

Effects of Surface Applications of Biosolids on Soil, Crops, Ground Water, and Streambed Sediment near Deer Trail, Colorado, 1999–2003

By Tracy J.B. Yager, David B. Smith, and James G. Crock

Prepared in cooperation with the
Metro Wastewater Reclamation District and the
North Kiowa Bijou Groundwater Management District

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Conversion Factors, Vertical Datum, Abbreviations, and Acronyms

Multiply	By	To obtain
micrometer (µm)	0.00003937	inch
millimeter (mm)	0.03937	inch
centimeter (cm)	0.3937	inch
inch	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
meter (m)	3.281	foot (ft)
mile (mi)	1.609	kilometer
acre	0.4047	hectares
square meter (m ²)	0.0002471	acre
square mile (mi ²)	2.590	square kilometer
milliliter (mL)	0.0610	cubic inch
liter (L)	0.2642	gallon (gal)
gallon (gal)	3.785	liter (L)
milligram (mg)	0.00003527	ounce, avoirdupois
gram (g)	0.03527	ounce, avoirdupois
kilogram (kg)	2.205	pound, avoirdupois
ton, short (2,000 lb)	0.9072	megagram
acre-foot per year (acre-ft/yr)	1,233	cubic meter per year
foot per year (ft/yr)	0.3048	meter per year
gallon per minute (gal/min)	0.06309	liter per second
gram per cubic centimeter (g/cm ³)	62.4220	pound per cubic foot

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

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

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

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

Additional Abbreviations and Acronyms

ft ² /min	foot squared per minute
µg/L	micrograms per liter
µm	micrometers
µS/cm	microsiemens per centimeter at 25 degrees Celsius
mg/kg	milligrams per kilogram
mg/L	milligrams per liter
pCi/g	picocuries per gram
pCi/L	picocuries per liter

CDPHE	Colorado Department of Public Health and Environment
DCPs	data collection platforms
Eco-SSLs	ecological soil screening levels
EDL	electronic data logger
EPA	Environmental Protection Agency
LFH-HU	Laramie-Fox Hills hydrostratigraphic unit
MDC	minimum detectable concentration
MRI	magnetic resonance imaging
MRL	minimum reporting limit
MWRD	Metro Wastewater Reclamation District
NWIS	National Water Information System
NWQL	National Water Quality Laboratory
US	United States
USGS	United States Geological Survey

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

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

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

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius.

Concentrations of chemical constituents in water are given in milligrams per liter (mg/L), micrograms per liter ($\mu\text{g/L}$), or picocuries per liter (pCi/L).

Effects of Surface Applications of Biosolids on Soil, Crops, Ground Water, and Streambed Sediment near Deer Trail, Colorado, 1999–2003

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Abstract

The U.S. Geological Survey, in cooperation with Metro Wastewater Reclamation District and North Kiowa Bijou Groundwater Management District, studied natural geochemical effects and the effects of biosolids applications to the Metro Wastewater Reclamation District properties near Deer Trail, Colorado, during 1999 through 2003 because of public concern about potential contamination of soil, crops, ground water, and surface water from biosolids applications. Parameters analyzed for each monitoring component included arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc (the nine trace elements regulated by Colorado for biosolids), gross alpha and gross beta radioactivity, and plutonium, as well as other parameters.

Concentrations of the nine regulated trace elements in biosolids were relatively uniform and did not exceed applicable regulatory standards. All plutonium concentrations in biosolids were below the minimum detectable level and were near zero. The most soluble elements in biosolids were arsenic, molybdenum, nickel, phosphorus, and selenium. Elevated concentrations of bismuth, mercury, phosphorus, and silver would be the most likely inorganic biosolids signature to indicate that soil or streambed sediment has been affected by biosolids. Molybdenum and tungsten, and to a lesser degree antimony, cadmium, cobalt, copper, mercury, nickel, phosphorus, and selenium, would be the most likely inorganic “biosolids signature” to indicate ground water or surface water has been affected by biosolids.

Soil data indicate that biosolids have had no measurable effect on the concentration of the constituents monitored. Arsenic concentrations in soil of both Arapahoe and Elbert County monitoring sites (like soil from all parts of Colorado) exceed the Colorado soil remediation objectives and soil cleanup standards, which were determined by back-calculating a soil concentration equivalent to a one-in-a-million cumulative cancer risk. Lead concentrations in soil slightly exceed the U.S. Environmental Protection Agency toxicity-derived ecological soil-screening levels for avian wildlife. Plutonium concentration in the soil was near zero.

Wheat-grain data were insufficient to determine any measurable effects from biosolids. Comparison with similar data from other parts of North America where biosolids were not applied indicates similar concentrations. However, the Deer Trail study area had higher nickel concentrations in wheat from both the biosolids-applied fields and the control fields. Plutonium content of the wheat was near zero.

Ground-water levels generally declined at most wells during 1999 through 2003. Ground-water quality did not correlate with ground-water levels. Vertical ground-water gradients during 1999 through 2003 indicate that bedrock ground-water resources downgradient from the biosolids-applied areas are not likely to be contaminated by biosolids applications unless the gradients change as a result of pumping.

Ground-water quality throughout the study area varied over time at each site and from site to site at the same time, but plutonium concentrations in the ground water always were near zero. Inorganic concentrations at well D6 were relatively high compared to other ground-water sites studied. Ground-water pH and concentrations of fluoride, nitrite, aluminum, arsenic, barium, chromium, cobalt, copper, lead, mercury, nickel, silver, zinc, and plutonium in the ground water of the study area met Colorado standards. Concentrations of chloride, sulfate, nitrate, boron, iron, manganese, and selenium exceeded Colorado ground-water standards at one or more wells. Nitrate concentrations at well D6 significantly ($\alpha = 0.05$) exceeded the Colorado regulatory standard. Concentrations of arsenic, cadmium, chromium, lead, mercury, nickel, and zinc in ground water had no significant ($\alpha = 0.05$) upward trends. During 1999–2003, concentrations of nitrate, copper, molybdenum, and selenium had significant ($\alpha = 0.05$) upward trends at one or more wells. The upward trend in nitrate concentration (well D6) could be caused, in part, by biosolids applications. Concentrations of biosolids-signature elements in the ground water indicate that ground water at wells D6, D25, DTX1, and possibly DTX2 and D17 are more likely affected by biosolids applications than ground water at the other monitoring wells of the study area. However, these results are not conclusive because of natural contributions from geochemical sources and likely old apparent ground-water ages at wells D6, D17,

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and D25. Additional age dating of the ground water could further indicate whether biosolids could have affected ground-water concentrations in the study area.

Few paired streambed-sediment samples could be collected during 1999 through 2003 because runoff was infrequent in the designated biosolids-applied and control basins; relatively less sediment usually was deposited in the biosolids-applied basin than in the control basin. No appropriate sediment regulatory standards are available for these sediment data, but trace-element concentrations are consistent with concentrations in uncontaminated soil. Plutonium concentrations were near zero. Concentrations of ammonia plus organic nitrogen, organic carbon, copper, lead, mercury, and silver were significantly ($\alpha < 0.10$) greater in sediment of the biosolids-applied basin than that of the control basin. Of the biosolids-signature elements, only copper, mercury, and silver concentrations were significantly ($\alpha < 0.10$) higher in sediment samples from the biosolids-applied basin than in sediment samples from the control basin, although no samples were analyzed for bismuth and only about one-half the sample pairs were analyzed for silver and uranium. Natural geochemical differences between the two basins could account for apparent differences in trace-element composition between the two basins.

A signature based not on inorganic- or radioactive-constituent concentrations is needed to help differentiate the effects of biosolids from the effects of natural geochemistry on all the monitoring components. Some other property or chemical presence, such as pharmaceutical or other anthropogenic organic compounds, that is not possibly characteristic of natural soil, rock, ground water, surface water, or sediment of the area is needed to determine if biosolids could possibly have affected concentrations in the study area.

Introduction

Since 1993, the Metro Wastewater Reclamation District (MWRD) has been applying biosolids resulting from the treatment of domestic sewage from the Denver metropolitan area to their property near Deer Trail, Colo. The biosolids are transported by truck about 75 mi east from Denver to the MWRD property and are applied to nonirrigated farmland. From 1993 through 1999, the U.S. Geological Survey (USGS), in cooperation with the MWRD, monitored the quality of shallow ground water on the MWRD central property (fig. 1), which encompassed about 15 mi². This was the first property the MWRD purchased near Deer Trail. In 1995, the MWRD traded some of the property and acquired additional property in the same area. The new property consisted of about 14.5 mi² known as the north property and about 50 mi² known as the south property. In 1999, the three MWRD properties together, known as the METROGRO Farm, encompassed about 81 mi² (52,000 acres) of farmland, including land in Arapahoe and Elbert Counties. The three MWRD properties and surrounding private property are hereinafter referred to as “the study area” (fig. 1).

Public concern about applications of biosolids to farmland increased after the MWRD agreed to accept treated ground water from the Lowry Landfill Superfund site in Denver. The concern was that water from the Lowry Superfund site might contain radionuclides that would then contaminate the MWRD biosolids. During 1998, the USGS worked with the MWRD and other stakeholders and designed a new, more comprehensive monitoring program for the biosolids-application area near Deer Trail, Colo. In January 1999, the USGS began the new monitoring program in cooperation with the MWRD and the North Kiowa Bijou Groundwater Management District. The USGS refers to the new monitoring program (1999 through 2004) as the “expanded monitoring program.”

The expanded monitoring program near Deer Trail is distinct from, but builds on, the previous monitoring program in which the USGS monitored the quality of shallow ground water on the MWRD central property (1993 through 1999). Relative to the previous program, the expanded program includes a larger study area (fig. 1) (all three MWRD properties and private-property locations), more monitoring components (biosolids, soils, crops, and streambed sediments in addition to ground water), a more comprehensive list of chemical constituents, expanded statistical analyses of data, and an extended monitoring period (1999 through 2003). Both programs are designed, accomplished, and interpreted independently by the USGS, and USGS data and reports are released to the public and the MWRD at the same time.

Biosolids are applied by the MWRD to their properties near Deer Trail according to agronomic loading rates, which result in biosolids sprinkled on the fields, not thickly laid (fig. 2). Land-applied biosolids must meet regulations (Colorado Department of Public Health and Environment, 1998; U.S. Environmental Protection Agency, 1993); otherwise, agronomic loading rates might be exceeded and soils could become overloaded with trace elements. Soil quality either can be improved by biosolids applications through increased nutrients and organic matter or degraded through accumulation of excessive nutrients or metals. Pesticides, herbicides, and other fertilizers also may have been applied to the MWRD properties in the past, but little information is available about these applications.

Animal waste related to grazing domestic livestock and applications of pesticides, herbicides, and fertilizers (including biosolids) can affect soil quality, crops, water quality in alluvial and bedrock aquifers, and streambed-sediment chemistry. Water quality can be affected directly by contaminated recharge water or by infiltration of water through contaminated soils or sediments (remobilization). Water quality can be affected indirectly by tilling that mobilizes or mixes subsurface chemical constituents or by contributions to natural processes such as nitrification. Contaminated ground water or surface water could contaminate other aquifers (such as bedrock water-supply aquifers or alluvial aquifers), other surface-water bodies (ponds or streams), or streambed sediments.

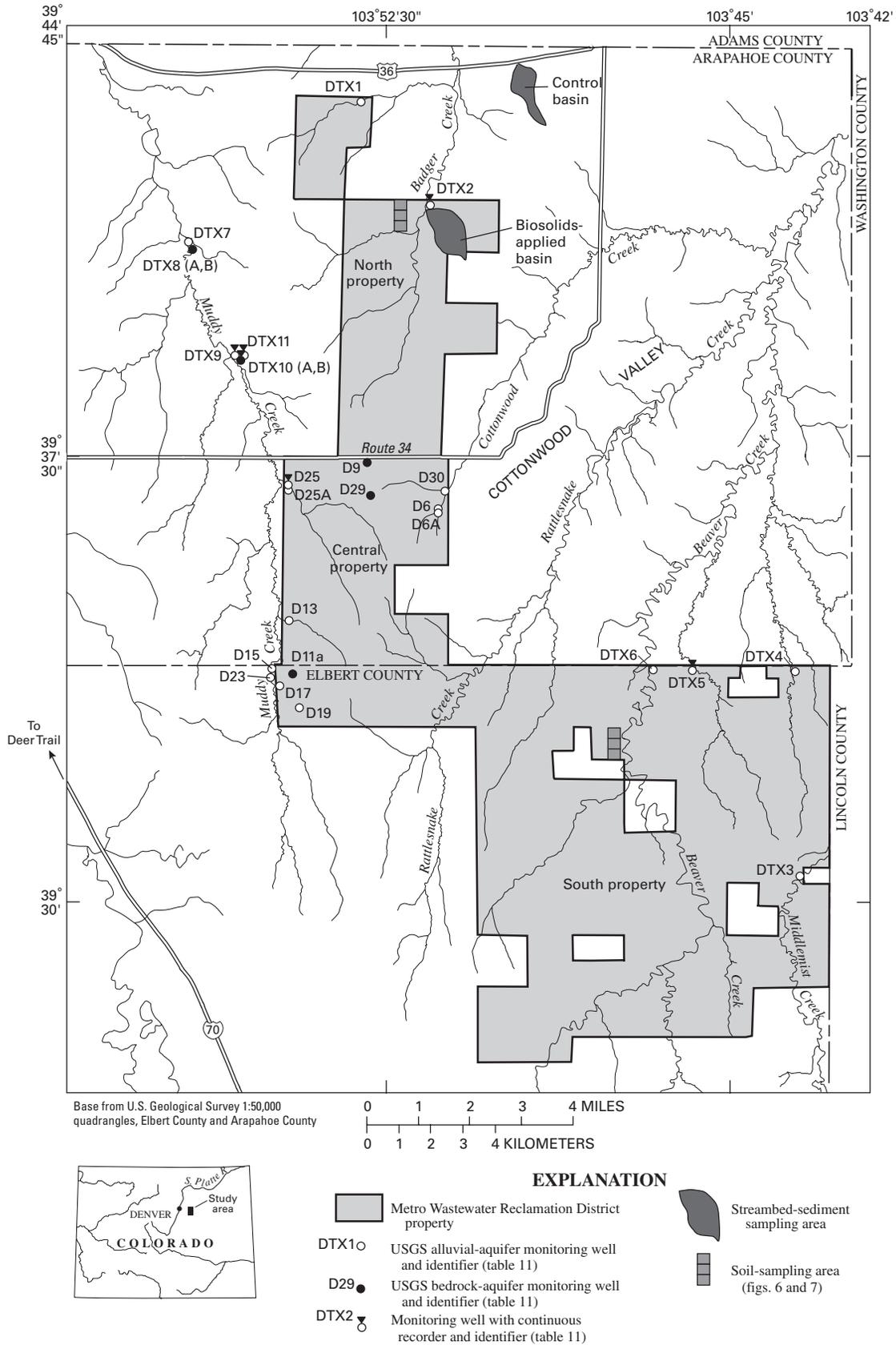


Figure 1. Location of study area and U.S. Geological Survey monitoring sites near Deer Trail, Colorado, 1999–2003. (Metro Wastewater Reclamation District property boundaries shown are from 1999.)



Figure 2. Biosolids (dark clumps) after application to a field near Deer Trail, Colorado.

The expanded monitoring program near Deer Trail addressed these concerns about biosolids applications and other farming-related effects on the environment and has increased scientific insight into Denver Basin hydrology. The objectives of this USGS program are to: (1) evaluate the combined effects of biosolids applications, land use, and natural processes on soils, crops, the bedrock aquifer, alluvial aquifers, and streambed sediments by comparing chemical data to (a) regulatory standards, (b) data from a site where biosolids are not applied (a control site), or (c) earlier data from the same site (trends); (2) monitor biosolids for trace elements and radioactivity and compare trace-element concentrations and radioactivity with regulatory standards; and (3) characterize the hydrology of the study area. Priority parameters identified by the stakeholders were slightly different for each monitoring component, but always included the nine trace elements regulated by Colorado for biosolids (arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc), gross alpha and gross beta radioactivity, and plutonium. The monitoring of each component (such as soil or ground water) is a stand-alone study that includes radioactivity analyses because of public concerns about effects of the transfer of treated water from the Lowry Landfill Superfund site to the MWRD treatment plant. More detailed information about the monitoring of each component is included later in this report. Monitoring data for 1999 are reported by Stevens and others (2003). Monitoring data for 2000 are reported by Yager and others (2004a). Monitoring

data for 2001 are reported by Yager and others (2004b). Monitoring data for 2002 through 2003 are reported by Yager and others (2004c).

Purpose and Scope

The purpose of this report is to present interpretive information about biosolids, soil, crops, ground water (alluvial and bedrock), and streambed sediment from the expanded monitoring program near Deer Trail for 1999 through 2003. This report presents interpretations for all monitoring components of the program. The Ground-Water section includes a discussion of hydrology and water quality. This report does not include the hydrogeologic structure maps that were done as part of the bedrock ground-water monitoring component of the program. The structure maps were used to select bedrock-aquifer monitoring locations for the expanded monitoring program. The structure maps, along with a more detailed discussion of the hydrogeology of the region, are included in another interpretive USGS report (Yager and Arnold, 2003).

This report is organized by monitoring component because each component (such as soil or ground water) was monitored as a separate study. For each monitoring component, component-specific objectives, approach, and interpretive discussions are included. The interpretive discussions for soil, crop, ground-water, and streambed-sediment components consider geochemical effects as well as effects of biosolids applications on that component.

Acknowledgments

The USGS thanks all private landowners for allowing access to their properties for data collection. The USGS especially thanks the Price and Weisensee families and the MWRD for allowing USGS instrument or well installations on their property and the Kalcevic family for timely sediment information after storms and for allowing streambed-sediment sampling on their property.

