	464032112023001	11N04W25DDDD01	Qal	U	08-07-95	11.53	20	17	20	1	09- -78
G3	464008112030201	11N04W36ACCA01	Kg	D	--	--	86	72	86	6	- -74
G4	464309111572001	11N03W14BBBB01	p€s	D	04-27-95 08-08-95	69.97 62.12	110	[3]--	--	6	04-01-87
G5	464306111595101	11N03W16BBBB01	p€s	D	05-24-95 08-22-95	60.90 50.12	125	[3]--	--	6	03-27-86
G6	464218112001301	11N03W17DDCC01	Qal	D	08-08-89	15	36	27	32	6	08-01-72
G7	464244112011401	11N03W18ADDD01	Qal	D	--	--	62	[3]--	--	6	08-08-73
G8	464208111583702	11N03W22BBCB02	Qal	U	06-12-90	9.06	48	33	38	2	06-04-90
G9	464039111550401	11N03W25DDBD01	Qal	D	--	--	40	--	--	--	--
G10[4]	464052111584201	11N03W28DAAD01	Qal	U	05-16-95 08-07-95	5.80 4.85	6.5	5.0	6.5	2	05-11-95
G11	464122112002901	11N03W29ABBA01	Qal	S	--	--	50	--	--	--	--
G12	464050112014501	11N03W30DBCA01	Qal	D	05-03-89	14.46	35	--	--	--	--
G13[4]	464011111584801	11N03W33ADDB01	Qal	U	05-16-95 08-04-95	3.65 3.00	8.3	6.2	8.3	2	05-12-95
G14	464031111593902	11N03W33BBAA02	Qal	U	08-20-90	5.23	25	20	25	2	07-10-90
G15	463953111562701	11N03W35DACC01	Qal	U	05-25-90	6.86	29	19	29	4	05-16-90
G16	464011111545001	11N02W31BCCB01	Qal	D	01-22-91	4.88	40	--	--	6	- -85
G17	463832112023203	10N04W12AACD01	Qal	C	09-29-89	6.46	59	35	57	8	09-11-89
G18	463914111570601	10N03W02BCDD01	Qal	D	--	--	35	--	--	--	--
G19	463847111561003	10N03W02DDDD03	Qal	U	08-07-95	10.35	25	20	25	2	07-13-90
G20	463701111591801	10N03W16DCCC02	Qal	D	04-28-95	36.59	72	[3]--	--	6	12-24-76
G21	463751112003201	10N03W17ABBB01	Qal	U	08-07-95	20.17	28	24	28	1.5	09- -78
G22	463743112011701	10N03W18AADA01	Qal	C	08-09-95	34.01	54	44	54	1	04-21-88
G23	463657111550401	10N03W24BBBC01	Qal	D	04-28-95 08-09-95	42.88 32.85	58	--	--	6	10-15-75
G24	463940111504901	10N02W03BBAB01	Ts	D	04-27-95 08-08-95	88.14 74.15	100	[3]--	--	6	09-22-86
G25	463928111534401	10N02W06AADC01	Ts	C	05-01-95 08-08-95	46.52 30.14	180	140	180	6	02-14-94
G26	463845111545001	10N02W07BBBB01	Qal	U	08-07-95	6.92	24	20	--	1.5	- -78
G27	463645111535201	10N02W19ADBB01	Qal	I	04-27-95 08-10-95	>71.92 60.95	--	--	--	--	--

---

[1] Fifteen-digit site-identification number is a unique identifier that represents the approximate latitude and longitude location of the site (first 13 digits), plus the sequence number (last 2 digits).

[2] Location number represents the township, range, section, and quadrants of section, plus the sequence number.

[3] Open-ended well with no casing perforations.

[4] Also site of clustered suction lysimeters for sampling soil moisture.

Table 3. Biological sampling sites in the Helena Valley, Montana

[Site number: Letter preceding number indicates medium type (B, biota; S, surface water). Data type: BL, bird liver; F, fish; I, aquatic invertebrate. Symbol: --, no corresponding surface-water site]

Site number (fig. 3)	Corresponding site number for surface water	Site-identification number[1]	Site name	Data type
B1	--	4637501115215	Helena Valley Regulating Reservoir (south)	BL
B2	--	4638351115250	Helena Valley Regulating Reservoir (west)	I,F
B3	--	4638441115227	Helena Valley Regulating Reservoir (north)	BL
B4	--	4639381115923	Tenmile Creek at East Sierra Road	F
B5	S5	4639391115833	Prickly Pear Creek above Tenmile Creek	F
B6	--	4641091115711	Lake Helena (southwest)	F
B7	--	4641591115741	Silver Creek at mouth	F
B8	--	4642091115729	Lake Helena (northwest)	I,F

[1] Site-identification number represents approximate latitude and longitude. Where sampling covered a broad area (for example, an entire pool or pond), a central location is given to seconds.

Table 4. Minimum reporting levels for inorganic and organic constituents analyzed in water, bottom sediment, and biota

[Abbreviations: BHC, benzenehexachloride; DDD, dichlorodiphenyldichloroethane; DDE, dichlorodiphenyldichloroethylene; DDT, dichlorodiphenyltrichloroethane; HCB, hexachlorobenzene; PCB, polychlorinated biphenyl; µg/g, micrograms per gram (dry weight for all sample media except wet weight for organic compounds in fish); µg/L, micrograms per liter; mg/L, milligrams per liter; percent, parts per hundred. Symbol: --, constituent not analyzed in the indicated medium]

Constituent	Minimum reporting level[1]		
	Water	Bottom eediment	Biota
PHYSICAL PROPERTY AND MAJOR IONS			
Alkalinity	1 mg/L	--	--
Bicarbonate	1 mg/L	--	--
Calcium	.1 mg/L	0.01 percent	--
Carbon, carbonate	0 mg/L	--	--
Chloride	.1 mg/L	--	--
Fluoride	.1 mg/L	--	--
Magnesium	.01 mg/L	.01 percent	5 µg/g
Potassium	.1 mg/L	.1 percent	--
Silica	.1 mg/L	--	--
Sodium	.2 mg/L	.01 percent	--
Solids, dissolved	1 mg/L	--	--
Sulfate	.1 mg/L	--	--
NUTRIENTS			
Nitrogen, ammonia	.015 mg/L	--	--
Nitrogen, nitrite	.01 -.1 mg/L	--	--
Nitrogen, nitrite plus nitrate	.05 mg/L	--	--
Phosphorus, orthophosphate	.01 -.1 mg/L	.01 percent	--
TRACE ELEMENTS			
Aluminum	--	0.1 percent	5 µg/g
Arsenic	1 µg/L	.1-10 µg/g	.5 µg/g
Barium	--	10 µg/g	1 µg/g
Beryllium	--	1 µg/g	.1 µg/g
Boron	--	--	2 µg/g
Cadmium	1-5 µg/L	2 µg/g	.1 µg/g
Chromium	1-5 µg/L	1 µg/g	.5 µg/g
Cobalt	--	1 µg/g	--
Copper	1-4 µg/L	1 µg/g	.5 µg/g
Iron	3-9 µg/L	.05 percent	5 µg/g
Lead	1-3 µg/L	10 µg/g	.5 µg/g
Lithium	--	10 µg/g	--
Manganese	1-3 µg/L	10 µg/g	1 µg/g
Mercury	.1 µg/L	.01 µg/g	.05 µg/g
Molybdenum	--	2 µg/g	2 µg/g
Nickel	--	1 µg/g	.5 µg/g
Selenium	1-2 µg/L	--	.5 µg/g
Silver	--	2 µg/g	--
Strontium	--	10 µg/g	.5 µg/g
Uranium	--	100 µg/g	--
Vanadium	--	10 µg/g	.5 µg/g
Zinc	2-6 µg/L	1 µg/g	1 µg/g
ORGANIC COMPOUNDS			
Aldrin	--	--	0.0002-.001 µg/g
Alpha-BHC	--	--	.0002-.001 µg/g
Beta-BHC	--	--	.0002-.001 µg/g
Delta-BHC	--	--	.0002-.001 µg/g
Gamma-BHC	--	--	.0002-.001 µg/g
Alpha-chlordane	--	--	.0002-.001 µg/g
Gamma-chlordane	--	--	.0002-.001 µg/g