Description of Study Area

The study area is located on Colorado's eastern plains, about 75 mi east of Denver and about 10 mi east of Deer Trail (fig. 1). The study area is in the Colorado Piedmont section of the Great Plains physiographic province, an area characterized as "late mature to old elevated plain" (Fenneman, 1931). Soils in the study area generally are sandy or loamy on flood plains and stream terraces, clayey to loamy on gently sloping to rolling uplands, and sandy and shaley on steeper uplands (Larsen and others, 1966; Larsen and Brown, 1971). Surface water consists of ponds (usually manmade impoundments) and intermittent and ephemeral streams; streams rarely flow except after rain. Ground water is present in alluvial and bedrock aquifers (Yager and Arnold, 2003). The study area generally was vegetated during 1999 through 2003 except where the land surface was rock or where farm fields were freshly tilled. Crops and prairie vegetation dominated the landscape. Tree canopy was sparse and consisted of primarily deciduous varieties such as cottonwood trees along streams.

Topographic Features

Topographic features of the study area include flood plains, terraces with incised channels, valleys with incised channels, rounded hills, and cliffs. The study area is drained by three major streams (fig. 1): Muddy Creek in the west, Badger Creek in the north, and Beaver Creek in the south and east (Seaber and others, 1987). All streams in the study area flow generally north and are within the South Platte drainage basin. Muddy Creek is characterized by a wide, flat flood plain; the stream channel generally is incised less than 10 ft. Within the study area, Badger Creek is characterized by steeper, less incised valleys compared to Muddy Creek. Beaver Creek is the largest stream on the south MWRD property and includes three tributary streams: Cottonwood Creek (drains the east side of the central MWRD property), Rattlesnake Creek (drains the northwest corner of the south MWRD property), and Middlemist Creek (drains the southeast corner of the south MWRD property) (fig. 1). Most of the MWRD property drained by Beaver Creek has wide, flat terraces with stream channels incised more than 10 ft. Upland (headwaters) parts of streams are characterized by steeper more V-shaped valleys than lowland, downgradient parts of streams. The north and south parts of the study area are characterized by rounded

hills and rolling topography. The central part of the study area between Muddy Creek and Rattlesnake Creek (fig. 1) is characterized by cliffs.

Geology

Geology of the study area is described by Yager and Arnold (2003). In general, the geology of the study area consists of interbedded shale, siltstone, and sandstone, which may be overlain by clay, windblown silt and sand, or alluvial sand and gravel (Sharps, 1980; Major and others, 1983; Robson and Banta, 1995). The study area is on the eastern margin of the Denver Basin, a bowl-shaped sequence of sedimentary rocks. In the study area, the uppermost rock formations are highly eroded Cretaceous-age units that consist of the upper part of the Pierre Shale, the Fox Hills Sandstone, and the lower part of the Laramie Formation. These geologic units were deposited in an ocean or near-shore environment and comprise the Laramie-Fox Hills hydrostratigraphic unit (LFH-HU), and where saturated, the Laramie-Fox Hills aquifer. Maps showing the extent and thickness of the LFH-HU are included in Yager and Arnold (2003). The LFH-HU is present beneath much of the study area but is not present in the eastern two-thirds of the MWRD's south property, which is underlain by Pierre Shale.

The Pierre Shale crops out and subcrops east of the MWRD central property and consists of dark gray shale with layers of siltstone and fine-grained sandstone. Approximately the upper 200 ft of the Pierre Shale is interbedded with siltstone and sandstone, which gives a striped appearance to core samples. This part of the Pierre Shale is known as the "transition zone" and becomes increasingly sandy toward the top of the formation, forming a gradational contact with the overlying Fox Hills Sandstone. Where the upper part of the Pierre Shale is near land surface, the heterogeneity of the transition zone in the Pierre Shale results in localized shaley or sandy regions within the study area.

The Fox Hills Sandstone consists of massive yellow-orange to tan, poorly consolidated, fine-grained sandstone and siltstone. The formation contains thin lenses of coal-rich shale, iron- and calcite-cemented concretions, and trace fossils of burrows. The top of this formation contains well-cemented sandstone in the southern one-half of the MWRD central property that formed cliff features.

The Laramie Formation consists of an upper part of mostly shale and siltstone with lenses of sandstone and coal, and a lower part of mostly sandstone interbedded with shale and coal. In the study area, the formation is mostly fine grained, consisting of brown to gray shale containing lenses of sandstone, shale, and coal.

Unconsolidated sediments in the study area are Pleistocene to modern in age and include Peoria Loess, windblown sand deposits, and alluvium. The Peoria Loess covers the bedrock in much of the study area, is covered by modern soil horizons, and may be interbedded with buried soil horizons (Muhs and others, 1999). The maximum

observed thickness of unconsolidated sediments that include the Peoria Loess in the study area is about 50 ft (north of well D29 near Route 34; fig. 1). On the MWRD property, the loess consists of fairly homogeneous tan to brown windblown clay and silt derived from weathered bedrock and older alluvium and commonly contains crystalline gypsum. Windblown sand deposits were less than 1 ft thick in the cores obtained from drilling in the study area and are derived from weathered bedrock and alluvium. Alluvium in the study area is present in paleochannels and along the flood plains and bottoms of larger stream valleys, sometimes beneath the Peoria Loess. Alluvium is less than 1 ft thick in the cores obtained from drilling in the study area. The composition and texture of the alluvium are not homogeneous but range from pink, white, and gray arkosic sands and gravels derived from igneous and metamorphic rock of the Rocky Mountains to dark yellowish gray to tan clay, silt, and sand locally derived from sedimentary rocks.

Climate

The climate in the study area is semiarid. Less than 20 inches of precipitation usually is received each year. Most of the precipitation occurs as rainfall in May or early June and in late summer (usually July through August). Precipitation data for two sites on the MWRD central property during 1996 through 1998 are reported by Yager and Arnold (2003). Precipitation data for four sites in the study area during 1999 through 2003 are reported by Stevens and others (2003) and Yager and others (2004a, 2004b, 2004c). A comparison of these precipitation data for these six sites during 1996 through 2003 indicates that precipitation quantities differed substantially over 3–4 mi, in general more precipitation was received in the north part of the study area; 2002 was an unusually dry year of this 8-year period, and 2001 was an unusually wet year of this 8-year period. Precipitation data were similar for the other 6 years of this 8-year period.

Air temperatures ranged from about 0°F October through April to about 105°F in July and August. Air-temperature data for the study area during 1999 through 2003 are reported by Stevens and others (2003) and Yager and others (2004a, 2004b, 2004c). These data indicate that air temperatures were similar throughout the study area during 1999 through 2003. The study area often is windy; prevailing winds are from the north in winter and from the west in summer. Average annual pan evaporation in the study area for 1946 through 1955 was about 70 inches (Robson and Banta, 1995, fig. 10).

Land Use

Land use in the study area historically was rangeland, cropland, and pasture (U.S. Geological Survey, 1980). Abandoned homesteads and other buildings were present on the MWRD property, along with associated outbuildings, animal pens, and shallow windmill-pumped wells (Yager and Arnold, 2003). No one lived on the MWRD property 1999 through

2003. However, rural residences in the study area include those west of well D13 near Muddy Creek, north of well D25 near Muddy Creek, north of well DTX6 near Rattlesnake Creek, and north of well DTX2 near Badger Creek. Some petroleum exploration has been done in the study area (Yager and Arnold, 2003), but the USGS is not aware of any petroleum or natural-gas exploration or production in the study area during 1999 through 2003. Land use on the MWRD property during 1993 through 2003 mostly was cropland. Land use within the rest of the study area during 1993 through 2003 mostly was rangeland or pasture with some cropland. Farmland in the study area was not irrigated. Biosolids were applied to the land surface of the MWRD property as a fertilizer, and the primary crop was wheat. Crop information for each of the MWRD property sections is included in Stevens and others (2003) and Yager and others (2004a, 2004b, 2004c). Cattle and sheep were the primary domestic animals grazing this area. Wildlife observed in the study area included pronghorn, deer, coyotes, herons, hawks, owls, rodents, and turtles.

Biosolids

Biosolids are solid organic matter recovered from a sewage-treatment process that meets State and Federal regulatory criteria for beneficial use, such as for fertilizer. The regulations state that land-applied biosolids (fig. 2) must meet or exceed Table 1 Ceiling Concentration Limits and Class B pathogen criteria (Grade II, Class B criteria in the Colorado regulations until June 2003) (Colorado Department of Public Health and Environment, 1998; U.S. Environmental Protection Agency, 1993). Table 3 and Grade I requirements are stricter than Table 1 and Grade II requirements. The MWRD applied Table 3 (Grade I) Class B biosolids to their properties near Deer Trail. More information about the sewage-treatment process that results in the MWRD biosolids can be found at <http://www.metrowastewater.com> (accessed on July 1, 2004). The biosolids-application areas, dates of application, and application rates provided by the MWRD for their properties near Deer Trail for 1999 through 2003 are detailed in Stevens and others (2003) and Yager and others (2004a, 2004b, 2004c).

Objectives of Monitoring Biosolids

The biosolids must meet State and Federal regulatory standards for trace elements (Colorado Department of Public Health and Environment, 1998). Exceeding these standards could adversely affect the quality of soil on which the biosolids are applied and could alter MWRD plans for the application of biosolids in Arapahoe and Elbert Counties. The composition of biosolids was monitored to provide an independently determined data set against which the MWRD chemical analyses and the regulatory standards for biosolids can be compared. The data also constitute a chemical baseline against which any future change in the concentration of

constituents analyzed for in this study may be recognized, measured, and compared. The data also establish an inorganic biosolids signature to help evaluate whether biosolids have affected soils or streambed sediments near Deer Trail, Colo.

Approach for Monitoring Biosolids

In 1999, the USGS began monitoring MWRD biosolids for concentrations of trace elements and radioactivity, as well as other selected parameters. The priority parameters identified by the stakeholders were the nine regulated trace elements (arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc), plutonium, and gross alpha and gross beta activity. Radioactivity analyses were included in response to public concerns that biosolids radioactivity could increase from the transfer of treated water from the Lowry Landfill Superfund site to MWRD. From January 1999 through June 2000 and May 2003 through September 2003, biosolids samples were collected quarterly. From August 2000 through April 2003, samples were collected monthly. This monthly sampling was initiated shortly after MWRD began receiving treated water from the Lowry Landfill Superfund site. The exact dates of collection and the data for biosolids samples are listed in Stevens and others (2003) and Yager and others (2004a, 2004b, 2004c).

Biosolids samples were collected directly from the MWRD facility in Denver rather than from individual trucks or fields near Deer Trail to enable the USGS to obtain a more representative sample. The samples were prepared and analyzed at the chemical laboratories of the USGS Mineral Resources Program in Denver. The concentrations in the samples were compared to applicable Colorado standards for biosolids (Colorado Department of Public Health and Environment, 1998).

Each biosolids sample is a 24-hour composite of 12 subsamples collected about every 2 hours by MWRD personnel at the MWRD facility. The subsamples were collected from the conveyor belt that transfers the biosolids into the transport trucks. Each sample was delivered to the USGS in two acid-washed, rinsed, 1-gal plastic or glass bottles.

The biosolids material was air dried and then ground to less than 150 μm prior to chemical analysis. Complete details on the analytical methods and the quality-assurance protocols used are described by Stevens and others (2003), and Yager and others (2004a, 2004b, 2004c).

Composition of Biosolids

Biosolids were analyzed for trace elements, radioactivity, and other parameters. Selected trace elements in biosolids are regulated by the State of Colorado. One measure of radioactivity (gross alpha) was regulated until June 30, 2003. Trace-element concentration and radioactivity for the 1999 through 2003 MWRD biosolids were reported by Stevens and others (2003) and Yager and others (2004a, 2004b, 2004c).

Trace Elements

Biosolids are regulated for nine trace elements: arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc (Colorado Department of Public Health and Environment, 1998). Molybdenum is regulated for Table 1 (Grade II) biosolids, but not Table 3 (Grade I) biosolids. Graphs of concentration for each of these nine trace elements compared to date of collection are shown in figure 3. The maximum allowable value for Table 3 (Grade I) biosolids also is shown on each plot; the molybdenum standard shown in figure 3 is that for Table 1 (Grade II) biosolids. The concentration of all nine elements remained relatively consistent throughout the study. Arsenic showed the most variability with its high and low concentration differing by a factor of six. The other eight elements varied by a factor of three or less. All trace-element concentrations were less than the maximum allowable concentrations established for Table 3 (Grade I) or Table 1 (Grade II) biosolids. Of these nine regulated trace elements, one element (arsenic) was present in substantially higher concentrations in soil and rock near Deer Trail than in the MWRD biosolids (table 1). Of these nine regulated trace elements, six elements (cadmium, copper, mercury, molybdenum, selenium, and zinc) were present in substantially higher concentrations in the MWRD biosolids than in soil, rock, and streambed sediment near Deer Trail (table 1). Of the regulated elements, copper and mercury had the largest difference in concentration (as much as two orders of magnitude) for biosolids compared to soil, rock, and streambed sediment near Deer Trail (table 1).

In addition to the nine trace elements that have regulatory standards established, the USGS analyzed biosolids samples for many other elements (Yager and others, 2004c, table 7). Concentrations of most of the nonregulated elements in biosolids were less than concentrations of the same elements in soil and rock near Deer Trail (Yager and others, 2004c, table 7). Gadolinium, an element related to magnetic resonance imaging (MRI) work, has been detected in Colorado liquid wastewater-treatment products (Murphy and others, eds., 2003; Verplanck and others, 2003), but concentrations of gadolinium in the MWRD biosolids were less than in the soil, rock, and streambed sediment near Deer Trail (Yager and others, 2004c, table 7). Of the nonregulated elements, bismuth, phosphorus, silver, and uranium have the highest concentrations in biosolids compared to soil, rock, and streambed sediment near Deer Trail (table 1); bismuth and silver had the largest difference in concentration (about two orders of magnitude). Therefore, elevated concentrations of bismuth, cadmium, copper, mercury, molybdenum, phosphorus, selenium, silver, uranium, and zinc would be the most likely inorganic biosolids signature to indicate that soils or streambed sediments have been affected by biosolids.

Radioactivity and Plutonium

Gross alpha and gross beta activity are shown by date of collection in figure 4. Measurements for each of these parameters indicate a relatively high uncertainty as shown by the uncertainty bars associated with each data point on the graphs.

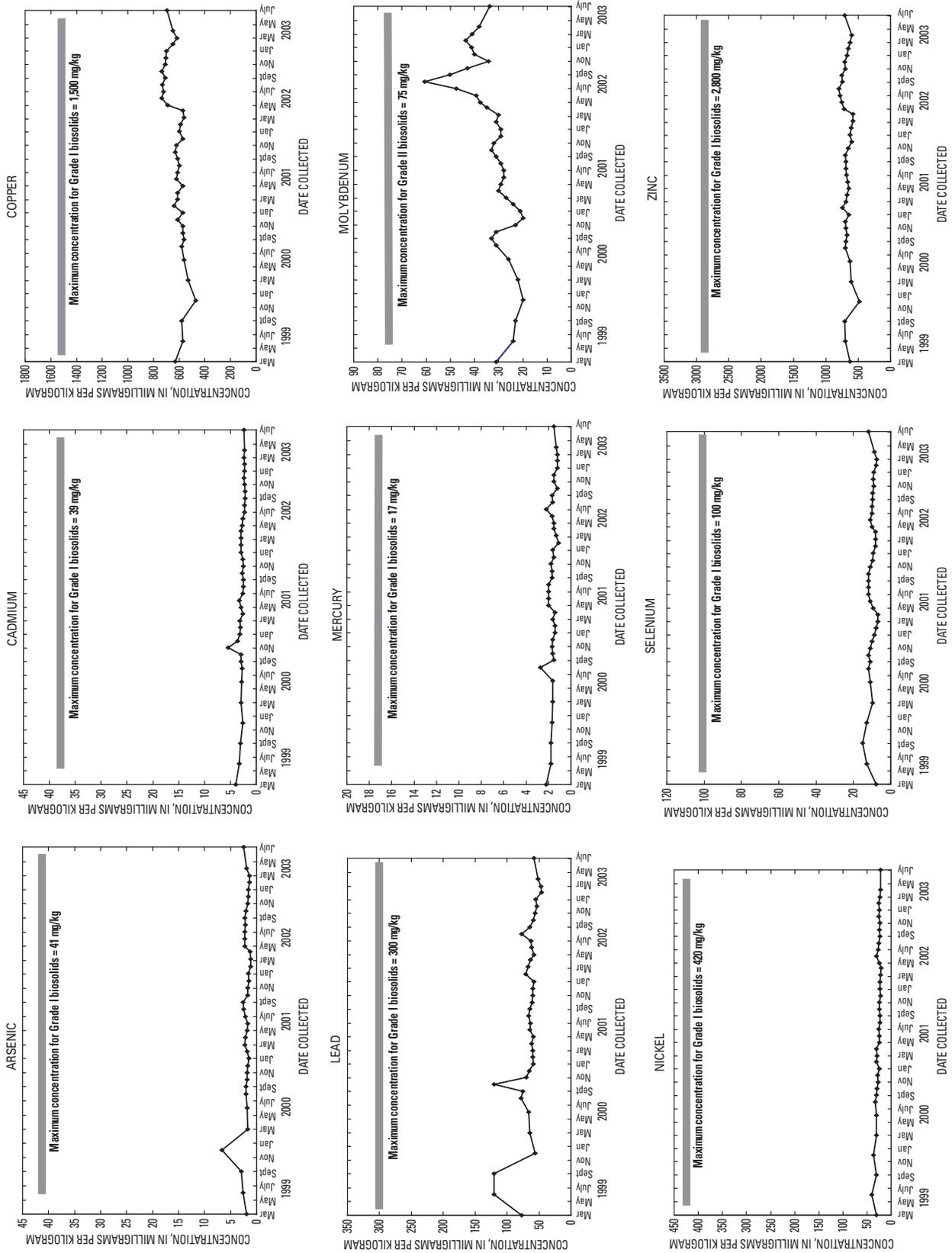


Figure 3. Trace-element concentrations in biosolids from the Metro Wastewater Reclamation District during 1999–2003 compared to Colorado standards for biosolids (Colorado Department of Public Health and Environment, 1998).

The uncertainty is the average of the 2-sigma combined standard uncertainty calculated by the laboratory. There is no regulatory value established for gross beta activity. Until June 30, 2003, there was a Colorado regulation for gross alpha activity that generally restricted land application of biosolids that exceeded a gross alpha activity of 40 pCi/g (Colorado Department of Public Health and Environment, 1998). It is this now outdated standard of 40 pCi/g that is shown in figure 4A.

The graph for gross alpha also shows a probable laboratory bias. The biosolids samples collected in July 2002 and later are lower in gross alpha activity than most of those samples collected before July 2002. The samples collected before July 2002 have an average gross alpha activity of 37 pCi/g, whereas the samples collected from July 2002 to the end of the study have an average of 18 pCi/g. The uncertainty in the analysis also is different; the samples collected before July 2002 have an average uncertainty of plus or minus 34 percent while the samples collected from July 2002 to the end of the study have an average uncertainty of plus or minus 12 percent. This same bias can be seen in the analysis of the National Institute of Standards standard reference material (SRM) 2781, a domestic sludge. This same SRM was submitted with each set of biosolids samples to determine the precision of the analytical results. The average gross alpha activity determined for this SRM before July 2002 was 40 pCi/g. The gross alpha activity determined after July 2002 was 17 pCi/g. The uncertainty showed a similar decrease from plus or minus 30 to plus or minus 13 percent. The samples collected from July 2002 and beyond were analyzed in a different laboratory from the samples collected before July 2002 (Yager and others, 2004c). USGS has no basis for determining which laboratory provided the most accurate values. A few of the gross alpha activities for the biosolids samples may have exceeded the old regulatory limit of 40 pCi/g, but with the uncertainty in the analyses, it is difficult to draw any conclusion from this data set.

A time series of biosolids plutonium (Pu) data are graphed in figure 4 (parts C and D). Figure 4C shows data for the isotope Pu-238 and figure 4D shows data for the sum of isotopes Pu-239 and Pu-240. The plutonium data are below the minimum detectable level for all samples (fig. 4 parts C and D) with a distribution near zero. There are no published regulatory values for plutonium in biosolids.

The radioactivity data for biosolids were reported in previous annual reports (Stevens and others, 2003; Yager and others, 2004a, 2004b, 2004c) in the uncensored form as received from the laboratory rather than censored by either the contract or calculated minimum detectable concentration (MDC). Relative to the censored form (data reported as less than the MDC), the uncensored form provides more information about the uncertainty, the very small concentrations of plutonium, and the gross alpha and gross beta activity. The negative activity concentration reported for the radiochemical samples means the sample count was less than the laboratory background count for that day. Radioactivity data are produced from instruments that detect radioactive decay (disintegrations) in a sample as counts per minute. The background count was subtracted from the sample count, and the resulting value

was converted to activity-concentration units of picocuries per gram. These uncensored values are graphed in figures 4C and 4D. It is important to note that caution should be used in interpreting individual values that are negative or less than the minimum detectable level.

“A negative value has no physical significance. Values less than minimum detectable levels lack statistical confidence as to what the actual number is, although it is known with high confidence that it is below the specified detection level. Such values should not be interpreted as being the actual amount of material in the sample, but should be seen as reflecting a range from zero to the minimum detectable level in which the actual amount would likely lie. These values are significant, however, when taken together with other analytical results that indicate that the distribution is near zero.” (EG&G Rocky Flats, 1994).

Composition of Water Leachates from Biosolids

Preliminary leach experiments were done to determine if there was substantial mobilization of elements upon contact of the biosolids with water. Biosolids collected from the MWRD facility during February 2001 and April 2001 were selected for this experiment. The air-dried and disaggregated biosolids material (50.0 g) was placed in 1.0 L of distilled-deionized water at ambient temperature. The mixture was shaken for 5 minutes and allowed to settle for 10 minutes. A portion of the leachate then was syringe filtered through a nitrocellulose capsule filter with a nominal pore size of 0.45 μm , and the filtrate was analyzed by inductively coupled plasma-mass spectrometry. The water-leach method is a modification of the Field Leach Test of Hageman and Briggs (2000).

Table 10 (in the Supplemental Information section at the back of the report) lists the results of the laboratory leach test of biosolids. Antimony, cadmium, cobalt, copper, mercury, molybdenum, nickel, phosphorus, selenium, and tungsten have the highest biosolids to soil leachate concentration ratios in water leachates and may be useful indicators of biosolids effects on ground and surface water. Leachate results for the nine trace elements regulated in biosolids plus five other elements are shown in figure 5. The results are expressed as the percentage of the element in the biosolids sample that is removed by the water leach. Arsenic, molybdenum, nickel, phosphorus, and selenium are removed more preferentially than the other elements. This more preferential removal indicates that these elements occur in biosolids in a more soluble form than most of the other elements. Almost 7 percent of the total molybdenum content and slightly more than 4 percent of the total arsenic content was extracted by this leach. These experiments indicate that a small portion of the elements within biosolids may be removed by exposure to rainwater over a period of time, with some elements being removed preferentially to others.

10 Effects of Surface Applications of Biosolids near Deer Trail, Colorado, 1999–2003

Table 1. Comparison of data for biosolids and samples collected near Deer Trail, Colorado, 1999–2003.

[ppm, parts per million, which is equivalent to mg/kg for soil, sediment, or rock and equivalent to mg/L for ground water; %, percent; NA, not applicable; ±, plus indicates concentrations naturally in the environment generally were at least one order of magnitude greater than biosolids concentrations; the color yellow indicates concentrations generally were about two orders of magnitude greater than concentrations naturally in the environment]

Sample type	Sample site (fig. 1)	Depth of sample below land surface, in feet	Sample description	Number of samples analyzed	Arsenic, ppm	Bismuth, ppm
Biosolids						
Biosolids samples from MWRD	MWRD plant in Denver, Colorado	NA	Mean value for the biosolids samples for 1999–2003 ±2 standard deviations	41	2.0±1.7	31±6
Aged biosolids sample from the field	About 1.75 miles northwest of DTX2	0	Biosolids applied to soil surface about 7–10 months before sampled on 6/6/01	1	6.0	22.4
Soil						
Soil samples with no biosolids applied	Soil site in Arapahoe County	0–1.2	Mean value for composited samples from control fields 1999–2003 ±2 standard deviations	6	7.2±1.3	0.21±0.10
Soil samples with biosolids applied	Soil site in Arapahoe County	0–1.2	Mean value for composited samples from biosolids-applied field 1999–2003 ±2 standard deviations	3	7.2±1.6	0.20±0.01
Soil samples with no biosolids applied	Soil site in Elbert County	0–1.2	Mean value for composited samples from control fields 1999–2003 ±2 standard deviations	6	13.4±4.1	0.27±0.10
Soil samples with biosolids applied	Soil plot in Elbert County	0–1.2	Mean value for composited samples from biosolids-applied field 1999–2003 ±2 standard deviations	3	15.5±2.5	0.37±0.12
Rock						
Rock core	D6A	14–28	Median value for February 2002 core samples ±2 standard deviations	5	13±20	0.10±0.02
Rock core	D9	32–59.5	Median value for February 2002 core samples ±2 standard deviations	5	6±15	<0.08±0
Rock core	D25A	14.5–20.5	Median value for February 2002 core samples ±2 standard deviations	5	8.4±9.0	<0.08±0
Streambed sediment						
Runoff-deposited sediment, biosolids applied	Basin near DTX2	0–0.06	Median value for the runoff-deposited samples for 1999–2003 ±2 standard deviations	Variable (number of samples analyzed in parentheses)	3.96±7.91 (10)	--
Runoff-deposited sediment, no biosolids applied	Control basin, about 3 miles northeast of DTX2	0–0.06	Median value for the runoff-deposited samples for 1999–2003 ±2 standard deviations	Variable (number of samples analyzed in parentheses)	5.1±6.3 (9)	--
Ground water						
Ground water	D6	12–22	Median value for quarterly samples from 1999–2003 ±2 standard deviations	20	0.003±0.004	--
Ground water	D25	10–20	Median value for quarterly samples from 1999–2003 ±2 standard deviations	20	0.003±0.001	--
Ground water	All	4–169	Median value for quarterly samples from 1999–2003 ±2 standard deviations	279	<0.002±0.002	--
Crops						
Crop samples with no biosolids applied	Soil site in Arapahoe County	NA	Mean value for composited wheat-grain samples from control fields 1999–2003 ±2 standard deviations	Variable (number of samples analyzed in parentheses)	<0.05 (3)	0.001±0.000 (2)
Crop samples with biosolids applied	Soil site in Arapahoe County	NA	Mean value for composited wheat-grain samples from control fields 1999–2003 ±2 standard deviations	Variable (number of samples analyzed in parentheses)	<0.05 (2)	0.003 (1)
Crop samples with no biosolids applied	Soil site in Elbert County	NA	Mean value for composited wheat-grain samples from control fields 1999–2003 ±2 standard deviations	Variable (number of samples analyzed in parentheses)	<0.05 (4)	0.003±0.002 (2)
Crop samples with biosolids applied	Soil site in Elbert County	NA	Mean value for composited wheat-grain samples from control fields 1999–2003 ±2 standard deviations	Variable (number of samples analyzed in parentheses)	<0.05 (2)	0.004 (1)

or minus; MWRD, Metro Wastewater Reclamation District; no data; <, less than; mg/kg, milligrams per kilogram; mg/L, milligrams per liter; the color green biosolids concentrations generally were about one order of magnitude greater than concentrations naturally in the environment; the color orange indicates biosolids

Cadmium, ppm	Chromium, ppm	Copper, ppm	Lead, ppm	Mercury, ppm	Molybdenum, ppm	Nickel, ppm	Nitrogen, total as N, ppm
Biosolids							
2.8±1.1	42±7	624±126	66±33	1.6±0.6	33±17	26±8	--
2.76	78	451	77	1.5	19	34	4,200
Soil							
0.20±0.02	42±14	14.6±5.0	18.0±1.3	0.04±0.07	0.67±0.11	14±3	--
0.27±0.06	45±15	16.5±1.7	19.6±2.4	0.02±0.01	0.73±0.23	16±1	--
0.21±0.03	57±24	20.2±5.4	25.0±1.5	0.03±0.01	1.3±0.2	20±6	--
0.21±0.01	56±17	23.1±4.9	30.6±9.4	0.04±0	1.6±0.3	22±2	--
Rock							
0.11±0.23	43±18	15.3±1.8	20.0±2.6	0.02±0.04	0.7±2.0	17.9±6.0	67±52
0.12±0.18	36±22	9.2±4.1	15.8±2.5	0.02±0.02	1.0±2.1	9.9±6.0	51±60
0.15±0.12	28±19	8.5±7.8	15.7±5.3	<0.02±0	0.6±0.4	10.5±9.4	71±31
Streambed sediment							
0.20±0.12 (10)	20±19 (10)	16±7 (10)	17±9 (10)	0.025±0.017 (10)	0.33±0.40 (10)	16±10 (10)	1,430±736 (9)
0.14±0.09 (9)	19±15 (9)	13±6 (9)	15±4 (9)	0.017±0.051 (9)	0.30±0.22 (9)	15±6 (9)	706±583 (9)
Ground water							
<0.0003±0.0053	<0.0016±0.0019	0.036±0.044	<0.0006±0.0052	<0.00002±0.00017	0.0036±0.0033	0.015±0.015	16.5±6.1
0.0002±0.0009	0.0009±0.0069	0.011±0.006	<0.0002±0.0009	<0.00002±0.00008	0.0099±0.0019	0.015±0.011	3.15±1.91
0.0001±0.0021	0.0008±0.0056	0.007±0.025	<0.0002±0.0020	<0.00002±0.00016	0.0020±0.0056	0.0066±0.0170	2.05±12.15
Crops							
0.03±0.00 (3)	0.7±0.4 (3)	5.6±1.8 (3)	0.01±0.01 (3)	< 0.02 (3)	0.7±0.5 (3)	1.8±2.2 (3)	--
0.03±0.02 (2)	0.7±1.0 (2)	7.0±1.2 (2)	0.01±0.01 (2)	< 0.02 (2)	0.9±0.3 (2)	2.4±2.9 (2)	--
0.02±0.01 (4)	2.1±5.8 (4)	5.1±1.4 (4)	0.01±0.02 (4)	< 0.02 (4)	0.9±0.6 (4)	1.6±3.0 (4)	--
0.01±0.01 (2)	9±13 (2)	5.4±1.8 (2)	0.04±0.08 (2)	< 0.02 (2)	1.1±1.6 (2)	4.6±12 (2)	--

12 Effects of Surface Applications of Biosolids near Deer Trail, Colorado, 1999–2003

Table 1. Comparison of data for biosolids and samples collected near Deer Trail, Colorado, 1999–2003.—Continued

[ppm, parts per million, which is equivalent to mg/kg for soil, sediment, or rock and equivalent to mg/L for ground water; %, percent; MWRD, Metro Wastewater Reclamation District; NA, not applicable; ±, plus or minus; --, no data; <, less than; mg/kg, milligrams per kilogram; mg/L, milligrams per liter; the color green indicates concentrations naturally in the environment generally were at least one order of magnitude greater than biosolids concentrations; the color yellow indicates biosolids concentrations generally were about one order of magnitude greater than concentrations naturally in the environment; the color orange indicates biosolids concentrations generally were about two orders of magnitude greater than concentrations naturally in the environment]

Sample type	Sample site (fig. 1)	Phosphorus, %	Selenium, ppm	Silver, ppm	Sulfur, %	Uranium, ppm	Zinc, ppm
Biosolids							
Biosolids samples from MWRD	MWRD plant in Denver, Colorado	2.7±1.0	10±4	34±27	--	46±22	671±120
Aged biosolids sample from the field	About 1.75 miles northwest of DTX2	2.33	8.8	40.5	0.82	41.0	577
Soil							
Soil samples with no biosolids applied	Soil site in Arapahoe County	0.06±0.01	0.38±0.09	0.3±0.1	--	2.7±0.3	56±5
Soil samples with biosolids applied	Soil site in Arapahoe County	0.06±0.01	0.38±0.08	0.4±0.0	--	3.1±0.2	60±5
Soil samples with no biosolids applied	Soil site in Elbert County	0.07±0.01	0.90±0.20	0.4±0.1	--	3.2±0.2	83±16
Soil samples with biosolids applied	Soil site in Elbert County	0.08±0.01	1.1±0.2	0.4±0.1	--	3.5±0.2	90±5
Rock							
Rock core	D6A	0.08±0.03	<2.0±2.3	0.10±0.02	0.70±0.96	3.3±1.2	71.9±29.3
Rock core	D9	0.06±0.04	0.3±1.7	0.07±0.03	<0.05±1.54	2.2±0.8	54.7±11.4
Alluvial core	D25A	0.05±0.02	0.4±1.5	0.07±0.03	<0.05±0.00	1.9±0.8	45.2±36.2
Streambed sediment							
Runoff-deposited sediment, biosolids applied	Basin near DTX2	¹ 625±639 (9)	0.88±0.99 (10)	0.34±0.36 (5)	--	1.9±1.6 (5)	65±41 (10)
Runoff-deposited sediment, no biosolids applied	Control basin, about 3 miles northeast of DTX2	¹ 582±414 (9)	0.60±0.77 (9)	0.13±0.09 (5)	--	1.5±0.7 (5)	57±25 (9)
Ground water							
Ground water	D6	² 0.04±0.02	0.0125±0.0164	<0.001±0.006	³ 13,000±505	0.170±0.089	0.032±0.034
Ground water	D25	² 0.13±0.03	0.0030±0.0013	<0.0020±0.0008	³ 2,610±129	0.042±0.010	0.008±0.004
Ground water	All	² 0.05±0.07	0.0030±0.0099	<0.001±0.003	³ 2,350±6,397	0.033±0.085	0.006±0.020
Crops							
Crop samples with no biosolids applied	Soil site in Arapahoe County	0.4 (1)	0.5±0.6 (3)	0.0008±0.0008 (2)	--	0.002±0.001 (2)	22±4 (3)
Crop samples with biosolids applied	Soil site in Arapahoe County	0.4 (1)	1.2±0.4 (2)	0.002±0.002 (2)	--	0.003 (1)	21±4 (2)
Crop samples with no biosolids applied	Soil site in Elbert County	0.4±0.2 (2)	1.4±2.4 (4)	0.001±0 (4)	--	0.004±0.001 (2)	25±6 (4)
Crop samples with biosolids applied	Soil site in Elbert County	0.4 (1)	0.5±0.4 (2)	0.001±0.000 (2)	--	0.014 (1)	30±14 (2)

¹Units are mg/kg.

²Units are mg/L.

³Value is for sulfate in units of mg/L.