Table 4. Minimum reporting levels for inorganic and organic constituents analyzed in water, bottom sediment, and biota (Continued)

Constituent	Minimum reporting level[1]		
	Water	Bottom sediment	Biota
	ORGANIC COMPOUNDS--Continued		
o,p'-DDD	--	--	.0002-.001 µg/g
p,p'-DDD	--	--	.0002-.001 µg/g
o,p'-DDE	--	--	.0002-.001 µg/g
p,p'-DDE	--	--	.0002-.001 µg/g
o,p'-DDT	--	--	.0002-.001 µg/g
p,p'-DDT	--	--	.0002-.001 µg/g
Dicamba (Mediben) (Banvel D)	.01 µg/L	--	--
Dieldrin	--	--	.0002-.001 µg/g
Endosulfan II	--	--	.0004-.002 µg/g
Endrin	--	--	.0002-.001 µg/g
HCB	--	--	.0002-.001 µg/g
Heptachlor	--	--	.0002-.001 µg/g
Heptachlor epoxide	--	--	.0002-.001 µg/g
Mirex	--	--	.0002-.001 µg/g
Cis-nonachlor	--	--	.0002-.001 µg/g
Trans-nonachlor	--	--	.0002-.001 µg/g
Oxychlordane	--	--	.0002-.001 µg/g
Total PCB's	--	--	.0018-.01 µg/g
Picloram (Tordon) (Amdon)	.01 µg/L	--	--
Silvex	.01 µg/L	--	--
2,4-D	.01 µg/L	--	--
2,4-DP	.01 µg/L	--	--
2,4,5-T	.01 µg/L	--	--

[1] Minimum reporting levels for several elements vary as a result of method detection capabilities and matrix interferences.

Table 5. Physical properties and inorganic-constituent concentrations in surface water from the Helena Valley, Montana

[Site number: Letter preceding number indicates medium type (S, surface water). Constituents are dissolved. Abbreviations: °C, degrees Celsius; E, estimated; inst., instantaneous; FET, fixed-endpoint titration; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter. Symbols: <, less than; --, no data]

Site number (fig. 3)	Date	Discharge, inst., (cubic feet per second)	Specific conductance, field (µS/cm)	pH, field (standard units)	Temperature, water (°C)	Oxygen, field (mg/L)	Hardness (mg/L as $CaCO_3$)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Sodium (percent)
S1	07-05-95	105	363	8.6	13.5	11.4	140	37	11	21	24
S2	03-27-95	6.3	428	8.1	5.0	--	--	--	--	--	--
	07-06-95	24	398	7.7	12.0	9.4	--	--	--	--	--
S3	03-27-95	9.7	440	8.4	6.0	--	--	--	--	--	--
	07-06-95	22	475	8.6	15.5	15.6	--	--	--	--	--
	07-06-95[1]	--	--	--	--	--	--	--	--	--	--
S4	03-23-95	39	255	8.7	6.0	--	--	--	--	--	--
	07-05-95	207	150	8.0	12.0	10.0	58	17	3.8	5.8	17
S5	03-23-95	--	381	8.4	8.5	--	--	--	--	--	--
	07-05-95	142	238	8.2	16.0	10.0	--	--	--	--	--
S6	03-27-95	52	380	8.3	5.0	--	--	--	--	--	--
	07-06-95	153	245	7.9	14.0	10.4	99	28	7.1	11	19
S7	03-23-95	.31	672	8.7	8.5	--	--	--	--	--	--
	07-05-95	14	399	8.7	--	11.0	160	40	14	23	24
S8	03-27-95	13	519	8.5	8.0	--	--	--	--	--	--
	07-06-95	48	480	8.2	15.0	14.4	200	52	16	25	21
S9	03-27-95	.07	922	8.8	6.0	--	--	--	--	--	--
	07-05-95	E.30	875	7.9	15.5	--	--	--	--	--	--
S10	03-27-95	--	363	9.0	4.5	11.5	140	37	12	20	23
	07-06-95	--	247	7.9	14.0	9.0	96	27	7.0	11	19
S11	07-06-95	--	311	9.0	20.0	11.2	--	--	--	--	--
S12	07-06-95	--	309	8.7	20.0	10.2	--	--	--	--	--
S13	03-27-95	--	363	8.8	3.0	12.2	--	--	--	--	--
	07-06-95	--	295	8.3	17.0	8.3	120	33	8.9	14	20

[1] Quality-control sample. Replicate arsenic analysis.

Table 5. Physical properties and inorganic-constituent concentrations in surface water from the Helena Valley, Montana (Continued)

Site number (fig. 3)	Sodium adsorption ratio	Potassium (mg/L as K)	Alkalinity, lab (FET) (mg/L as $CaCO_3$)	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Dissolved solids, calculated (mg/L)	Nitrite (mg/L as N)	Nitrite plus nitrate (mg/L as N)
S1	0.8	3.8	134	32	13	1.1	199	<0.01	<0.05
S2	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--
S3	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--
S4	--	--	--	--	--	--	--	--	--
	.3	1.6	49	20	1.1	.10	79	<.01	<.05
S5	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--
S6	--	--	--	--	--	--	--	--	--
	.5	2.3	86	26	5.4	.30	133	.02	.24
S7	--	--	--	--	--	--	--	--	--
	.8	3.4	150	36	13	1.0	223	<.01	.59
S8	--	--	--	--	--	--	--	--	--
	.8	3.4	184	44	14	.80	268	<.01	.51
S9	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--
S10	.7	3.5	123	49	12	.40	208	--	--
	.5	2.3	86	26	5.5	.20	132	.03	.26
S11	--	--	--	--	--	--	--	--	--
S12	--	--	--	--	--	--	--	--	--
S13	--	--	--	--	--	--	--	--	--
	.6	2.7	107	29	7.2	.40	160	.02	.07

Table 5. Physical properties and inorganic-constituent concentrations in surface water from the Helena Valley, Montana (Continued)

Site number (fig. 3)	Ammonia (mg/L as N)	Phosphorus, ortho (mg/L as P)	Arsenic (μg/L as As)	Cadmium (μg/L as Cd)	Chromium (μg/L as Cr)	Copper (μg/L as Cu)	Lead (μg/L as Pb)	Mercury (μg/L as Hg)	Selenium (μg/L as Se)	Zinc (μg/L as Zn)
S1	0.020	<0.01	31	<1	<1	<1	<1	<0.1	<1	<3
S2	--	--	2	--	--	--	--	--	--	--
	--	--	15	--	--	--	--	--	--	--
S3	--	--	2	--	--	--	--	--	--	--
	--	--	7	--	--	--	--	--	--	--
	--	--	7	--	--	--	--	--	--	--
S4	--	--	7	--	--	--	--	--	--	--
	.020	<.01	5	<1	<1	3	1	<.1	<1	40
S5	--	--	8	--	--	--	--	--	--	--
	--	--	8	--	--	--	--	--	--	--
S6	--	--	8	--	--	--	--	--	--	--
	.080	.03	12	<1	<1	3	1	<.1	<1	20
S7	--	--	2	--	--	--	--	--	--	--
	.020	<.01	25	<1	<1	1	<1	<.1	<1	<3
S8	--	--	3	--	--	--	--	--	--	--
	.020	<.01	17	<1	<1	<1	<1	.2	<1	<3
S9	--	--	17	--	--	--	--	--	--	--
	--	--	11	--	--	--	--	--	--	--
S10	--	--	6	<1	<1	2	<1	<.1	<1	<3
	.11	.03	12	<1	<1	3	<1	<.1	<1	9
S11	--	--	15	--	--	--	--	--	--	--
S12	--	--	15	--	--	--	--	--	--	--
S13	--	--	5	--	--	--	--	--	--	--
	.060	.06	17	<1	<1	2	<1	<.1	<1	<3