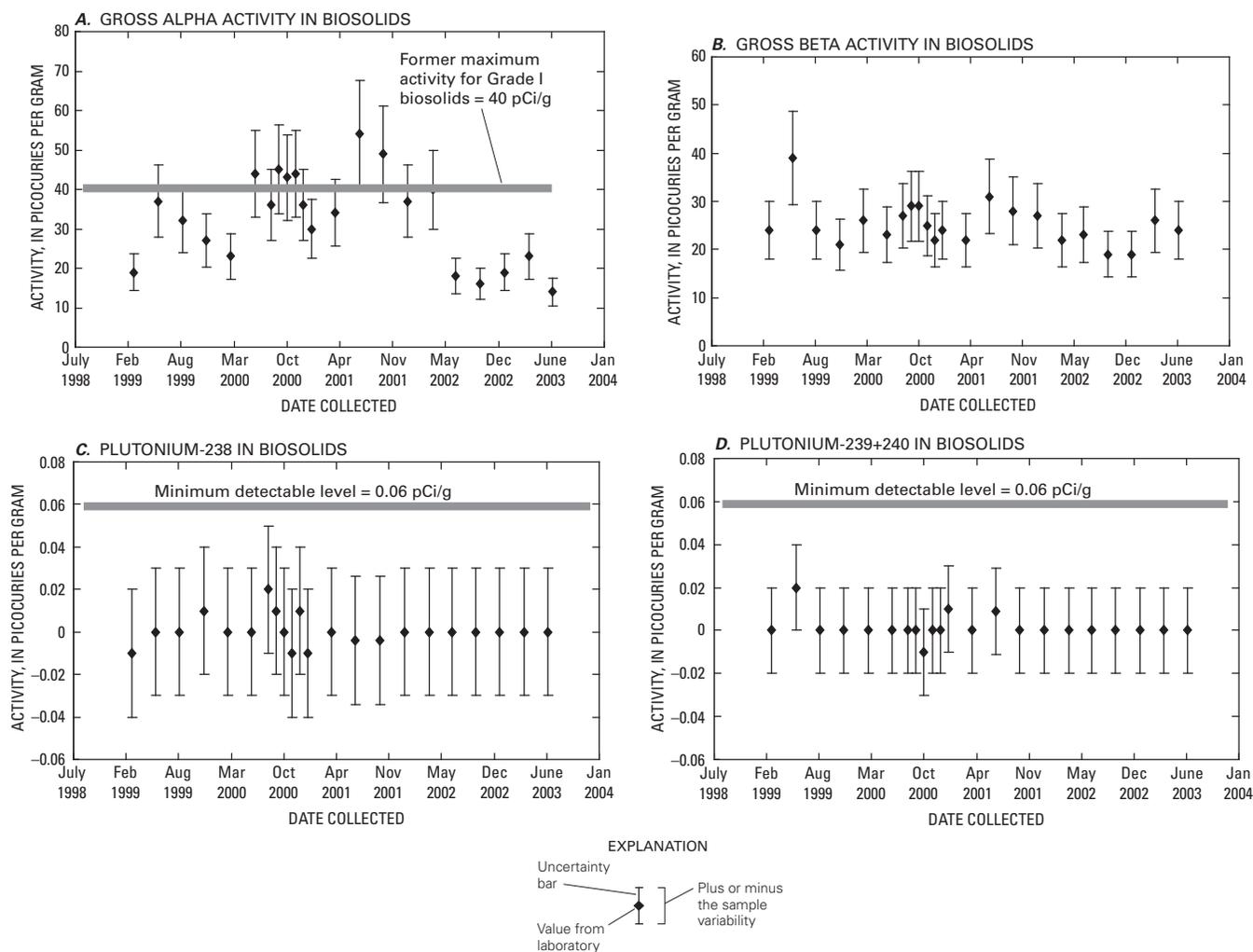


Figure 4. Radioactivity of biosolids from the Metro Wastewater Reclamation District during 1999–2003 for (A) gross alpha, (B) gross beta, (C) plutonium-238, and (D) plutonium-239+240. (Uncertainty bars are the average of the combined standard uncertainty provided by the laboratory, expressed as a percentage.)

Soil

Biosolids can contain elevated concentrations of certain trace constituents. Therefore, the application of biosolids to farmland has caused public concern regarding the potential short-term and long-term effects on soil quality.

Objectives of Monitoring Soil

Soils were monitored for trace elements and plutonium and gross alpha and gross beta activity to establish independent geochemical data sets for the composition of soil before and after the application of biosolids. Such data, collected over a sufficient time, will make it possible to recognize and quantify significant changes, if any, in soil composition caused by the application of biosolids to agricultural soils or by other natural or human-induced processes.

Approach for Monitoring Soil

In August 1999, the USGS began monitoring soils on two sites, one site on MWRD property in Arapahoe County and one site on MWRD property in Elbert County. The sites were monitored for priority parameters consisting of (1) nine trace elements for which biosolids are regulated (Colorado Department of Public Health and Environment, 1998): arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc; (2) plutonium, and gross alpha and gross beta activity; and (3) other selected parameters. The radioactivity analyses were included in response to public concerns that biosolids radioactivity could increase from the transfer of water from the Lowry Landfill Superfund site to the MWRD treatment plant. Soil samples were collected once in 1999 before the application of biosolids to monitoring sites, and these data were reported by Stevens and others (2003). Soil monitoring continued through two cycles of biosolids

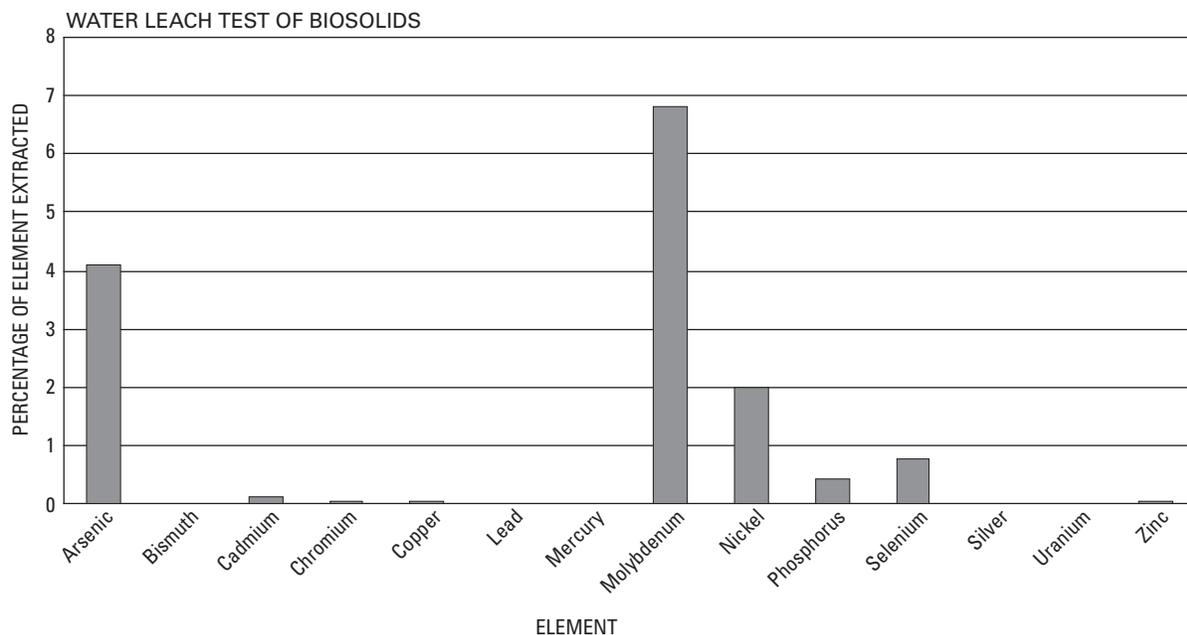


Figure 5. Selected elements extracted by water leach of biosolids. (Concentration data listed in table 10.)

application and crop harvest; soil sampling was done within a few months after each harvest. Fields that received biosolids applications were monitored in addition to fields that received no biosolids, which represented reference conditions for comparison. These data are reported by Yager and others (2004c).

Each of the two soil-monitoring sites consisted of three 20-acre (933 ft × 933 ft) fields separated by 100-ft buffer zones (figs. 6 and 7). Biosolids were applied on the center 20-acre field at each site after the initial soil sampling and again after each harvest. The other two 20-acre fields at each site never had biosolids applied and were used as control fields to determine the natural variability of soil composition for the duration of the study. All three 20-acre fields at each site were farmed in a similar way as the rest of the MWRD property and had crops planted and harvested.

The sampling protocol was designed to provide data to determine how the application of biosolids affects soil chemistry within the top 12 inches of the surface; if there is a short-term and long-term buildup of metals and radioactivity in the top 12 inches of soil caused by the application of biosolids; and if a buildup occurs, is it within acceptable limits for soil quality as established by Federal and State agencies.

A standard soil auger was used to collect subsamples in each field to a depth of 12 inches according to a systematic grid pattern. During each sampling event, 30 to 36 subsamples were collected for each of the 20-acre fields. After air drying, disaggregating, sieving to less than 2 mm, and grinding to less than 150 μm, splits of the subsamples were composited into one sample that represented the entire field for chemical analysis. Complete details on site selection, dates of sample collection, sample-collection protocols, analytical methods, and quality-assurance protocols are described by Stevens and others (2003) and Yager and others (2004a, 2004b, 2004c).

Effects of Biosolids on Soil

To evaluate the potential effects of biosolids on soils near Deer Trail, the natural geochemical variability associated with estimating the average composition of soil in the 20-acre monitoring fields is ascertained. This natural variability is caused by (1) the heterogeneous nature of the soil and by (2) the uncertainty associated with laboratory chemical analyses.

Natural Geochemical Variability of Soil near Deer Trail, Colorado

Soil exhibits two primary types of heterogeneity. The first type is called “constitutional heterogeneity” (Pitard, 1993) and refers to the difference in chemical composition among the particles that make up the soil. The second type is called “distribution heterogeneity” (Pitard, 1993) and refers to the uneven distribution of the soil particles throughout each monitoring field. The variability caused by these types of heterogeneity generally is much larger than the variability caused by laboratory uncertainty, although for some elements, the laboratory variability may exceed the sampling variability (Crock and others, 1992, 1994; Severson and others, 1990; Stewart and others, 1993). In order to state with confidence that the composition of soil in the biosolids-applied field is being affected by biosolids, the change in composition for a given element must exceed the natural variability for that element as determined in the control fields.

The geochemical data from the first soil sampling in 1999, prior to any biosolids application to the monitoring sites, showed a substantial difference in the composition of

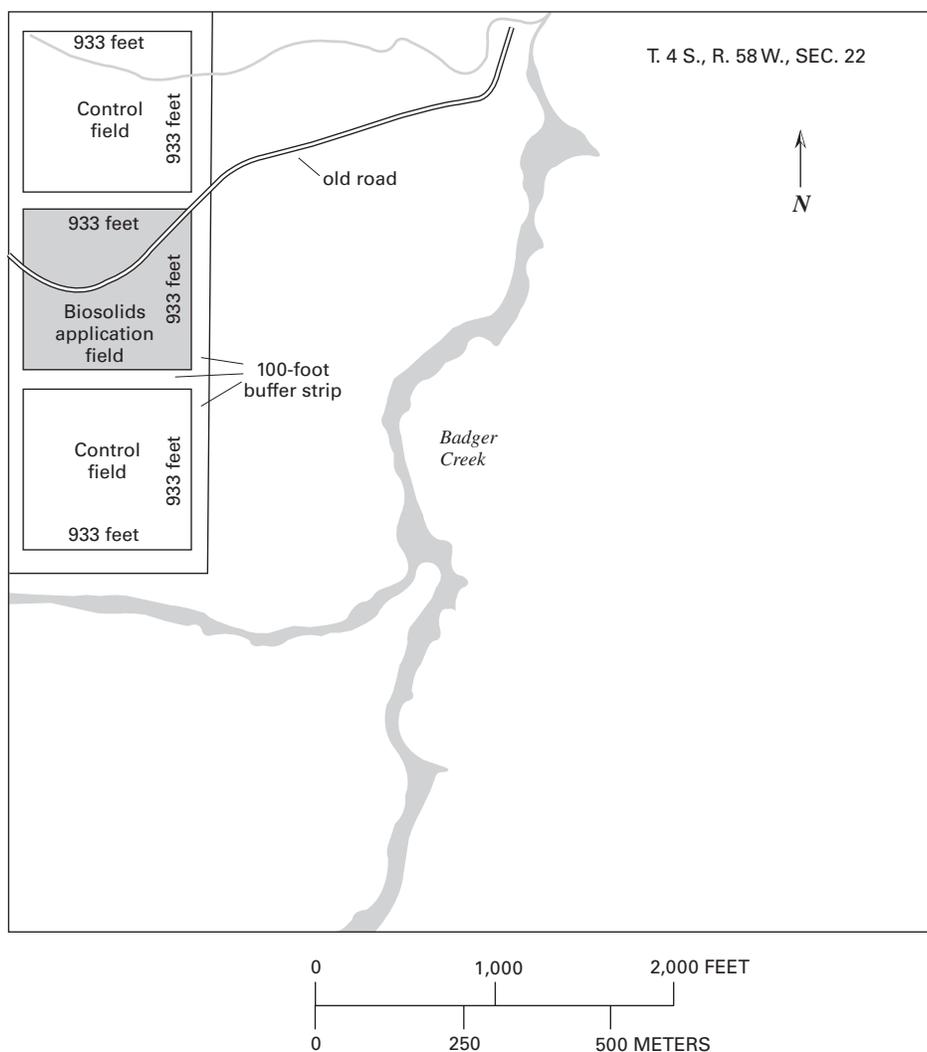


Figure 6. Arapahoe County, Colorado, soil-monitoring site (modified from Metro Wastewater Reclamation District).

soils collected from the Arapahoe County site in comparison to those collected from the Elbert County site (Stevens and others, 2003). The Elbert County soils generally showed higher concentrations of trace elements than Arapahoe County soils. This higher concentration was confirmed in data from the two subsequent sampling events (Yager and others, 2004c), and is likely related to the observed higher clay content of the Elbert County soils, which, in turn, is related to the parent material of the soil. Most of the soils at the Elbert County site belong to the Renohill Series, which developed in material weathered from shale (Larsen and others, 1966). Most of the Arapahoe County site contains soils from the Baca Series, which has a larger component of sandstone in its parent material (Larsen and Brown, 1971). It is well documented in the geochemical literature that shales contain higher concentration of trace elements than sandstones (Drever, 1988) and, thus, the Elbert County soils have a higher concentration of these elements than the Arapahoe County soils.

The natural variability in soil geochemistry is indicated by comparing the concentrations for the same element in the same control field over the course of several different samplings. Soil samples were collected three times during this study. The variation in concentration for the priority parameters over the course of the three sampling events is shown in figures 8 and 9. The uncertainty bars on these figures represent plus or minus two standard deviations for the concentration of the parameter on the biosolids-applied field. This is a common way of visually illustrating the natural variability of soil composition and means that if a similar soil-sampling event took place, the concentration of a given parameter would fall within these uncertainty bars 95 percent of the time. For most parameters, there is almost complete overlap of these uncertainty bars with the concentrations of the same element in one or both control fields for the same county. This overlap indicates that two applications of biosolids have not had a measurable effect on soil geochemistry. The only instance where this may not be obvious is for cadmium in the Arapahoe County site

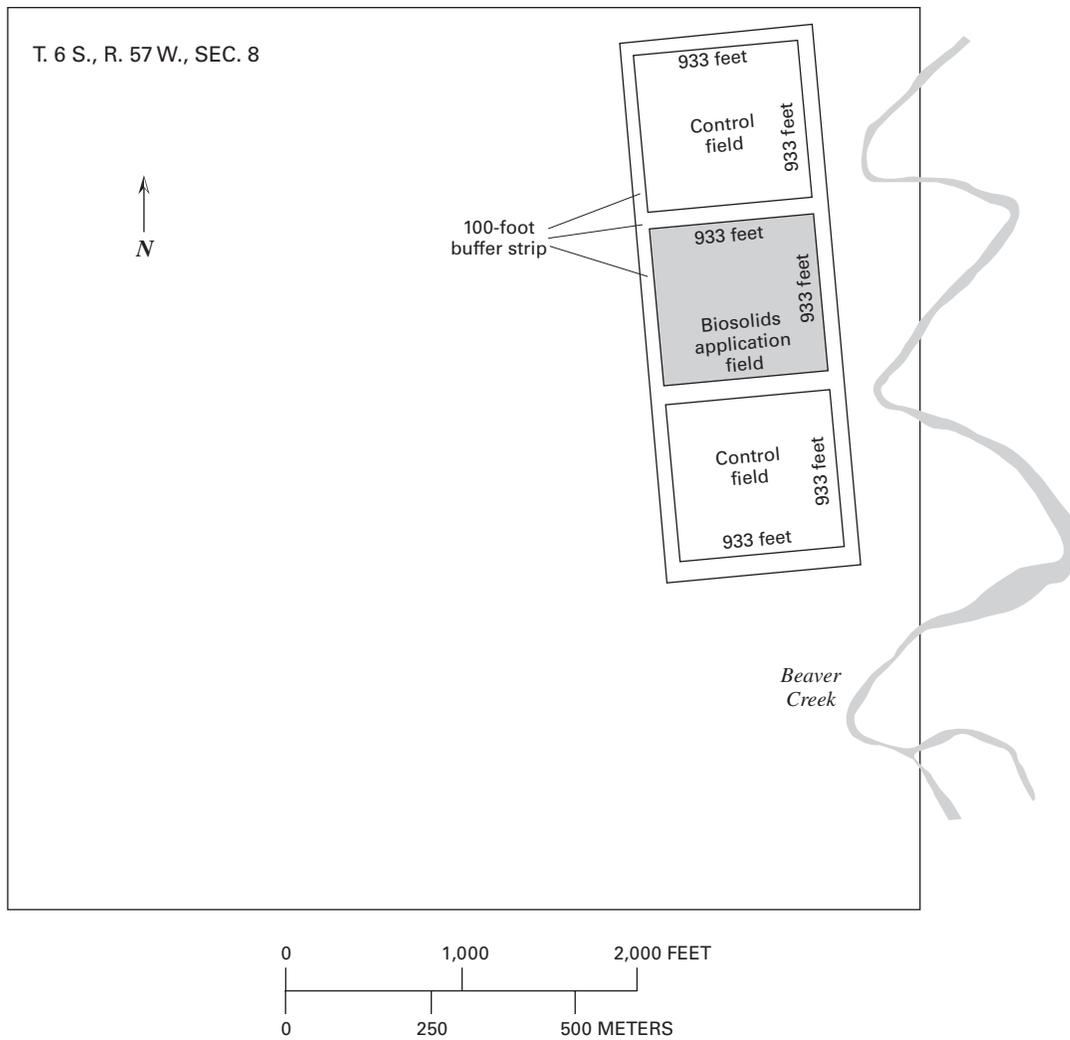


Figure 7. Elbert County, Colorado, soil-monitoring site (modified from Metro Wastewater Reclamation District).

(fig. 8) where the concentration in the 2001 sample is higher in the biosolids-applied field than in either of the control fields. Does this indicate that the application of biosolids caused this difference? Inspection of the cadmium data for 1999, prior to biosolids being applied, indicates that the biosolids-applied field also showed a higher cadmium concentration in 1999 than either of the control fields and changed little during the remainder of this study, which covered two applications of biosolids. If the uncertainty bars also were shown on the data points for the control fields, no statistical difference would be indicated in any of these analytical values for cadmium. Thus, it is concluded that during the 5 years of this study, which included only two applications of biosolids, there is no measurable effect on the concentration of the priority parameters in soils near Deer Trail.

Simple calculations will enable us to determine if any measurable effect on the soils should have been expected from two applications of biosolids and also to determine how many applications it would take before a measurable difference in

composition of the soil is observed. These calculations assume that all the applied biosolids remain within the top 12 inches of soil. In other words, it is assumed there is no physical transport by wind or water or chemical transport beyond the boundaries of the monitoring field or to a depth greater than 12 inches. Of the nine trace elements regulated for biosolids, copper shows the largest difference in concentration between the biosolids (about 620 mg/kg average) and soils in the control fields (15 mg/kg average for Arapahoe County control fields) (table 1). By using the biosolids application rate of 1.14 tons (1,034 kg) per acre used during 2002 for the Arapahoe County site (Becky Patterson, Metro Wastewater Reclamation District, written commun., February 25, 2004), the number of milligrams of copper applied to one of the 20-acre fields can be calculated as follows:

$$(1,034 \text{ kg biosolids/acre}) \times (20 \text{ acres}) \\ \times (620 \text{ mg copper/kg biosolids}) = 1.28 \times 10^7 \text{ mg copper} \\ \text{applied to one 20-acre field.} \quad (1)$$

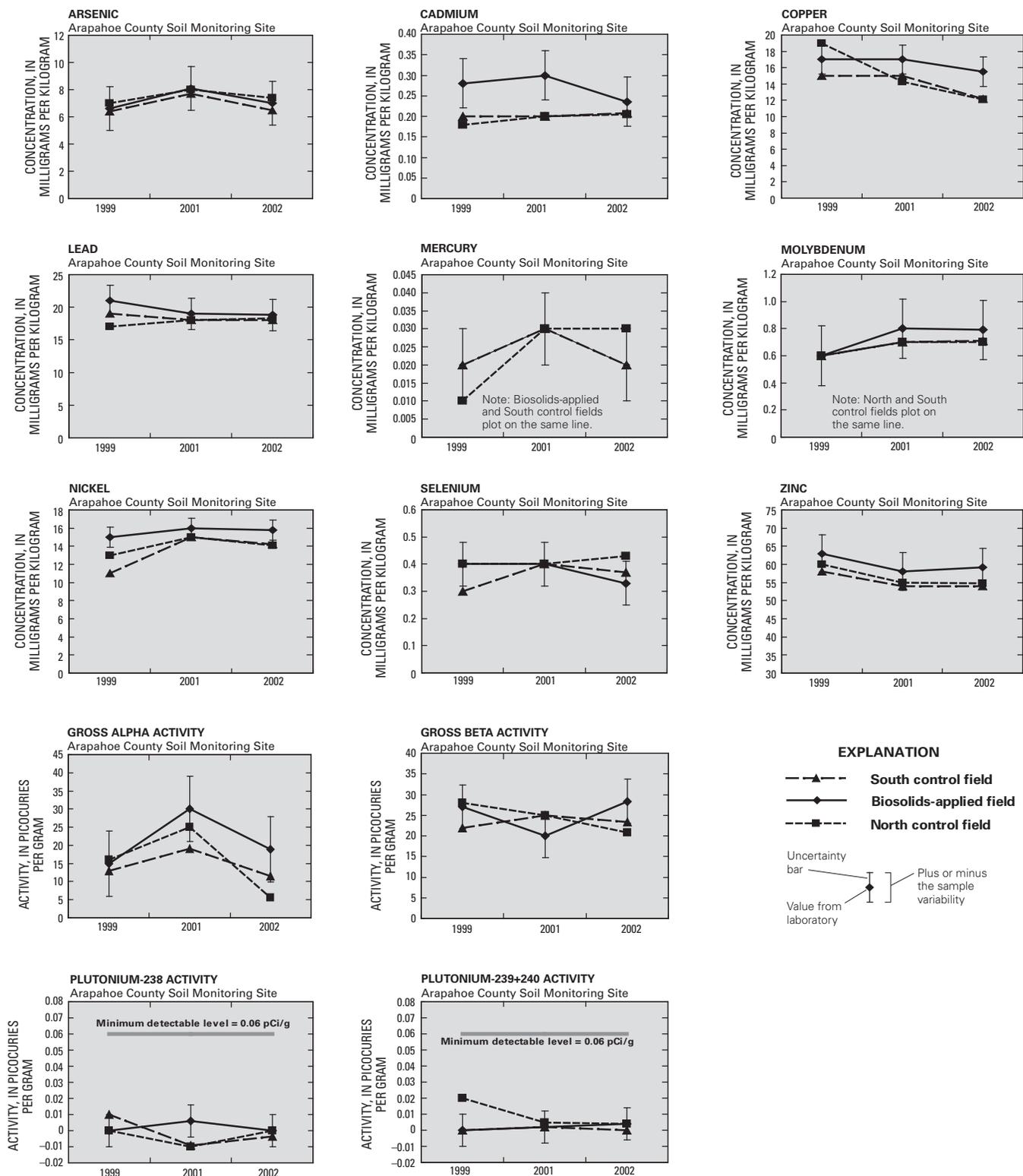


Figure 8. Concentrations of priority parameters in soil from the Arapahoe County monitoring site. (Uncertainty bars for trace elements represent plus or minus 2 standard deviations; see table 1. Uncertainty bars for radiochemical data are the average of the combined standard uncertainty provided by the laboratory.)

18 Effects of Surface Applications of Biosolids near Deer Trail, Colorado, 1999–2003

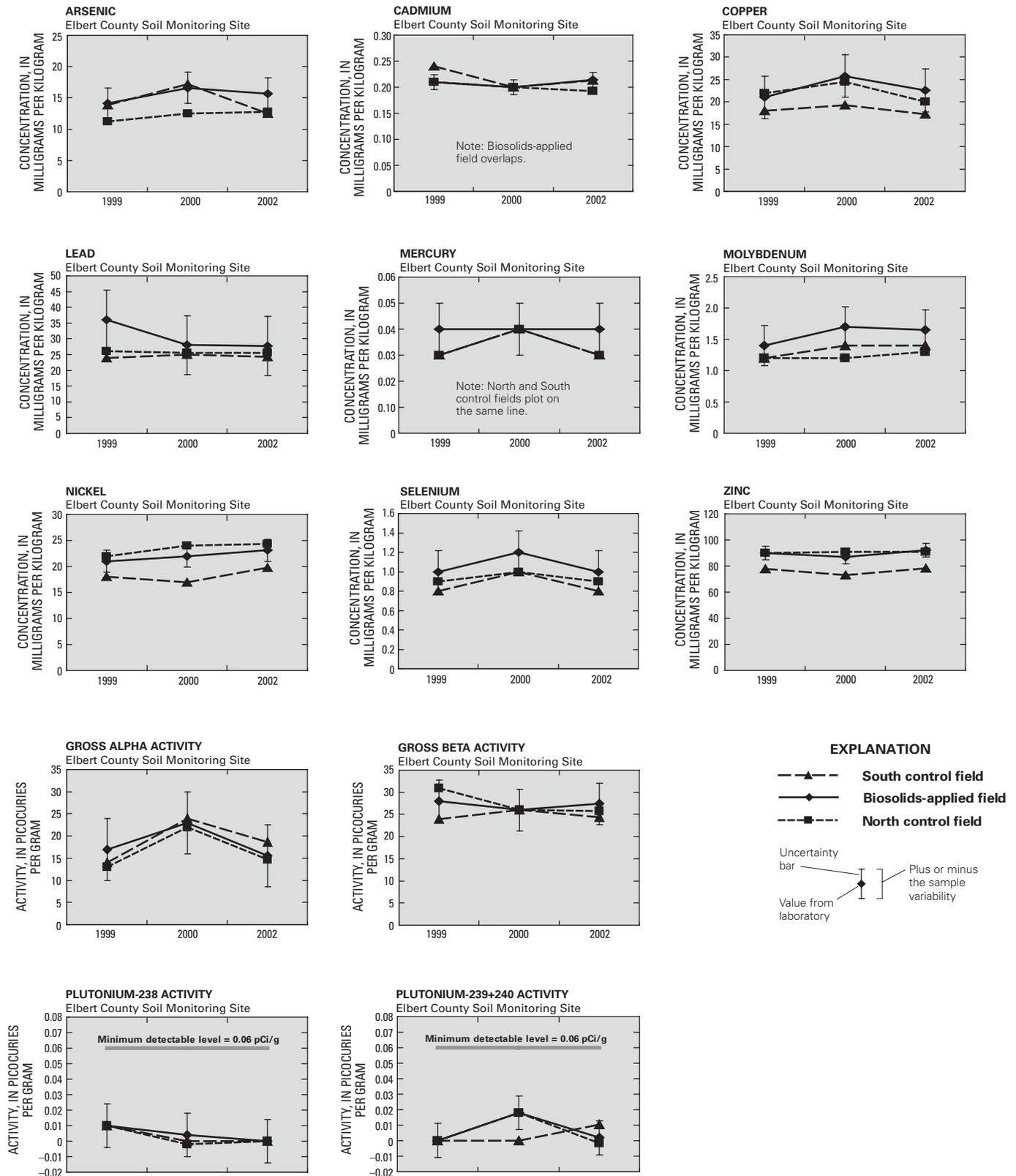


Figure 9. Concentrations of priority parameters in soil from the Elbert County monitoring site. (Uncertainty bars for trace elements represent plus or minus 2 standard deviations; see table 1. Uncertainty bars for radiochemical data are the average of the combined standard uncertainty provided by the laboratory.)

Next, the total number of kilograms of soil contained in the top 12 inches (30.5 cm) of a 20-acre (284 m × 284 m = 80,656 m²) field is determined. To calculate this number, the density of the soil must be known. The density was measured in the field by the USGS and was found to be approximately 1.4 g/cm³. This value was confirmed by bulk density information for soils of Arapahoe County given on the Web site of the Natural Resources Conservation Service (<http://ssldata.nrcs.usda.gov/querypage.asp>, accessed on July 1, 2004). With this information, the following calculation is made:

$$(80,656 \text{ m}^2) \times (10,000 \text{ cm}^2/\text{m}^2) \times (30.5 \text{ cm}) \\ \times (1.4 \text{ g/cm}^3) \times (1 \text{ kg}/1,000 \text{ g}) = 3.44 \times 10^7 \text{ kg} \\ \text{of soil in the top 12 inches of a 20-acre field.} \quad (2)$$

Now divide the results of calculation (1) by calculation (2) to obtain the concentration of copper in the top 12 inches of soil as a result of applying biosolids at a rate of 1.14 tons/acre:

$$(1.28 \times 10^7 \text{ mg copper}) / (3.44 \times 10^7 \text{ kg soil}) \\ = 0.37 \text{ mg copper/kg soil.} \quad (3)$$

This result indicates that one application of biosolids at a rate of 1.14 tons/acre increases the concentration of copper in the top 12 inches of soil by only 0.37 mg/kg. Given that the average copper content of soils on the Arapahoe County site is about 15 mg/kg, this is only about a 2-percent increase. Such a small increase is beyond our capability of measuring with any degree of confidence. The natural variability for copper in soils from the Arapahoe County control fields is plus or minus 5 mg/kg (table 1). It would take about 14 applications of biosolids at the above application rate, with an increase of 0.37 mg/kg with each application, to exceed this 5 mg/kg uncertainty. Assuming that the application rate for biosolids remained constant at 1.14 tons/acre and that applications took place every other year, then it would take about 28 years before the copper content increased to the point where the natural variability could begin to be ruled out. For those elements whose concentrations in biosolids are not so drastically different from their concentration in soil, it would take considerably longer before the effects of biosolids application could be measured beyond the natural variability. Arsenic has a concentration in biosolids that is less than the arsenic concentration in soils of Arapahoe and Elbert Counties (table 1). A decrease in arsenic content in the upper soil zone would result from the dilution effect of biosolids application if measurements were made for a sufficiently long period of time.

In table 1, bismuth, chromium, phosphorus, and silver are listed as potential indicators for the effects of biosolids on soils. These elements have concentrations in biosolids that are as much as two orders of magnitude higher than their concentrations in soils near Deer Trail. For example, bismuth concentration in biosolids averages 31 ppm, whereas its concentration in soils of the Arapahoe County control fields averages 0.21 ppm (table 1), a difference by a factor of more than 100. Calculations similar to (1), (2), and (3) above show

that one application of biosolids at a rate of 1.14 tons/acre could cause an increase in bismuth concentration in soil of 0.02 ppm. This represents an increase of almost 10 percent from the pre-biosolids bismuth concentration. At this rate of increase, bismuth concentration would increase beyond the 0.10 ppm natural variability within about five applications of biosolids, or about 10 years.

Application of biosolids has had no measurable effect on the radioactivity of the soils from the monitoring sites (figs. 8 and 9). As was true for the trace elements, all the values for gross alpha and gross beta activity and plutonium activity in the control fields generally fall within the two-standard-deviation uncertainty bars calculated for the biosolids-applied field. This means there is no significant difference between the measured parameter in the biosolids-applied field compared to the control fields. The plutonium data are below the minimum detectable level for all samples (figs. 8 and 9) with a distribution near zero.

These graphs also illustrate why it is important to have control fields (no biosolids ever applied) in this study and why it is important to exercise caution in interpreting a very small number of data points. Looking at the 1999 and 2000/2001 data points on the gross alpha activity graphs for the biosolids-applied fields, the activity increases from 15 to 30 pCi/g for the Arapahoe County field (fig. 8) and from 17 to 23 pCi/g for the Elbert County field (fig. 9). Some who are not sufficiently familiar with the uncertainties of this type of study may point to these data as evidence for radioactivity of the soil increasing because of biosolids application. However, the gross alpha activity graphs for the control fields, which have never received biosolids, show a similar increase. For example, the Arapahoe County north control field increased from 16 to 25 pCi/g (fig. 8), and the Elbert County south control field increased from 14 to 24 pCi/g (fig. 9). All four of the control fields showed an apparent increase in gross alpha activity from the 1999 sampling to the 2000/2001 sampling. This increase could not be an effect of biosolids application because these control fields never received biosolids. Such a uniform increase for all the fields (both application and control) likely is caused by a slight bias in the analytical laboratories. The 2002 data points indicate that the gross alpha activity data are similar to the 1999 data.

Comparison with Established Soil Standards and Screening Levels

Agencies such as the Colorado Department of Public Health and Environment (CDPHE) and the U.S. Environmental Protection Agency (USEPA) have established standards for certain elements in soil protective of ecological and human health. In 1997, the CDPHE released a policy document stating soil remediation objectives and soil cleanup standards designed to provide adequate protection of human health and the environment considering both direct contact pathways (ingestion, inhalation, skin exposure) and potential migration to ground water

(Colorado Department of Public Health and Environment, 1997b). Cleanup value standards for arsenic, lead, and mercury for three alternative land uses (residential, commercial, industrial) are listed in table 2. The lowest lead and mercury cleanup levels (400 mg/kg and 17.66 mg/kg, respectively, for residential use) are much higher than the lead and mercury concentrations in soils on the Arapahoe and Elbert County monitoring sites (table 1). The standards for these two elements were determined based on noncancer effects by using a reference dose approach or, in the case of lead, a target blood level. However, the arsenic cleanup value standards for all three land uses are lower than the concentration in soils near Deer Trail. The CDPHE developed this arsenic standard by back-calculating a soil concentration equivalent to a one-in-a-million cumulative cancer risk (Colorado Department of Public Health and Environment, 1997b). This type of calculation for arsenic has led to a standard that is actually below the arsenic concentration of sampled soils in Arapahoe and Elbert Counties. Such a scenario is not uncommon for States that have used a similar approach for calculating cleanup value standards.

The USEPA recently released toxicity-derived ecological soil screening levels (Eco-SSLs) for eight metals, two of which (cadmium and lead) are regulated in biosolids (U.S. Environmental Protection Agency, 2003a, 2003b). This document defines Eco-SSLs as “concentrations of contaminants in soil that are protective of ecological receptors that commonly come into contact with soil or ingest biota that live in or on soil.” Eco-SSLs were derived separately for four groups of ecological receptors: plants, soil invertebrates, birds, and mammals. As such, the values are presumed to provide adequate protection of terrestrial ecosystems. The Eco-SSLs for lead and cadmium in these four receptors are listed in table 3. Cadmium concentrations in soils from the Arapahoe and Elbert County monitoring sites are below all of these Eco-SSLs. However, lead concentrations in both counties are slightly above the Eco-SSL for birds. This is true for both the control and application fields, so application of biosolids likely is not the cause of this exceedance. According to the USEPA Web site (<http://www.epa.gov/ecotox/ecossl/faq.htm>, accessed on June 30, 2004), the agency plans to release other Eco-SSLs at some point in the future, and these will include other biosolids-regulated trace elements (arsenic, copper, nickel, selenium, and zinc).

Table 2. Soil cleanup value standards for Colorado.

[From Colorado Department of Public Health and Environment (1997b); mg/kg, milligrams per kilogram]

Element	Land use		
	Residential	Commercial	Industrial
Arsenic (mg/kg)	0.21	1.04	0.82
Lead (mg/kg)	400	2,920	1,460
Mercury (inorganic) (mg/kg)	17.66	176.53	137.07

Table 3. Ecological soil-screening levels for cadmium and lead.

[All values are milligrams per kilogram dry weight of soil]

Element	Plants	Soil invertebrates	Birds	Mammals
Cadmium ¹	32	140	1.0	0.38
Lead ²	110	1,700	16	59

¹U.S. Environmental Protection Agency (2003b).

²U.S. Environmental Protection Agency (2003a).