Table 6. Lithologic logs of test-well boreholes in the Helena Valley, Montana

[Site number: Letter proceeding number indicates medium type (G, ground water)]

Site number (fig. 4)	Lithology	Top of interval (feet below land surface)	Bottom of interval (feet below land surface)
G10	Topsoil, brownish-gray, clayey, silty, recently plowed, dry	0	2.5
	Clay, dark-brownish-gray, silty, slightly damp; contains sporadic sand	2.5	3.0
	Clay, dark-gray, slightly mottled with rust color, damp, hard; contains little silt and fine sand	3.0	4.0
	Same, with increasing sand and mottling; also contains gravel and sporadic whitish-yellow, sandy, noncalcareous veins	4.0	5.0
	Clay and gravel, light-brownish-gray mottled with rust color and dark gray, sandy; contains decomposed plant fragments and white to light-pink, noncalcareous salt crystals	5.0	5.5
	Sand and gravel, brown, coarse, well-rounded, wet; some cobbles more than 3 inches in diameter	5.5	6.5
G13	Topsoil, brownish-gray, clayey, silty	0	.7
	Sand and gravel, brown, poorly sorted	.7	1.0
	Same, slightly mottled with rust color and gray	1.0	1.5
	Sand, gray with rust-colored mottling, fine to very coarse, poorly sorted; contains some clay and fine gravel	1.5	3.0
	Sand, gray with rust-colored mottling; increasing clay content with depth	3.0	4.0
	Clay, dark-gray, dense, hard; contains some silt and brown, decomposed plant fragments and sporadic fine sand	4.0	6.6
	Same, with little sand and gravel	6.6	7.0
	Sand, gray, fine to medium, wet	7.0	9.5

Table 7. Physical properties and inorganic-constituent concentrations in soil moisture and ground water from clustered suction-lysimeter and monitoring-well sites in the Helena Valley, Montana

[Site number: Letter preceding number indicates medium type (G, ground water and soil moisture). Constituents are dissolved. Sampling equipment: L, suction lysimeter; W, test well. Sample type: CF, capillary fringe; GW, ground water; GW-R, ground-water field replicate; SM, soil moisture. Abbreviations: ft, feet; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter; lab, laboratory. Symbols: --, no data; <, less than]

Site number (fig. 3)	Sampling equipment	Depth of sampled interval (ft below land surface)	Date[1]	Depth to ground water (ft below land surface)	Sample type[2]	Specific conductance, lab (µS/cm)	pH, lab (standard units)	Hardness (mg/L as $CaCO_3$)	Calcium (mg/L as Ca)
				Sprinkler-irrigated site					
G10	L	1.8 - 2.0	08-04-95	5.00	SM	--	--	--	--
	L	4.1 - 4.3	07-31-95	4.94	SM	3,170	8.1	810	230
			08-04-95	5.00	SM	2,290	7.8	690	200
	W	5.0 - 6.5	08-07-95	4.85	GW	[3]630	[3]7.6	260	80
				Flood-irrigated site					
G13	L	2.3 - 2.5	07-31-95	2.37	GW	1,450	7.7	600	170
			08-04-95	3.00	CF	1,300	7.7	570	160
	L	4.4 - 4.6	07-31-95	2.37	GW	1,200	7.5	600	170
			08-04-95	3.00	GW	1,180	7.9	590	170
			08-04-95	3.00	GW-R	1,190	7.7	620	180
	W	6.2 - 8.3	08-07-95	--	GW	[3]755	[3]7.0	330	97

[1] Irrigation dates: 07-21-95 to 07-28-95, 08-04-95 (sprinkler-irrigated site); 07-30-95 (flood-irrigated site).

[2] Owing to fluctuating water tables, lysimeters could produce different types of samples on different dates.

[3] Parameter measured in the field.

Table 7. Physical properties and inorganic-constituent concentrations in soil moisture and ground water from clustered suction-lysimeter and monitoring-well sites in the Helena Valley, Montana (Continued)

Site number (fig. 3)	Date[1]	Magnesium (mg/L as Mg)	Sodium (mg/L as Na)	Sodium (percent)	Sodium adsorption ratio	Potassium (mg/L as K)	Alkalinity, whole (mg/L as $CaCO_3$)	Sulfate (mg/L as SO_4)	Chloride (mg/L as Cl)	Fluoride (mg/L as F)
Sprinkler-irrigated site										
G10	08-04-95	--	--	--	--	--	--	--	--	--
	07-31-95	57	480	56	7.0	17	319	1,400	52	1.0
	08-04-95	47	290	47	5.0	16	295	900	68	.80
	08-07-95	15	19	13	.5	11	[3]223	110	25	.60
Flood-irrigated site										
G13	07-31-95	42	100	26	2.0	5.1	432	170	33	1.4
	08-04-95	41	97	27	2.0	4.2	357	180	38	1.4
	07-31-95	42	53	16	.9	2.0	476	69	25	1.0
	08-04-95	41	56	17	1.0	1.6	241	86	28	1.0
	08-04-95	42	57	17	1.0	1.6	356	86	27	1.0
	08-07-95	21	27	15	.6	4.7	[3]350	36	17	.70

Table 7. Physical properties and inorganic-constituent concentrations in soil moisture and ground water from clustered suction-lysimeter and monitoring-well sites in the Helena Valley, Montana (Continued)

Site number (fig. 3)	Date[1]	Silica (mg/L as SiO_2)	Dis-solved solids, calcu-lated (mg/L)	Nitrite (mg/L as N)	Nitrite plus nitrate (mg/L as N)	Am-monia (mg/L as N)	Phos-pho-rus, ortho (mg/L as P)	Ar-senic (µg/L as As)	Iron (µg/L as Fe)	Man-ga-nese (µg/L as Mn)
Sprinkler-irrigated site										
G10	08-04-95	--	--	--	--	--	--	22	--	--
	07-31-95	72	2,530	<0.01	5.4	0.27	0.37	12	<9	<3
	08-04-95	75	1,790	<.01	2.9	.04	.17	9	<9	<3
	08-07-95	--	395	<.01	.11	.07	.03	16	--	--
Flood-irrigated site										
G13	07-31-95	45	910	<.01	19	.02	.04	14	<3	1
	08-04-95	48	899	<.01	27	.02	.04	12	<3	2
	07-31-95	54	709	<.01	1.2	.07	.18	10	670	750
	08-04-95	53	589	.01	1.4	.08	.17	7	160	810
	08-04-95	54	670	.01	1.4	.08	.16	7	160	820
	08-07-95	--	415	<.01	.36	.35	<.01	6	--	--

Table 8. Physical properties and inorganic-constituent concentrations in ground water from the Helena Valley, Montana

[Site number: Letter preceding number indicates medium type (G, ground water). Constituents are dissolved. Analyzing agency: MBMG, Montana Bureau of Mines and Geology; USGS, U.S. Geological Survey. Abbreviations: °C, degrees Celsius; IT, incremental titration; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25°C; mg/L, milligrams per liter. Symbols: --, no data; <, less than]

Site number (fig. 3)	Location number	Date	Specific conductance, field (µS/cm)	pH, field (standard units)	Temperature, water (°C)	Oxygen, field (mg/L)	Hardness (mg/L as $CaCO_3$)	Calcium (mg/L as Ca)	Magnesium (mg/L as Mg)
G1	11N04W25AABA01	08-09-95	385	7.7	14.5	7.7	150	39	13
G2	11N04W25DDDD01	08-07-95	403	7.5	--	--	170	41	16
G3	11N04W36ACCA01	08-09-95	400	7.8	14.0	--	200	44	21
G4	11N03W14BBBB01	08-08-95	422	7.9	13.0	8.3	120	28	12
G5	11N03W16BBBB01	08-08-95	722	7.7	11.0	8.2	260	74	18
G6	11N03W17DDCC01	06-30-93	525	7.6	10.5	8.3	--	--	--
G7	11N03W18ADDD01	08-09-95	409	7.7	15.0	8.4	170	45	14
G8	11N03W22BBCB02	07-08-93	1,790	7.3	10.0	.9	550	120	59
G9	11N03W25DDBD01	06-29-93	433	6.8	10.0	2.9	--	--	--
G10	11N03W28DAAD01	08-07-95	630	7.6	11.0	2.0	260	80	15
G11	11N03W29ABBA01	06-28-93	615	7.6	10.0	4.3	--	--	--
G12	11N03W30DBCA01	06-28-93	688	7.3	9.5	6.9	--	--	--
G13	11N03W33ADDB01	08-07-95	755	7.0	12.0	3.1	330	97	21
G14	11N03W33BBAA02	07-08-93	504	7.0	8.0	1.4	210	61	15
G15	11N03W35DACC01	07-08-93	463	7.1	8.5	3.9	190	56	13
G16	11N02W31BCCB01	06-29-93	405	6.8	11.0	3.4	160	46	10
	Replicate[1]	06-29-93	413	7.0	--	--	150	44	10
G17	10N04W12AACD01	09-29-89	600	6.9	9.0	5.2	320	89	23
		08-10-95	671	7.3	9.0	6.6	--	--	--
G18	10N03W02BCDD01	06-30-93	394	7.1	10.0	2.8	170	51	11
G19	10N03W02DDDD03	08-14-90	480	7.1	12.0	--	210	62	14
		08-07-95	426	7.3	10.0	6.4	--	--	--
G20	10N03W16DCCC02	08-13-90	425	8.0	13.0	--	150	29	18
		08-08-95	387	8.0	13.0	6.7	--	--	--
G21	10N03W17ABBB01	08-07-95	508	6.5	12.5	--	210	70	9.7
G22	10N03W18AADA01	08-09-95	400	7.7	13.5	--	190	54	13
G23	10N03W24BBBC01	08-09-95	308	7.4	11.0	8.6	120	35	8.5
	Replicate[1]	08-09-95	307	7.3	--	--	120	36	8.4
G24	10N02W03BBAB01	08-08-95	398	7.9	11.5	7.8	110	34	6.0
G25	10N02W06AADC01	08-08-95	390	7.7	13.0	7.6	140	44	8.3
G26	10N02W07BBBB01	08-17-90	390	6.6	17.0	--	150	41	12
		08-07-95	328	7.5	14.0	3.9	--	--	--
G27	10N02W19ADBB01	08-10-95	404	7.5	13.5	6.8	160	48	9.7
--	Field blank[1]	08-10-95	2	7.6	--	--	--	.2	<.01

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[1] Quality-control sample. Specific conductance, pH, and alkalinity were measured in the laboratory.

[2] Filtered sample.

Table 8. Physical properties and inorganic-constituent concentrations in ground water from the Helena Valley, Montana (Continued)

Site number (fig. 3)	Location number	Sodium (mg/L as Na)	Sodium (percent)	Sodium adsorption ratio	Potassium (mg/L as K)	Bicarbonate, field (IT) (mg/L as HCO_3)	Carbonate, field (IT) (mg/L as CO_3)	Alkalinity, field (IT) (mg/L as $CaCO_3$)	Sulfate (mg/L as SO_4)
G1	11N04W25AABA01	20	22	0.7	3.4	157	0	129	33
G2	11N04W25DDDD01	20	20	.7	1.7	220	0	180	34
G3	11N04W36ACCA01	23	20	.7	1.6	187	0	153	85
G4	11N03W14BBBB01	47	45	2	2.7	186	0	153	91
G5	11N03W16BBBB01	47	28	1	2.9	186	0	153	120
G6	11N03W17DDCC01	--	45	--	--	224	0	184	--
G7	11N03W18ADDD01	22	22	.7	1.3	185	0	151	35
G8	11N03W22BBCB02	210	45	4	1.8	405	0	332	550
G9	11N03W25DDBD01	--	--	--	--	161	0	132	--
G10	11N03W28DAAD01	19	13	.5	11	272	0	223	110
G11	11N03W29ABBA01	--	--	--	--	293	0	240	--
G12	11N03W30DBCA01	--	--	--	--	309	0	253	--
G13	11N03W33ADDB01	27	15	.6	4.7	427	0	350	36
G14	11N03W33BBAA02	21	17	.6	2.9	205	0	168	71
G15	11N03W35DACC01	17	16	.6	3.2	202	0	165	51
G16	11N02W31BCCB01	19	21	.7	3.4	165	0	135	49
	Replicate[1]	19	21	.7	3.3	165	0	135	49
G17	10N04W12AACD01	18	11	.4	2.8	344	0	282	65
		--	--	--	--	--	--	--	--
G18	10N03W02BCDD01	13	14	.4	2.8	179	0	147	43
G19	10N03W02DDDD03	14	12	.4	3.5	197	0	162	78
		--	--	--	--	--	--	--	--
G20	10N03W16DCCC02	29	30	1	3.6	198	0	162	44
		--	--	--	--	--	--	--	--
G21	10N03W17ABBB01	27	21	.8	2.9	--	--	--	37
G22	10N03W18AADA01	22	20	.7	3.1	[2]212	[2]0	[2]174	77
G23	10N03W24BBBC01	14	19	.6	3.0	126	0	103	32
	Replicate[1]	15	20	.6	2.7	--	--	107	58
G24	10N02W03BBAB01	37	40	2	8.6	121	0	--	34
G25	10N02W06AADC01	26	27	.9	8.8	174	0	143	79
G26	10N02W07BBBB01	22	24	.8	3.8	173	0	142	37
		--	--	--	--	167	0	137	--
G27	10N02W19ADBB01	22	23	.8	3.0	187	0	153	36
--	Field blank[1]	<.2	--	--	<.1	--	--	1	<.10

Table 8. Physical properties and inorganic-constituent concentrations in ground water from the Helena Valley, Montana (Continued)