Biosolids Signature

Differences in trace-element composition between the biosolids-applied and control fields were not identified when variability and soil heterogeneity were considered. If sufficient samples were collected over a long enough period of biosolids applications, differences between the biosolids-applied and control fields could emerge. How would we know if these differences were because of biosolids applications or because of natural geochemical differences between the fields? A larger component of shale in the soil parent material of the biosolids-applied fields could cause localized higher trace-element concentrations in the soil samples from the biosolids-applied fields. A biosolids chemical signature would be helpful to distinguish biosolids effects from the natural geochemical signature of the soil.

An inorganic-chemical signature for biosolids can be determined from the 1999 through 2003 data summary in table 1. By comparing chemical data for biosolids with chemical data for the various soil control plots (soil-sampling areas where biosolids are never applied), the only elements for which biosolids concentrations are substantially greater than natural soil concentrations are bismuth, cadmium, copper, mercury, molybdenum, phosphorus, selenium, silver, uranium, and zinc (table 1). The largest concentration differences are seen for bismuth, mercury, phosphorus, and silver. Therefore, an inorganic-chemical signature for biosolids relative to soil would be significantly higher concentrations of bismuth, mercury, phosphorus, and silver, and possibly cadmium, copper, molybdenum, selenium, uranium, and zinc, in soil samples from the biosolids-applied fields compared to those of the control fields. A clear biosolids signature is not evident in the 1999 through 2003 soil data. Bismuth, cadmium, copper, mercury, molybdenum, selenium, silver, uranium, and zinc are elements that are present in soil because of natural rock weathering (geochemistry) (Drever, 1988; Pais and Jones, 1997).

Water Leachates from Soil

Preliminary experiments were conducted to determine if there was substantial mobilization of constituents upon contact of the soils with water. The same leach procedure using distilled-deionized water was followed as discussed previously in the Biosolids section. Table 10 in the Supplemental Information section lists the results and compares these results to the biosolids leach results. The results for soil from Arapahoe and Elbert Counties expressed as percentage of the

total concentration of the element removed by the water leach are shown in figure 10. Selenium is removed in higher percentages from the soils of Arapahoe County compared to other elements, whereas molybdenum and selenium are removed in higher percentages from the soils of Elbert County. No conclusion can be drawn regarding the effect of biosolids on the amount of leachable elements because these 1999 samples were collected prior to any biosolids application.

Crops

Biosolids can contain elevated concentrations of certain trace elements. The application of biosolids to farmland on which grain crops are grown that will eventually be consumed by animals or humans has led to public concern about the composition of the crops grown on the fields receiving biosolids.

Objectives of Monitoring Crops

Crops are monitored for priority parameters that include the nine trace elements regulated for biosolids (and plutonium and gross alpha and gross beta activity in selected samples) to establish independent chemical data sets for the composition of crops before and after the application of biosolids. The data will enable the recognition and quantification of significant changes, if any, in crop composition caused by the application of biosolids to agricultural soils or by other natural or human-induced processes.

Approach for Monitoring Crops

In the summer of 2000, monitoring of crops grown on the two soil-monitoring sites was begun. One of these sites is on MWRD property in Arapahoe County (fig. 6), and one site is on MWRD property in Elbert County (fig. 7). Samples were

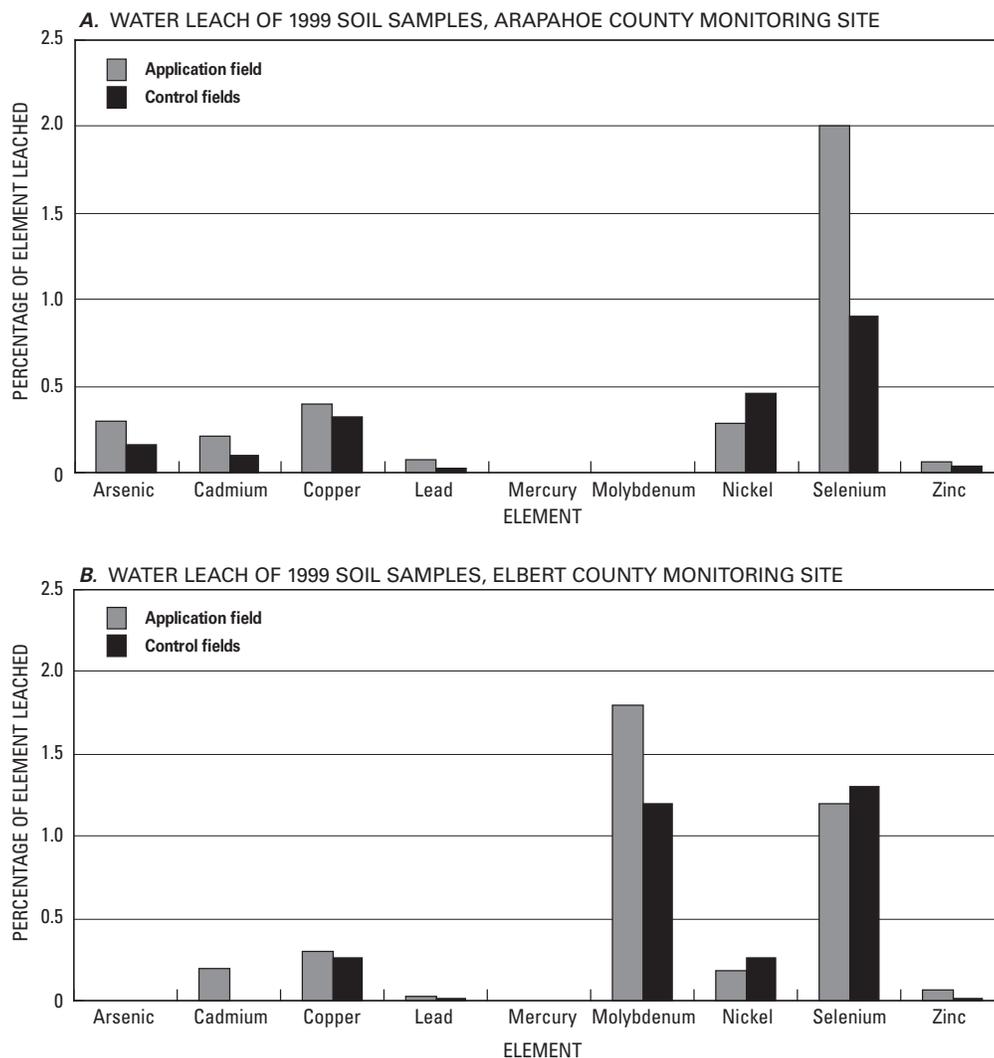


Figure 10. Trace elements extracted by water leach of the 1999 soil sample from the (A) Arapahoe County monitoring site and (B) the Elbert County monitoring site.

collected from the control and biosolids-application fields. The crop samples were analyzed for the nine trace elements that are regulated in biosolids (Colorado Department of Public Health and Environment, 1998): arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc. Selected samples also were analyzed for plutonium and gross alpha and gross beta activity in response to public concerns that biosolids radioactivity could increase from the transfer of treated water from the Lowry Landfill Superfund site to the MWRD treatment plant. The study was carried out over two crop harvests, 2000 and 2002, and data were reported, respectively, in Yager and others (2004a, 2004c).

The sampling protocol was designed to determine the average composition of the crop in each of the six 20-acre fields. A variety of hard red winter wheat was planted at each site (Drex Disbrow, Metro Wastewater Reclamation District, written commun., April 12, 2004). In 2000, wheat-plant samples were collected prior to crop maturity, and then mature wheat grain samples were collected about 1 month later just before harvest. In addition, millet grain was collected on the Arapahoe County site where it had been planted in the western part of the site after failure of the wheat crop. In 2002, wheat grain in the Arapahoe County fields was collected after harvest, and wheat grain in the Elbert County fields was collected during harvest. Complete details regarding dates of collection, sample-collection protocols, sample preparation, and analytical methods are provided in Yager and others (2004a, 2004c).

Effects of Biosolids on Crops

With only two data points (2000 and 2002), it is impossible to draw definitive conclusions about trends in crop composition or about comparisons between wheat grain grown on the control fields and grain grown on fields where biosolids were applied. For this reason, the following discussion will focus on comparing the wheat-grain data produced during this study with composition data found in the literature for similar winter wheat (no biosolids applied).

Table 4 lists the average composition (average of the 2000 and 2002 data) of wheat collected in the Arapahoe and Elbert County sites compared with data from the northern Great Plains of the United States (Erdman and Gough, 1979); Adams County, Colo. (Erdman and Tourtelot, 1976); San Joaquin Valley, Calif. (Severson and others, 1991); and from crop districts in Manitoba, Saskatchewan, and Alberta, Canada (Gawalko and others, 2001). For all elements in common with the data sets, the wheat from Arapahoe and Elbert Counties has similar composition to those from the other localities. The one exception to this statement may be nickel. The wheat collected from the 2000 and 2002 harvests from Arapahoe and Elbert Counties has a substantially higher nickel content than the data reported for the Great Plains of the United States and for Adams County, Colo. (the only data sets with nickel analysis). This is true for both the control fields and the applications fields. Data from several more harvests, and data for winter wheat from different parts of the world, are necessary to establish the validity of this observation.

Table 4. Comparison of concentration of priority parameters in wheat grain from monitoring fields near Deer Trail, Colorado (this study), with those from other published studies.

[Deer Trail study values are averages of the 2000 and 2002 data; biosolids-applied field received biosolids; control fields received no biosolids; other published studies had no biosolids applications; U.S., United States; CO, Colorado; CA, California; <, less than; --, not determined; mg/kg, milligrams per kilogram; pCi/g, picocuries per gram]

Parameter	Deer Trail study				Other published studies			
	Arapahoe County		Elbert County		Great Plains, U.S. ¹	Adams County, CO ²	San Joaquin Valley, CA ³	Western Canada ⁴
	Control fields	Biosolids-applied field	Control fields	Biosolids-applied field				
Arsenic, mg/kg	<0.05	0.05	<0.05	<0.05	--	--	--	--
Cadmium, mg/kg	0.03	0.02	0.015	0.015	0.035	0.042	--	0.034
Copper, mg/kg	5.5	7.0	5.1	5.4	3.9	5.3	4.6	4.06
Lead, mg/kg	0.01	0.02	0.02	0.04	--	--	--	--
Mercury, mg/kg	<0.002	<0.02	<0.02	<0.02	--	--	--	--
Molybdenum, mg/kg	0.73	0.9	0.87	1.1	0.64	1.4	0.6	--
Nickel, mg/kg	1.8	2.4	1.6	4.6	0.27	0.32	--	--
Selenium, mg/kg	0.4	1.2	1.4	0.5	0.44	0.29	0.18	0.4
Zinc, mg/kg	22	21	25	30	27	49	34	33.3
Gross alpha radioactivity, pCi/g	--	0.6±0.5	1±1	1±1	--	--	--	--
Gross beta radioactivity, pCi/g	--	3.5±0.8	5.5±2	5.5±2	--	--	--	--
Plutonium-238, pCi/g	--	0.0036±0.0070	0.0005±0.0200	0.00±0.01	--	--	--	--
Plutonium-239+240, pCi/g	--	-0.0035±0.0035	0.00±0.01	0.00±0.00	--	--	--	--

¹Erdman and Gough (1979).

²Erdman and Tourtelot (1976).

³Severson and others (1991).

⁴Gawalko and others (2001).

Another interesting observation is that wheat grain from all the Arapahoe and Elbert County fields showed substantial increases in nickel concentration from 2000 to 2002 (Yager and others, 2004a, 2004c). For Elbert County, nickel in the north control field increased from 0.43 to 1.7 mg/kg; in the south control field the increase was from 0.5 to 3.6 mg/kg; and the application field increased from 0.5 to 8.7 mg/kg. For Arapahoe County, nickel in the south control field increased from 0.74 to 3.0 mg/kg, while the application field showed an increase from 1.35 to 4.0 mg/kg. No wheat grain was collected in the north control field of Arapahoe County during 2000 because of crop failure. Because the increase occurs for both control and application fields in each county, it is concluded that the increase is not likely an effect of biosolids application. As discussed in Yager and others (2004c), it may be possible that this variation is nothing more than the normal variation that would be expected from using a small number of subsamples to characterize a large population. However, it seems just as likely that the cause may be an analytical bias from 2000 to 2002. Several more years of sampling are needed to fully document these variations.

In Elbert County, the radioactivity data for the wheat grains show that gross alpha activity averages about 1 pCi/g for both the control and application fields and gross beta activity averages about 5.5 pCi/g for both the control and application fields (table 4). Plutonium concentration is below detection for all samples with the distribution near zero. After two applications of biosolids, there is no indication that radioactivity has increased in the wheat.

Ground Water

Applications of pesticides, herbicides, or fertilizers (including biosolids) to the land surface can affect the quality of shallow ground water directly by contaminated recharge or by infiltration through contaminated soils or sediments (remobilization). These applications also can affect the quality of shallow ground water indirectly by tilling (which could mobilize subsurface constituents) or by contributions to natural processes such as nitrification. Further, discharge from contaminated alluvial ground water could contaminate surface water (ponds or streams) or bedrock aquifers. For this report, alluvial ground water is defined as the water contained in subsurface, unconsolidated (uncemented), wind- or water-transported sediments in current or historical stream channels or flood plains. Bedrock ground water is defined as the water contained in the fractures or pore spaces of the rock (consolidated sediments) that underlies soil or other uncemented materials; the primary bedrock aquifer in the study area is the Laramie-Fox Hills aquifer (Robson and Banta, 1995). Alluvial and bedrock ground water are separate components in the monitoring program but are combined in this report because the data were collected in the same way, and the types of data included are the same.

Objectives of Monitoring Ground Water

Ground water was monitored to characterize the hydrology and water quality of the aquifers to (1) determine if concentrations of nitrate, arsenic, cadmium, copper, chromium, lead, mercury, molybdenum, nickel, selenium, zinc, and plutonium and gross alpha and gross beta activity in the ground water are significantly greater than regulatory standards and (2) determine if concentrations of these constituents are increasing with time in ground water at or near the MWRD properties.

Approach for Monitoring Ground Water

Ground water routinely was monitored for chemistry at 14 wells and for hydrology at 23 wells. Bedrock ground water routinely was monitored for chemistry at three wells (DTX8, DTX10, and D29) and for hydrology at four wells (DTX8, DTX10, D11a, and D29). Alluvial ground water routinely was monitored for chemistry at 11 wells (DTX1, DTX2, DTX3, DTX4, DTX5, DTX6, D6, D13, D17, D25, and D30) and for hydrology at 17 wells (DTX1, DTX2, DTX3, DTX4, DTX5, DTX6, DTX7, DTX9, DTX11, D6, D6A, D13, D17, D19, D25, D25A, and D30). Vertical ground-water recharge was evaluated at two sites (DTX8 and DTX10) by using water-level data from wells at various depths at the same site and precipitation data. Continuous recorders with electronic data logger equipment (EDL) or data-collection platforms (DCP) provided detailed hydrologic information for six sites (DTX2, DTX5, DTX9, DTX10, DTX11, and D25). Selected core samples were analyzed for inorganic chemistry, and the data are reported by Stevens and others (2003) and Yager and others (2004c). Detailed information about site selection, well completion, lithology, data-collection methods, and quality assurance are provided by Stevens and others (2003), Yager and Arnold (2003), and Yager and others (2004a, 2004b, 2004c).

Structure maps of the top and base of the Laramie-Fox Hills aquifer were compiled for the study area. The structure maps are included in an interpretive USGS report by Yager and Arnold (2003). The structure maps were used to determine locations for well pairs: two bedrock-aquifer wells and two alluvial-aquifer wells that constitute two recharge-evaluation areas.

Monitoring wells for the expanded monitoring program included selected wells installed as part of the previous monitoring program and new wells. Of the 33 USGS ground-water monitoring wells from the previous study on the MWRD central property, 8 wells were included in this study (8 wells routinely were monitored for water levels, and 6 wells routinely were sampled for water quality). New monitoring wells were installed in the study area in 1999, 2000, and 2002. "D"-numbered wells were drilled before 1999 as part of the previous monitoring program (except for wells D6A and D25A), and "DTX"-numbered wells were drilled in 1999 or

2000 (fig. 1). Information for all the USGS wells monitored during 1999 through 2003 as part of this expanded monitoring program is summarized in table 11 (in the Supplemental Information section at the back of the report).

Water levels in the monitoring wells were measured monthly during 1999 through 2003. DCPs with various sensors operated 1999 through 2003 at wells D25, DTX2, and DTX5 to continuously measure ground-water levels, water temperature, precipitation, and air temperature. The data provided information about the hydrology in the study area and about the response of ground water to climate variables. Ground-water levels were continuously measured by EDL at DTX9, DTX10, and DTX11 from 2000 through 2003.

Water samples were collected from alluvial-aquifer wells on the MWRD properties, and water samples were collected from the shallowest zones of the bedrock aquifer at three locations (DTX8, DTX10, and D29) that are important to alluvial/bedrock ground-water interactions (fig. 1). During most of the monitoring program, the remaining USGS monitoring wells were used to provide hydrologic information only. During 1999 through 2003, ground-water samples were collected quarterly using standard USGS clean-hands protocols (U.S. Geological Survey, variously dated). Ground-water samples were analyzed for many parameters, including the priority parameters identified by the stakeholders (nitrate, arsenic, cadmium, copper, chromium, lead, mercury, molybdenum, nickel, selenium, zinc, and plutonium and gross alpha and gross beta activity). Ground-water samples were analyzed quarterly for physical properties, dissolved major ions and trace elements, and dissolved and total nutrients. Ground-water samples were analyzed annually for plutonium. Gross alpha and gross beta activity analyses were included in the 1999 monitoring but were discontinued because of matrix-interference problems caused by the high concentrations of dissolved solids in the ground-water samples. The plutonium and gross alpha and gross beta activity analyses were included in the monitoring program in response to public concerns that radioactivity in biosolids could increase from the transfer of treated water from the Lowry Landfill Superfund site to the MWRD treatment plant. Water levels and field measurements such as pH and specific conductance were recorded with the collection of each ground-water sample. Blank and replicate samples were analyzed to evaluate bias and variability of the ground-water data. Sampling and analytical methods are described by Stevens and others (2003) and Yager and others (2004a, 2004b, 2004c).