Site number (fig. 3)	Location number	Chloride (mg/L as Cl)	Fluoride (mg/L as F)	Dissolved solids, calculated (mg/L)	Nitrite (mg/L ss N)	Nitrite plus nitrate (mg/L as N)	Ammonia (mg/L as N)	Phosphorus, ortho (mg/L as P)
G1	11N04W25AABA01	12	1.1	199	<0.01	0.13	<0.015	0.02
G2	11N04W25DDDD01	12	.90	239	<.01	.87	<.015	<.01
G3	11N04W36ACCA01	9.0	1.0	283	<.01	1.4	<.015	.01
G4	11N03W14BBBB01	8.5	.50	283	<.01	.35	<.015	.01
G5	11N03W16BBBB01	52	.40	414	<.01	1.8	<.015	.01
G6	11N03W17DDCC01	13	--	--	--	--	--	--
G7	11N03W18ADDD01	6.5	.90	216	<.01	.07	<.015	<.01
G8	11N03W22BBCB02	71	.50	1,240	<.1	.87	--	<.1
G9	11N03W25DDBD01	11	--	--	--	--	--	--
G10	11N03W28DAAD01	25	.60	395	<.01	.11	.07	.03
G11	11N03W29ABBA01	13	--	--	--	--	--	--
G12	11N03W30DBCA01	11	--	--	--	--	--	--
G13	11N03W33ADDB01	17	.70	415	<.01	.36	.35	<.01
G14	11N03W33BBAA02	14	.35	311	<.1	--	--	<.1
G15	11N03W35DACC01	10	.22	281	<.1	--	--	<.1
G16	11N02W31BCCB01	12	.35	246	--	--	--	<.1
	Replicate[1]	12	.35	244	--	--	--	.15
G17	10N04W12AACD01	12	.44	410	--	--	--	<.1
		--	--	--	--	--	--	--
G18	10N03W02BCDD01	6.4	.26	246	<.1	--	--	<.1
G19	10N03W02DDDD03	9.6	.25	303	--	--	--	--
		--	--	--	--	--	--	--
G20	10N03W16DCCC02	15	.95	263	--	--	--	--
		--	--	--	--	--	--	--
G21	10N03W17ABBB01	41	.20	312	.03	.39	.14	<.01
G22	10N03W18AADA01	9.1	1.0	284	<.01	.14	.04	<.01
G23	10N03W24BBBC01	6.4	.60	161	<.01	<.05	<.015	.01
	Replicate[1]	11	.40	196	<.01	.05	<.015	<.01
G24	10N02W03BBAB01	12	1.0	192	--	--	--	--
G25	10N02W06AADC01	10	.80	264	<.01	.23	<.015	.02
G26	10N02W07BBBB01	12	1.1	237	--	--	--	--
		--	--	--	--	--	--	--
G27	10N02W19ADBB01	12	.70	225	<.01	.30	<.015	.05
--	Field blank[1]	<.10	<.10	--	<.01	<.05	<.015	<.01

Table 8. Physical properties and inorganic-constituent concentrations in ground water from the Helena Valley, Montana (Continued)

Site number (fig. 3)	Location number	Arsenic (µg/L as As)	Cadmium (µg/L as Cd)	Chromium (µg/L as Cr)	Copper (µg/L as Cu)	Lead (µg/L aa Pb)	Mercury (µg/L as Hg)	Selenium (µg/L as Se)	Zinc (µg/L as Zn)	Analyzing agency
G1	11N04W25AABA01	3	<1	<1	<1	<1	<0.1	<1	5	USGS
G2	11N04W25DDDD01	<1	<1	<1	<1	<1	<.1	<2	--	USGS
G3	11N04W36ACCA01	6	<1	<1	<1	<1	<.1	<1	3	USGS
G4	11N03W14BBBB01	3	<1	<1	<1	<1	<.1	<1	<3	USGS
G5	11N03W16BBBB01	2	<1	<1	3	<1	.1	1	12	USGS
G6	11N03W17DDCC01	2	--	--	--	--	--	--	--	MBMG
G7	11N03W18ADDD01	2	<1	<1	<1	<1	<.1	<1	7	USGS
G8	11N03W22BBCB02	4	<2	<2	<2	<3	--	3	<2	MBMG
G9	11N03W25DDBD01	1	--	--	--	--	--	--	--	MBMG
G10	11N03W28DAAD01	16	<1	1	2	<1	<.1	<1	<3	USGS
G11	11N03W29ABBA01	2	--	--	--	--	--	--	--	MBMG
G12	11N03W30DBCA01	3	--	--	--	--	--	--	--	MBMG
G13	11N03W33ADDB01	6	<1	1	<1	<1	<.1	<1	7	USGS
G14	11N03W33BBAA02	1	<2	<2	<2	<3	--	<1	<2	MBMG
G15	11N03W35DACC01	1	<2	<2	<2	<3	--	<1	<2	MBMG
G16	11N02W31BCCB01	<1	<2	<2	<2	<3	--	<1	15	MBMG
	Replicate[1]	1	2	2	2	3	--	1	18	MBMG
G17	10N04W12AACD01	--	<5	<5	<4	--	--	--	11	USGS
		3	--	--	--	--	--	--	--	
G18	10N03W02BCDD01	1	<2	<2	<2	<3	--	<1	29	MBMG
G19	10N03W02DDDD03	--	<5	<5	<4	--	--	--	<6	USGS
		1	--	--	--	--	--	--	--	
G20	10N03W16DCCC02	--	<5	<5	<4	--	--	--	<6	USGS
		5	--	--	--	--	--	--	--	
G21	10N03W17ABBB01	<1	<1	<1	2	<1	<.1	<1	--	USGS
G22	10N03W18AADA01	<1	<1	<1	--	<1	<.1	<1	5	USGS
G23	10N03W24BBBC01	1	<1	<1	<1	<1	<.1	<1	<3	USGS
	Replicate[1]	1	<1	<1	<1	<1	--	<1	<3	USGS
G24	10N02W03BBAB01	22	<1	<1	<1	<1	--	<1	5	USGS
G25	10N02W06AADC01	17	<1	<1	<1	<1	<.1	<1	55	USGS
G26	10N02W07BBBB01	--	<5	<5	<4	--	--	--	<6	USGS
		2	--	--	--	--	--	--	--	
G27	10N02W19ADBB01	1	<1	<1	<1	<1	<.1	<1	20	USGS
--	Field blank[1]	<1	<1	<1	<1	<1	<.1	<1	<3	USGS

Table 9. Inorganic-constituent concentrations in bottom sediment from Lake Helena, Montana

[Samples collected July 6, 1995. Analyses by the U.S. Geological Survey. Analyses conducted on sediment fraction finer than 0.063 millimeter diameter. All concentrations are total. Abbreviations: µg/g, microgram per gram of dry sample weight; percent, percent of dry sample weight. Symbol: <, less than; --, no data]

Inorganic conatituent	Site S10, Lake Helena (west)	Site S11, Lake Helena (south)	Site S12, Lake Helena (north)	Helena Valley soil, geometric mean[1]
MAJOR IONS				
Calcium (percent)	4.0	6.7	4.1	--
Magnesium (percent)	1.4	1.4	1.5	--
Phosphorus (percent)	.14	.19	.14	--
Potassium (percent)	1.9	1.9	1.9	--
Sodium (percent)	1.2	1.5	1.2	--
TRACE ELEMENTS				
Aluminum (percent)	6.2	6.4	6.3	12
Arsenic (µg/g)	46	18	34	[2]42
Barium (µg/g)	600	580	600	132
Berylliu (µg/g)	2	2	2	.9
Cadmium (µg/g)	4	<2	4	[2]7
Chromium (µg/g)	43	47	45	13
Cobalt (µg/g)	12	13	12	8.6
Copper (µg/g)	77	47	82	[2]41
Iron (percent)	3.1	3.5	3.2	14
Lead (µg/g)	170	38	170	[2]200
Lithium (µg/g)	35	33	37	--
Manganese (µg/g)	610	760	630	[2]460
Mercury (µg/g)	.48	.06	.32	[2].71
Molybdenum (µg/g)	<2	<2	<2	--
Nickel (µg/g)	17	17	17	11
Silver (µg/g)	<2	<2	<2	[2].7
Strontium (µg/g)	280	420	270	--
Uranium (µg/g)	<100	<100	<100	--
Vanadium (µg/g)	83	100	86	25
Zinc (µg/g)	590	200	600	140

[1] Geometric mean of 157 samples (U.S. Environmental Protection Agency, 1987).

[2] Enriched above Helena Valley background concentration (U.S. Environmental Protection Agency, 1987, p. 3.6).