All data are maintained in the USGS National Water Information System (NWIS) database. Selected data were published in the “USGS Expanded Monitoring Program Near Deer Trail” quarterly and progress reports (available online at <http://co.water.usgs.gov/projects/CO406/CO406.html> accessed on July 1, 2004). All ground-water data collected for this program during 1999 through 2003 were published in Stevens and others (2003) and Yager and others (2004a, 2004b, 2004c).

Hydrology

The primary water-supply aquifer is the Laramie-Fox Hills aquifer, which is a bedrock aquifer that ranges from 0 to about 200 ft thick in the study area and is the bottom aquifer in the Denver Basin aquifer sequence (Robson and others, 1981; Robson and Banta, 1995). Multiple alluvial aquifers are present in the study area. These aquifers are associated with the surficial drainage network and contain water of variable quality, are of limited extent, and generally yield little water (Stevens and others, 2003; Yager and Arnold, 2003; Yager and others, 2004a, 2004b, 2004c).

The study area is within the South Platte River drainage basin; all streams in the study area are connected to the South Platte River (U.S. Geological Survey, 1974). Short segments of some of the streams are intermittent, but in general, the streams are ephemeral and flow only after storms. In general, the streams of the study area lose water to ground water when they flow. Muddy Creek, a stream on the western side of the study area, is hydraulically connected to the water table in both the alluvial and bedrock aquifers (Yager and Arnold, 2003). Beaver Creek, a stream in the southeastern part of the study area, also is hydraulically connected to the water table but only in the alluvial aquifer; no bedrock aquifer is present in that part of the study area (Yager and Arnold, 2003). Badger Creek, a stream in the northern part of the study area, is hydraulically connected to the water table in at least the alluvial aquifer in the vicinity of wells DTX1 and DTX2 (fig. 1). Hydraulic characteristics of Cottonwood and Rattlesnake Creeks on the MWRD properties are variable; lower reaches of the streams on the MWRD properties are hydraulically connected to the water table in alluvial aquifers, but upper reaches are disconnected from the water table.

Water Levels

Water-level data for 1999 through 2003 at selected sites are shown in figure 11. Depth to water below land surface ranged from about 2 to about 152 ft in the bedrock-aquifer monitoring wells. Depth to water below land surface ranged from about 3 to about 20 ft in the alluvial-aquifer monitoring wells.

Water levels fluctuated the least at wells DTX8B, D11a, and D19. Water levels fluctuated the most at wells DTX4 and DTX5. Water levels fluctuated the least during winter and the most during summer. At some wells, these fluctuations are present in a distinct seasonal pattern. Seasonal water-level declines followed by seasonal water-level increases are evident at some wells where the aquifers had shallow ground water, such as wells DTX1, DTX2, DTX4, DTX7, DTX8A, D13, and D25. Seasonal water-level declines indicate periods where evapotranspiration exceeds ground-water recharge (Yager and Arnold, 2003). Seasonal water-level increases indicate periods where recharge exceeds evapotranspiration.

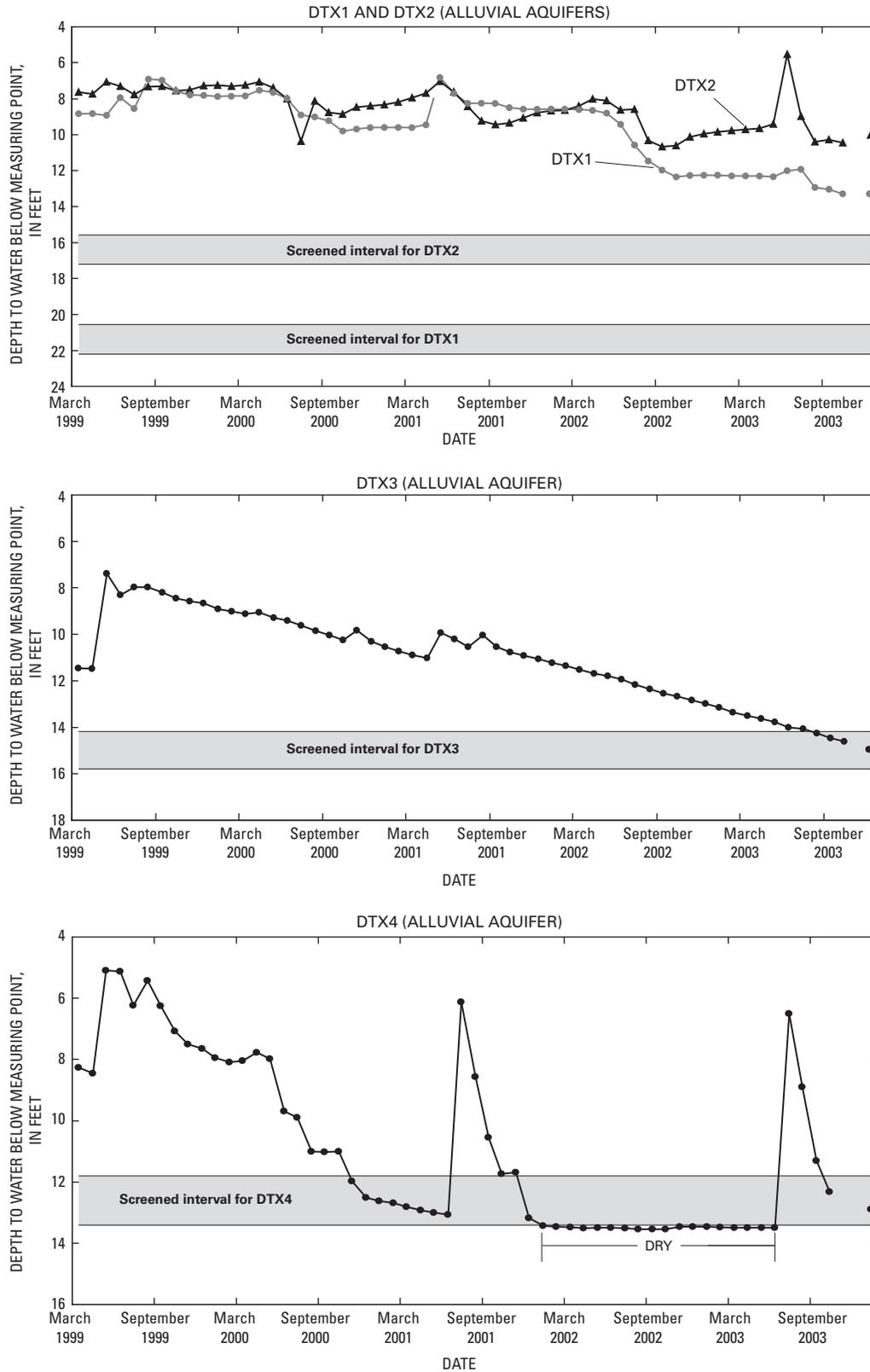


Figure 11. Monthly water-level data for selected U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1999–2003. (Earlier data are included for selected wells for comparison purposes.)

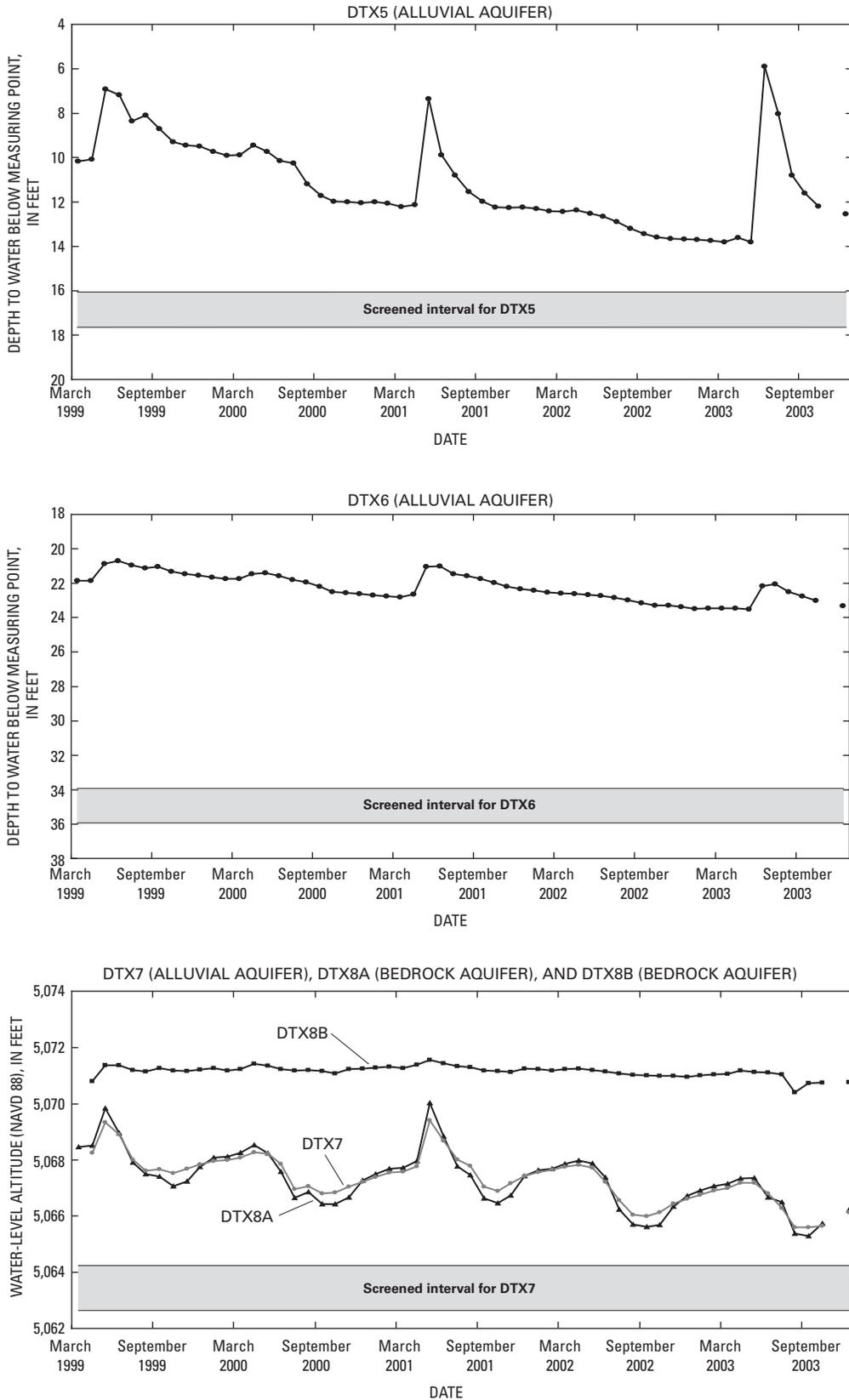


Figure 11. Monthly water-level data for selected U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1999–2003. (Earlier data are included for selected wells for comparison purposes.)
—Continued

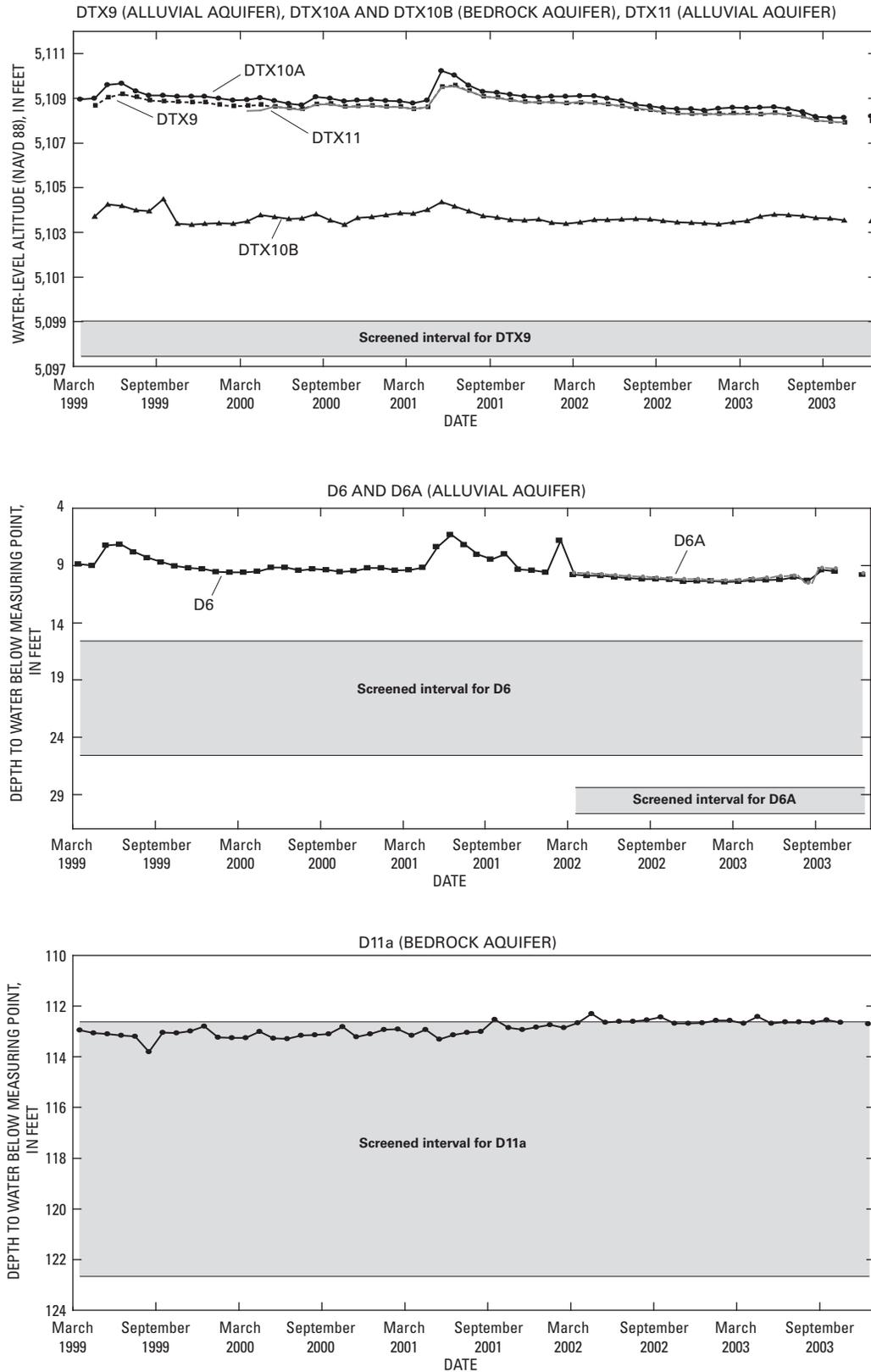


Figure 11. Monthly water-level data for selected U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1999–2003. (Earlier data are included for selected wells for comparison purposes.)

—Continued

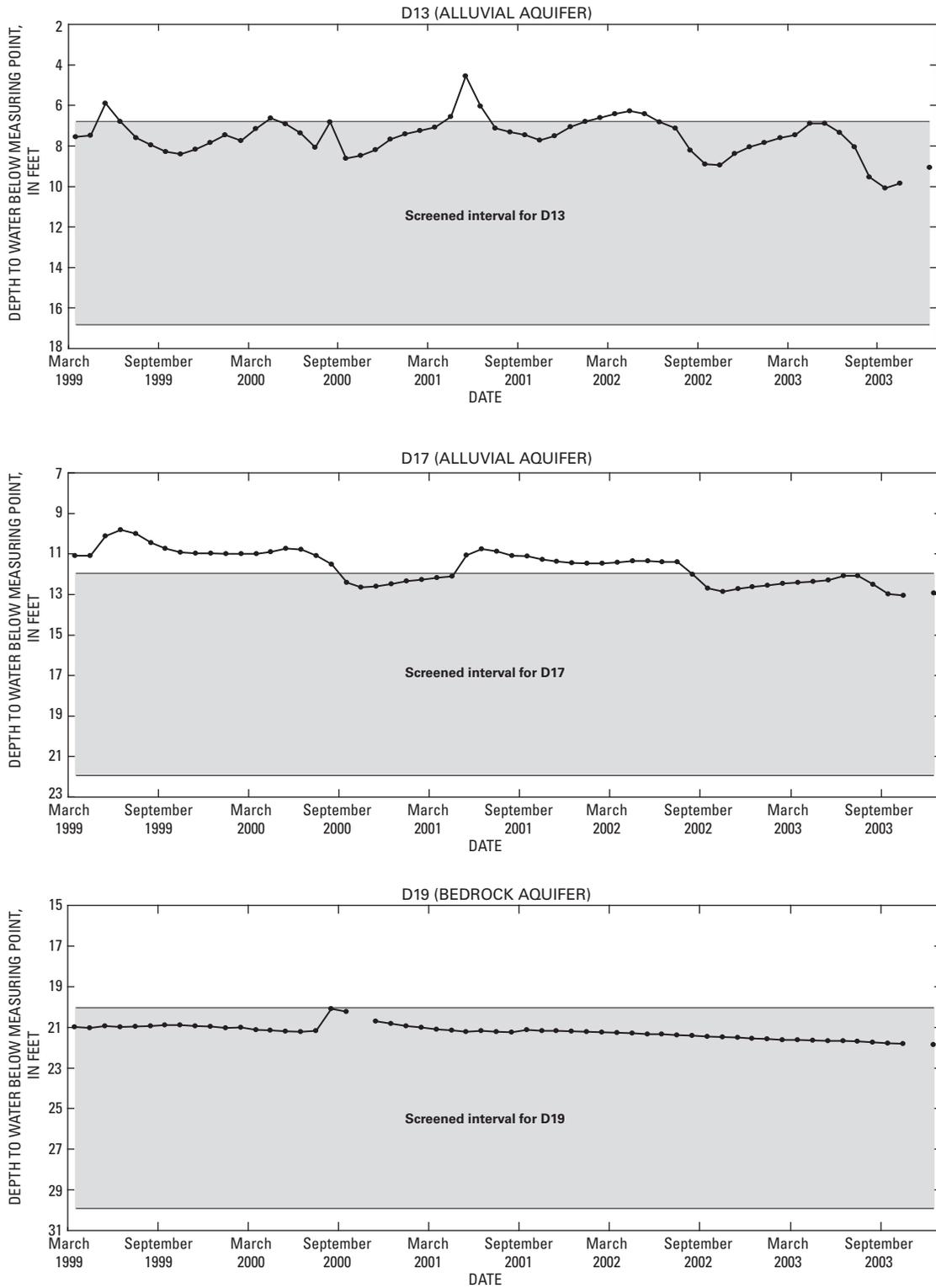


Figure 11. Monthly water-level data for selected U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1999–2003. (Earlier data are included for selected wells for comparison purposes.)—Continued