Table 10. Montana water quality maximum guideline concentrations for selected water uses

[Abbreviations: µg/L, micrograms per liter; mg/L, milligrams per liter. Symbol: --, no guideline concentration has been adopted]

Constituent	Maximum guideline concentration for indicated water use				
	Human consumption[1]	Aquatic life[1]		Irrigation[2]	Livestock watering[2]
		Acute	Chronic		
		TRACE ELEMENTS			
Arsenic (µg/L)	18	360	190	100	200
Cadmium (µg/L)	5	[3]3.9	[3]1.1	50	50
Chromium (µg/L)	100	--	--	1,000	--
Copper (µg/L)	1,000	[3]18	[3]12	5,000	500
Iron (µg/L)	300	--	1,000	20,000	--
Lead (µg/L)	15	[3]82	[3]3.2	10,000	100
Manganese (µg/L)	50	--	--	10,000	--
Mercury (µg/L)	.14	2.4	.012	--	10
Selenium (µg/L)	50	20	5	20	50
		NUTRIENTS			
Nitrogen, ammonia (mg/L)[4]	--	[5].15	[5].02	--	--
Nitrogen, nitrite (mg/L)[4]	1	--	--	--	10
Nitrogen, nitrite plus nitrate (mg/L)[4]	10	--	--	--	100
Phosphorus, orthophosphate (mg/L)[4]	--	--	--	--	--

[1] Montana Department of Environmental Quality (1995).

[2] Montana Department of Health and Environmental Science (1986, p. 8).

[3] Specific criteria for the protection of aquatic life are based on a water hardness of 100 milligrams per liter as calcium carbonate.

[4] A plant nutrient, excessive amounts of which may cause violations of Administrative Rules of Montana (ARM) 16.20.633.(1)(e).

[5] Specific criteria for the protection of aquatic life are based on a pH of between 8 and 9 and a temperature of less than 15 degrees Celsius.

Wildlife Service (unpubl. data). Abbreviations: DDD, dichlorodiphenydichloroethane; DDE, dichlorodiphenyldichloroethylene; µg/g, micrograms per gram; NC, not calculable because more than half of the samples had concentrations below the detection limit; PCB, polychlorinated biphenyl. Symbols: --, no minimum reported in cited reference; <, less than]

Constituent	Number of samples	Concentration (µg/g)			Sampling location[1]	Wet or dry weight	Source of information
		Minimum	Maximum	Geometric mean			
			AQUATIC INVERTEBRATES				
Arsenic	359	<0.2	53	1.5	Montana	dry	4
	8	.94	30	5.8	Milltown Reservoir	dry	1
Cadmium	398	<.1	3.4	NC	Montana	dry	4
	8	.40	12	2.6	Milltown Reservoir	dry	1
Copper	399	<.5	260	19	Montana	dry	4
	8	34	130	74	Milltown Reservoir	dry	1
Lead	399	<.5	20	NC	Montana	dry	4
	8	<4	20	NC	Milltown Reservoir	dry	1
Zinc	399	<2	340	98	Montana	dry	4
	8	120	1,400	520	Milltown Reservoir	dry	1
			FISH				
Arsenic	128	<.09	21	NC	Montana	dry	4
	315	<.09	1.5	.14	United States	wet	2
Cadmium	128	<.09	.31	NC	Montana	dry	4
	315	--	.22	.03	United States	wet	2
Copper	128	<2	88	4.9	Montana	dry	4
	315	--	23	.65	United States	wet	2
Lead	128	<.5	4.1	NC	Montana	dry	4
	315	-	4.9	.11	United States	wet	2
Zinc	128	29	320	97	Montana	dry	4
	315	--	120	22	United States	wet	2
p,p'-DDD	321	--	2.6	.06	United States	wet	3
p,p'-DDE	321	--	4.7	.19	United States	wet	3
Total PCB's	321	---	6.7	.39	United States	wet	3
			MALLARD LIVERS				
Arsenic	7	<.2	.13	NC	Montana	dry	4
Cadmium	7	<.1	2.1	NC	Montana	dry	4
Copper	7	19	150	56	Montana	dry	4
Lead	7	<.5	4.8	NC	Montana	dry	4
Zinc	7	110	190	150	Montana	dry	4
			NORTHERN SHOVELER LIVERS				
Arsenic	12	<.3	<.5	NC	Montana	dry	4
Cadmium	14	<.1	6.0	.58	Montana	dry	4
Copper	14	8.0	230	31	Montana	dry	4
Lead	14	<.5	.70	NC	Montana	dry	4
Zinc	14	79	150	110	Montana	dry	4

[1] Samples from "Montana" were collected from presumably unimpaired National Wildlife Refuges, Waterfowl Production Areas, and Wildlife Management Areas in Montana. Samples from "Milltown Reservoir" were collected from the Milltown Reservoir Sediments Superfund Site. This site presumably is impaired. Samples from the "United States" were collected nationwide.

Table 12. Risk levels associated with harmful effects of selected trace elements and organochlorine compounds on biota

[Abbreviations: µg/g, micrograms per gram; PCB, polychlorinated biphenyl. Symbol: >, greater than]

Constituent	Risk level	Source of Information
Arsenic	30 µg/g (weight basis unknown) in ration adversely affects growth in ducklings	Eisler (1994, p. 232)
	1.3 µg/g wet weight in muscle of immature bluegills is associated with diminished growth and survival	Eisler (1994, p. 246)
	2-10 µg/g wet weight in liver or kidney of birds is considered elevated	Eisler (1994, p. 246)
Cadmium	0.100 µg/g wet weight in diet is potentially harmful if consumed by wildlife on a sustained basis	Eisler (1985, p. 34)
	10.0 µg/g wet weight in vertebrate liver or kidney is evidence of poisoning	Eisler (1985, p. 34)
Lead	>2 µg/g wet weight in waterfowl liver is considered elevated	Eisler (1988, p. 103)
	>8 µg/g wet weight in waterfowl liver is evidence of poisoning	Eisler (1988, p. 103)
	0.3 µg/g wet weight is maximum allowable in human diet	Eisler (1988, p. 105)
Zinc	>2,100 µg/g dry weight in bird liver or kidney is indicative of poisoning	Eisler (1993, p. 3)
Total PCB's	5.0 µg/g wet weight is maximum allowable in fish eaten by humans	Eisler (1986, p. 58)

Table 13. Trace-element concentrations in aquatic invertebrates from the Helena Valley, Montana

[Site number: Letter preceeding number indicates medium type (B, biota). All samples are composites representing multiple species, including daphnia (Order Cladocera) and waterboatmen (Order Hemiptera). Concentrations in micrograms per gram of dry sample weight. All concentrations are total. Symbol: <, less than]

Site number (fig. 3)	Sample identification	Date	Moisture content[1] (percent)	Aluminum	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Copper
B2	RRIN0395	08/16/95	89.2	1,016	4.2	19.4	<0.1	<2.0	2.1	4.9	19.6
B2	RRIN0295	08/16/95	92.2	1,324	5.1	23.4	<.1	<2.0	2.3	2.8	18.8
B2	RRIN0195	08/16/95	88.4	658	3.7	9.8	<.1	5.4	1.9	2.6	18.2
B2	RRIN0495	08/16/95	92.9	1,441	5.5	23.4	<.1	2.5	2.1	1.0	18.1
B8	LHIN0395	08/16/95	78.4	229	1.6	26.6	<.1	<2.0	.2	<.5	28.9
B8	LHIN0295	08/16/95	77.8	152	1.0	43.7	<.1	<2.0	.2	.5	28.1
B8	LHIN0195	08/16/95	76.2	140	.6	46.0	<.1	<2.0	.1	<.5	29.9

Site number (fig. 3)	Sample identification	Iron	Lead	Magnesium	Manganese	Mercury	Molybdenum	Nickel	Selenium	Strontium	Vanadium	Zinc
B2	RRIN0395	824	1.9	1,272	57.9	0.13	2.2	1.8	2.2	50.4	1.6	105
B2	RRIN0295	993	1.9	1,420	60.5	.17	<2.0	.6	2.0	102	2.1	102
B2	RRIN0195	524	1.1	1,079	46.4	<.05	<2.0	<.5	2.5	26.6	1.0	104
B2	RRIN0495	1,059	2.3	1,436	63.0	.12	<2.0	<.5	2.0	82.6	2.2	98.7
B8	LHIN0395	263	.5	1,173	32.3	.09	<2.0	<.5	1.7	42.0	<.5	149
B8	LHIN0295	239	<.5	1,083	27.9	.09	<2.0	<.5	1.5	10.9	.5	130
B8	LHIN0195	223	<.5	1,059	28.4	.08	<2.0	<.5	1.4	10.9	<.5	143

[1] To convert from concentration of dry sample weight to concentration of wet sample weight, use the equation: concentration of wet sample weight = concentration of dry sample weight x [1 - (moisture content in percent x 0.01)].

Table 14. Trace-element concentrations in fish from the Helena Valley, Montana

[Site number: Letter preceeding number indicates medium type (B, biota). Concentrations in micrograms per gram of dry sample weight. All concentrations are total. Symbol: <, less than]

Site number (fig. 3)	Sample identification	Date	Taxon	Moisture content[1] (percent)	Aluminum	Arsenic	Barium	Beryllium	Boron	Cadmium	Chromium	Copper
B2	RRC0195	08/16/95	CARP	80.9	71.2	1.2	10.3	<0.1	<2.0	0.3	<0.5	5.4
B2	RRC0295	08/31/95	CARP	81.3	75.9	1.8	9.5	<.1	<2.0	.3	.6	4.8
B2	RRC0395	08/31/95	CARP	80.6	96.2	2.4	9.4	<.1	<2.0	.3	<.5	4.9
B4	TMS0195	08/15/95	LONGNOSE SUCKER	81.8	1,289	5.5	36.7	<.1	<2.0	.8	5.4	10.1
B5	PPS0195	08/17/95	LONGNOSE SUCKER	82.8	779	2.7	22.7	<.1	<2.0	.7	2.5	9.0
B6	LH9501C	06/30/95	CARP	63.9	172	.9	5.6	<.1	<2.0	.1	<.5	3.6
B6	LH9503C	06/30/95	CARP	68.9	74.6	.7	4.0	<.1	<2.0	<.1	<.5	5.5
B6	LH9505C	06/30/95	CARP	67.1	161	.8	4.1	<.1	<2.0	.1	.7	5.0
B6	LH9502C	06/30/95	CARP	64.2	142	1.1	3.8	<.1	<2.0	.1	<.5	4.3
B6	LH9504C	06/30/95	CARP	66.1	36.1	<.5	<1.0	.2	<2.0	<.1	<.5	3.5
B7	SCC0195	08/31/95	CARP	81.1	200	1.0	9.4	<.1	<2.0	<.1	1.8	3.6
B8	LHC0195	08/16/95	CARP	83.5	380	1.4	11.6	<.1	<2.0	<.1	.3	4.6
B8	LHC0395	08/31/95	CARP	82.0	170	.8	10.3	<.1	<2.0	<.1	1.0	5.6
B8	LHC0295	08/31/95	CARP	82.3	246	1.5	12.1	<.1	2.5	<.1	.6	5.5

Site number (fig. 3)	Sample identification	Iron	Lead	Magnesium	Manganese	Mercury	Molybdenum	Nickel	Selenium	Strontium	Vanadium	Zinc
B2	RRC0195	132	<0.5	1,384	20.1	0.3	<2.0	1.5	1.5	68.4	<0.5	186
B2	RRC0295	134	.5	1,477	14.7	.3	<2.0	<.5	1.5	70.4	<.5	179
B2	RRC0395	152	<.5	1,435	25.5	.3	<2.0	1.7	.6	75.2	<.5	170
B4	TMS0195	1,514	4.5	2,047	204.1	.2	<2.0	2.4	1.8	58.6	5.6	198
B5	PPS0195	872	8.8	1,790	58.0	.2	<2.0	<.5	1.6	49.4	2.4	160
B6	LH9501C	242	1.9	882	14.8	.1	<2.0	2.4	1.0	36.5	.8	265
B6	LH9503C	217	1.2	964	22.7	.1	<2.0	3.2	1.5	34.9	2.4	249
B6	LH9505C	289	2.0	911	15.0	.2	<2.0	.6	1.6	38.7	1.3	326
B6	LH9502C	248	1.3	794	12.7	.1	<2.0	2.8	1.0	27.0	2.4	188
B6	LH9504C	110	.6	578	6.3	.3	<2.0	.7	1.3	10.4	1.2	497
B7	SCC0195	236	<.5	1,468	12.8	.2	<2.0	<.5	1.9	58.8	2.2	152
B8	LHC0195	350	.8	1,774	23.4	.1	<2.0	<.5	1.9	66.1	1.9	196
B8	LHC0395	208	<.5	1,608	12.5	.1	<2.0	<.5	1.7	66.4	<.5	161
B8	LHC0295	279	.5	1,655	14.1	.1	<2.0	<.5	1.8	67.2	1.5	174

[1] To convert from concentration of dry sample weight to concentration of wet sample weight, use the equation:
concentration of wet sample weight = concentration of dry sample weight x [1 - (moisture content in percent x 0.01)].

Table 15. Trace-element concentrations in water-bird livers from the Helena Valley Regulating Reservoir, Montana

[Site number: Letter preceeding number indicates medium type (B, biota). Concentrations in micrograms per gram of dry sample weight. All concentrations are total. Symbol: <, less than]

Site number (fig. 3)	Sample identification	Date	Taxon	Moisture content[1] (percent)	Aluminum	Arsenic	Barium	Beryllyum	Boron	Cadmium	Chromium	Copper
B1	RRML0495	08/11/95	MALLARD	73.8	<5.0	<0.5	<1.0	<0.1	<2.0	1.5	<0.5	140
B1	RRML0395	08/11/95	MALLARD	72.5	<5.0	1.0	<1.0	<.1	<2.0	1.4	<.5	131
B1	RRML0295	08/11/95	MALLARD	71.8	<5.0	1.0	<1.0	<.1	<2.0	1.4	<.5	180
B1	RRML0195	08/11/95	MALLARD	74.1	<5.0	1.1	<1.0	<.1	<2.0	1.6	<.5	150
B3	RRSL0195	08/11/95	NORTHERN SHOVELER	70.6	<5.0	<.5	<1.0	<.1	<2.0	3.1	<.5	29.2

Site number (fig. 3)	Sample identification	Iron	Lead	Magnesium	Manganese	Mercury	Molybdenum	Nickel	Selenium	Strontium	Vanadium	Zinc
B1	RRML0495	1,135	<0.5	652	11.8	0.4	2.9	<0.5	19.0	<0.5	0.5	139
B1	RRML0395	1,197	<.5	702	12.0	.4	2.4	<.5	19.5	<.5	.6	130
B1	RRML0295	1,446	<.5	677	15.6	.4	2.6	<.5	21.1	<.5	.9	150
B1	RRML0195	1,493	<.5	679	12.1	.4	<2.0	.9	20.1	<.5	1.1	137
B3	RRSL0195	4,659	<.5	661	13.2	4.3	5.8	1.2	5.5	<.5	1.8	135

[1] To convert from concentration of dry sample weight to concentration of wet sample weight, use the equation:
concentration of wet sample weight = concentration of dry sample weight x [1 - (moisture content in percent x 0.01)].

Table 16. Organochlorine-compound concentrations in fish from the Helena Valley, Montana

[Site number: Letter preceding number indicates medium type (B, biota). Concentrations in micrograms per gram of wet sample weight. All concentrations are total. Abbreviations: BHC, benzenehexachloride; DDD, dichlorodiphenyldichloroethane; DDE, dichlorodiphenyldichloroethylene; DDT, dichlorodiphenyltrichloroethane; HCB, hexachlorobenzene; PCB, polychlorinated biphenyl. Symbol: <, less than]

Site number (fig. 3)	Sample identification	Date	Taxon	Moisture content[1] (percent)	Aldrin	Alpha-BHC	Beta-BHC	Delta-BHC	Gamma-BHC	Alpha-chlordane
B2	RRC0195	08/16/95	CARP	80.9	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010	<0.0010
B2	RRC0295	08/31/95	CARP	81.3	<.0010	<.0010	<.0010	<.0010	<.0010	<.0010
B2	RRC0395	08/31/95	CARP	80.6	<.0009	<.0010	<.0009	<.0009	<.0009	<.0009
B4	TMS0195	08/15/95	LONGNOSE SUCKER	81.8	<.0010	<.0010	<.0010	<.0010	<.0010	<.0010
B5	PPS0195	08/17/95	LONGNOSE SUCKER	82.8	<.0009	<.0009	<.0009	<.0009	<.0009	<.0009
B6	LH9502C	06/30/95	CARP	63.9	<.0002	.0010	.0003	.0016	.0009	.0042
B6	LH9503C	06/30/95	CARP	68.9	.0003	.0005	<.0002	.0011	.0006	.0039
B6	LH9504C	06/30/95	CARP	67.1	<.0002	.0006	<.0002	<.0002	.0010	.0054
B6	LH9501C	06/30/95	CARP	64.2	.0006	.0007	<.0002	.0012	.0008	.0032
B6	LH9505C	06/30/95	CARP	66.1	<.0002	.0005	<.0002	.0008	.0008	.0064
B7	SCC0195	08/31/95	CARP	81.1	<.0010	<.0010	<.0010	<.0010	<.0010	<.0010
B8	LHC0395	08/31/95	CARP	83.5	<.0010	<.0010	<.0010	<.0010	<.0010	<.0010
B8	LHC0195	08/16/95	CARP	82.0	<.0009	<.0009	<.0009	<.0009	<.0009	<.0009
B8	LHC0295	08/31/95	CARP	82.3	<.0010	<.0010	<.0010	<.0010	<.0010	<.0010

Site number (fig. 3)	Sample identification	Taxon	Gamma-chlordane	o,p'-DDD	p,p'-DDD	o,p'-DDE	p,p'-DDE	o,p'-DDT	p,p'-DDT
B2	RRC0195	CARP	<0.0010	<0.0010	<0.0010	<0.0010	0.0010	<0.0010	<0.0010
B2	RRC0295	CARP	<.0010	.0011	.0011	<.0010	<.0010	.0011	<.0010
B2	RRC0395	CARP	<.0009	<.0009	.0009	<.0009	<.0010	.0009	<.0009
B4	TMS0195	LONGNOSE SUCKER	<.0010	<.0010	<.0010	<.0010	.0027	<.0010	<.0010
B5	PPS0195	LONGNOSE SUCKER	<.0009	<.0009	<.0009	<.0009	.0019	<.0009	<.0009
B6	LH9502C	CARP	.0046	.0052	.0183	.0005	.0176	.0011	<.0002
B6	LH9503C	CARP	.0024	.0035	.0170	.0003	.0165	.0010	.0011
B6	LH9504C	CARP	.0035	.0087	.0246	<.0002	.0334	.0013	.0013
B6	LH9501C	CARP	.0041	.0029	.0130	.0021	.0124	.0008	.0008
B6	LH9505C	CARP	.0049	.0049	.0313	<.0002	.0490	.0024	.0024
B7	SCC0195	CARP	<.0010	<.0010	<.0010	<.0010	.0014	<.0010	<.0010
B8	LHC0395	CARP	<.0010	<.0010	<.0010	<.0010	.0013	<.0010	<.0010
B8	LHC0195	CARP	<.0009	<.0009	<.0009	<.0009	.0021	<.0009	<.0009
B8	LHC0295	CARP	<.0010	<.0009	<.0009	<.0009	.0011	<.0009	<.0009

Table 16. Organochlorine-compound concentrations in fish from the Helena Valley, Montana (Continued)

Site number (fig. 3)	Sample identification	Date	Taxon	Dieldrin	Endosulfan II	Endrin	HCB	Heptachlor	Heptachlor epoxide
B2	RRC0195	08/16/95	CARP	0.0018	<0.0019	<0.0010	<0.0010	<0.0010	<0.0010
B2	RRC0295	08/31/95	CARP	<.0012	<.0020	<.0010	<.0010	<.0010	<.0010
B2	RRC0395	08/31/95	CARP	<.0009	<.0020	<.0009	<.0009	<.0009	<.0009
B4	TMS0195	08/15/95	LONGNOSE SUCKER	<.0010	<.0020	<.0010	<.0010	<.0010	<.0010
B5	PPS0195	08/17/95	LONGNOSE SUCKER	<.0009	<.0019	<.0009	<.0009	<.0009	<.0009
B6	LH9502C	06/30/95	CARP	.0031	.0007	.0006	.0016	<.0002	.0006
B6	LH9503C	06/30/95	CARP	.0016	.0005	<.0002	.0007	<.0002	.0003
B6	LH9504C	06/30/95	CARP	.0025	.0006	<.0002	.0014	<.0002	.0008
B6	LH9501C	06/30/95	CARP	.0025	<.0004	.0003	.0014	<.0002	.0005
B6	LH9505C	06/30/95	CARP	.0013	<.0004	<.0002	.0013	<.0002	.0007
B7	SCC0195	08/31/95	CARP	<.0010	<.0019	<.0010	<.0010	<.0010	<.0010
B8	LHC0395	08/31/95	CARP	<.0010	<.0020	<.0010	<.0010	<.0010	<.0010
B8	LHC0195	08/16/95	CARP	<.0009	<.0018	<.0009	<.0009	<.0009	<.0009
B8	LHC0295	08/31/95	CARP	<.0015	<.0019	<.0010	<.0010	<.0010	<.0010

Site number (fig. 3)	Sample identification	Taxon	Mirex	Cis-nonachlor	Transnonachlor	Oxychlordane	Total PCB's
B2	RRC0195	CARP	<0.0010	<0.0010	<0.0010	<0.0010	0.0240
B2	RRC0295	CARP	<.0010	<.0010	<.0010	<.0010	.0167
B2	RRC0395	CARP	<.0009	<.0009	<.0009	<.0009	.0141
B4	TMS0195	LONGNOSE SUCKER	<.0010	<.0010	<.0010	<.0010	.1097
B5	PPS0195	LONGNOSE SUCKER	<.0009	<.0009	<.0009	<.0009	.0344
B6	LH9502C	CARP	<.0002	.0029	.0033	.0010	.3241
B6	LH9503C	CARP	<.0002	<.0027	.0036	<.0002	.2810
B6	LH9504C	CARP	.0002	<.0039	.0049	.0012	.4342
B6	LH9501C	CARP	<.0002	<.0019	.0024	.0006	.2023
B6	LH9505C	CARP	.0007	<.0051	.0064	.0013	.6139
B7	SCC0195	CARP	<.0010	<.0010	<.0010	<.0010	.0222
B8	LHC0395	CARP	<.0010	<.0010	<.0010	<.0010	.0328
B8	LHC0195	CARP	<.0009	<.0009	<.0009	<.0009	.0499
B8	LHC0295	CARP	<.0010	<.0010	<.0010	<.0010	.0235

[1] To convert from concentration of dry sample weight to concentration of wet sample weight, use the equation: concentration of wet sample weight = concentration of dry sample weight x [1 - (moisture content in percent x 0.01)].

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