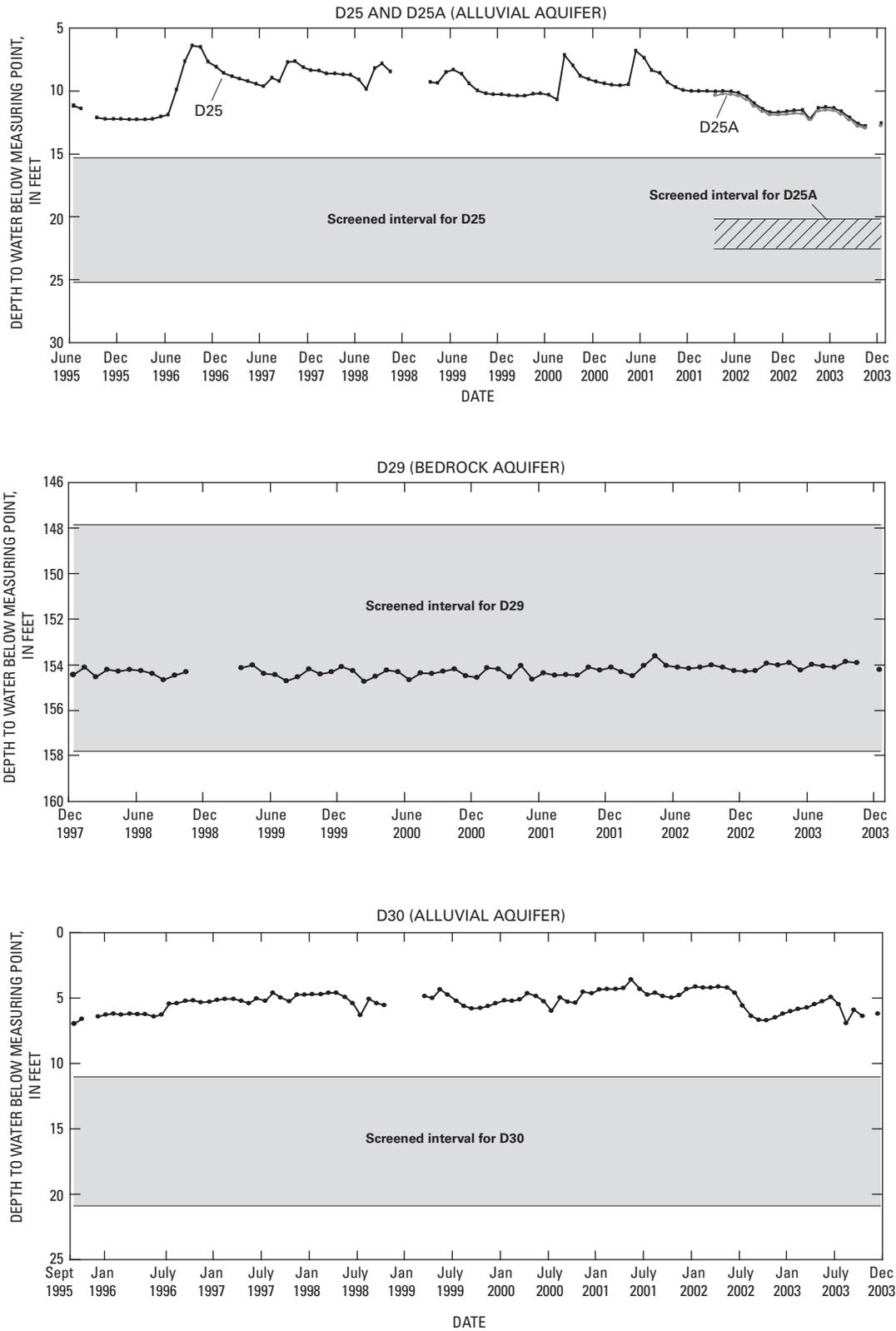


Figure 11. Monthly water-level data for selected U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1999–2003. (Earlier data are included for selected wells for comparison purposes.)—Continued

Visual inspection of the water-level data indicates that ground-water levels generally declined during 1999 through 2003 (fig. 11). Water levels declined in all the alluvial wells (fig. 1) monitored. Water levels in the alluvial aquifer in Middlemist Creek at well DTX3 declined about 2 ft/yr during 1999 through 2003. Well DTX3 is completed at the base of the alluvial aquifer, and the aquifer at this location was nearly dry by December 2003 and subsequently was completely dry. Water levels in the alluvial aquifer in the eastern Beaver Creek tributary at well DTX4 declined about 4 ft/yr during June 1999 to April 2001. Well DTX4 is completed at the base of the alluvial aquifer, and the aquifer at this location was completely dry during October 2001 until May 2003 then periodically recharged. The water-level data indicate smaller rates of decline for other aquifers. None of the other wells were dry or nearly dry by the end of 2003, as evidenced by the distance of the water level above the bottom of the screened interval (fig. 11).

Why did water levels decline during 1999 through 2003? Precipitation, the ultimate source of most of the ground water in the study area, was considerably less in 2002 compared with other years during 1996 through 2003 (figs. 12–15; Yager and Arnold, 2003). Intense rain is more likely to run off quickly than to infiltrate to ground water, and the USGS observed more runoff in the study area in 2001 and 2002 than in 1999, 2000, and 2003. Ground water from the monitoring wells is not pumped for agricultural or other use, but a supply well upstream from well DTX3 in Middlemist Creek was pumped since 1999 (perhaps about 5 acre-ft/yr, according to Mitch Costanzo, Metro Wastewater Reclamation District, written commun., January 15, 2004). Water levels in well DTX3 may be declining from less precipitation during the last few years of the study and also because of upstream pumping of the supply well. Location could explain declining water levels, although both wells DTX1 and DTX2 are located in the northern part of the study area in alluvial aquifers, but water levels at well DTX1 declined more than water levels at well DTX2 during 1999 through 2003 (fig. 11). Lithology of the aquifer could be the reason for the declining water levels in the study area, although well DTX4 is completed in a 0.5-ft-thick sand-gravel paleochannel deposit and was dry for about 2 years, whereas nearby well DTX5 is completed in a 0.3-ft-thick sandy-silt deposit and declined only about 1 ft/yr. Thin aquifers of small areal extent usually are more vulnerable to depletion from drought or other factors. Declining ground-water levels in the study area likely are caused by a combination of factors that include less precipitation and more runoff than infiltration in recent years and pumping or other upstream effects.

Not all wells indicated declining ground-water levels for 1999 through 2003. In fact, water levels in the bedrock aquifer at wells D11a and D29 on the ridge of the MWRD central property increased about 0.1 ft/yr during 1999 through 2003. Depth to ground water at these locations was more than 100 ft, so this part of the bedrock aquifer is less likely to be affected by less precipitation. Differences in recharge sources and pathways also could be reasons why water levels increased at these wells and decreased at other wells.

Water-level data for the study area before 1999 were included in figure 11 for three wells, D25, D29, and D30, and were included in Yager and Arnold (2003) for other wells. These data indicate that bedrock-aquifer water levels were similar from 1997 through 2003 at well D29, but alluvial-aquifer water levels varied considerably during 1995 through 2003 at well D25 (fig. 11). Water levels at well D6 generally increased during 1993–98 (Yager and Arnold, 2003, p. 48) but generally were flat during 1999 through 2003 (fig. 11). Water levels at wells D17 and D19 generally increased during 1994–98 (Yager and Arnold, 2003, p. 47) but generally decreased during 1999 through 2003 (fig. 11). Such data indicate that the ground-water levels in the study area naturally fluctuate over various time scales but generally have decreased from a recent dry climate cycle. Except where ground water is affected by pumping, ground-water levels in the study area could increase again in response to a wetter climate cycle, much like 1993–98.

Water-level data were recorded hourly by continuous recorders at six wells, and precipitation data were recorded hourly at four sites (summarized by daily values shown in figs. 12–14; fig. 15). Continuous-recorder data for the study area indicate that well DTX2 had the strongest diurnal water-level pattern, likely because ground-water levels at this well were more affected by evapotranspiration than at other wells. The data indicate that a single, unusually cool, cloudy day in October can raise water levels in well DTX2 by 0.15 ft because apparent water-level recharge did not result from precipitation but from a lack of discharge (evapotranspiration). The continuous-recorder data from well D25 indicate a strong hydraulic connection between well D25 and well D25A, about 15 ft away. Drilling, well completion, and well development of well D25A in 2002 affected water levels in well D25 by as much as 0.3 ft, and the effects lasted several days.

Recharge

Ground water can recharge directly or indirectly. Precipitation can directly recharge ground water by percolation through porous rock outcrops or through the unsaturated zone. Precipitation can indirectly recharge ground water by producing streamflow or pond water that infiltrates. In a sense, ground-water flow within the same aquifer can be a form of recharge in that any discrete parcel of water has traveled from some place else to that location. Ground water in one aquifer also can recharge ground water in a different, hydraulically connected aquifer (such as an alluvial aquifer recharging the bedrock aquifer, or the other way around) (Yager and Arnold, 2003). Age-dating ground water at selected sites in the study area in 1998 indicated that the ground water recharges too slowly at wells D13 and D17 to show the effects from biosolids applications at this time (2004), but recharge ages were inconclusive for wells D6 and D25 (old and young ground water mix at well D6, and a different test is needed at well D25 because of methane concentrations) (Yager and Arnold, 2003, table 3).

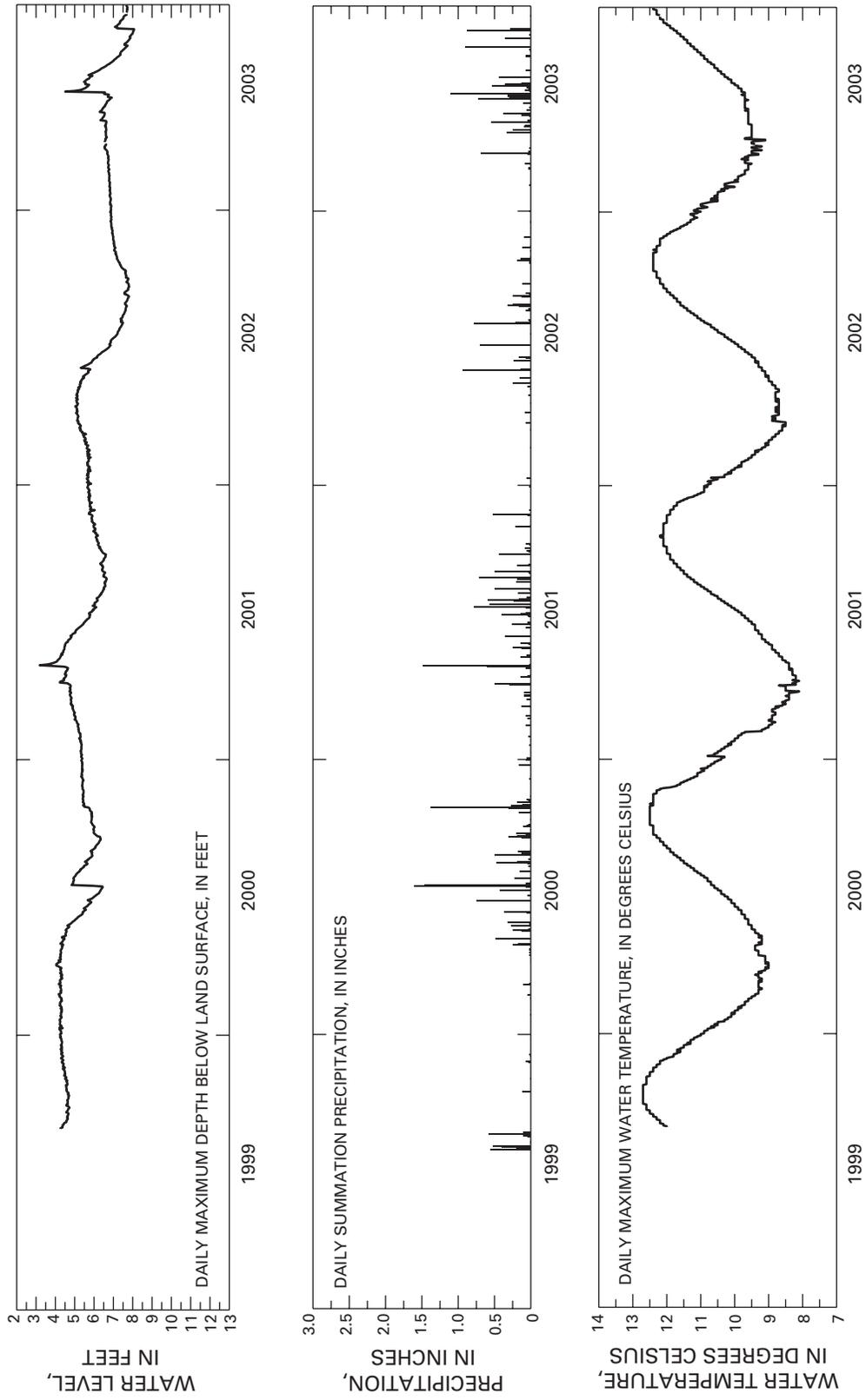


Figure 12. Continuous water-level, water-temperature, and precipitation data for well DTX2 near Deer Trail, Colorado, 1999–2003.

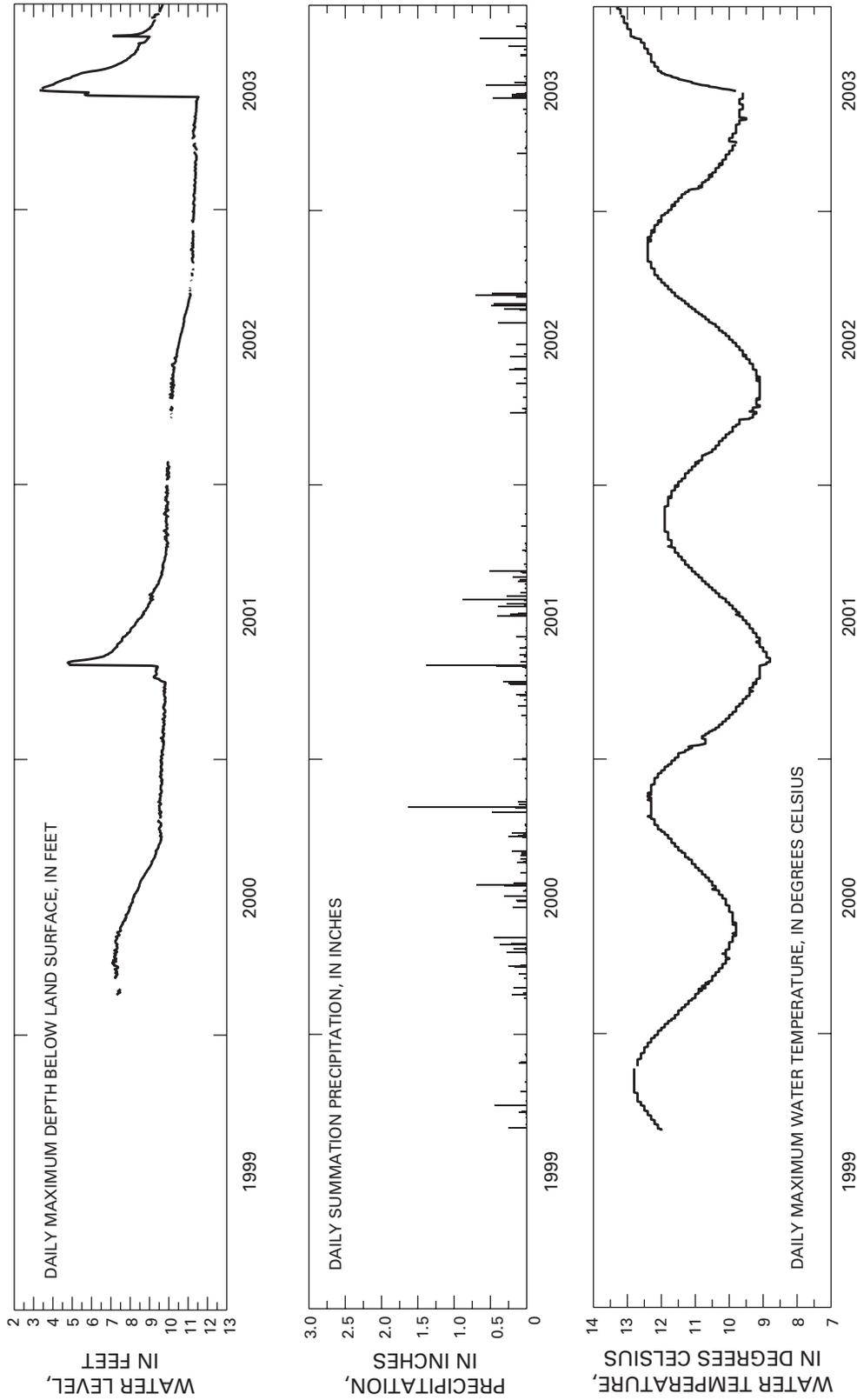


Figure 13. Continuous water-level, water-temperature, and precipitation data for well DTX5 near Deer Trail, Colorado, 1999–2003.

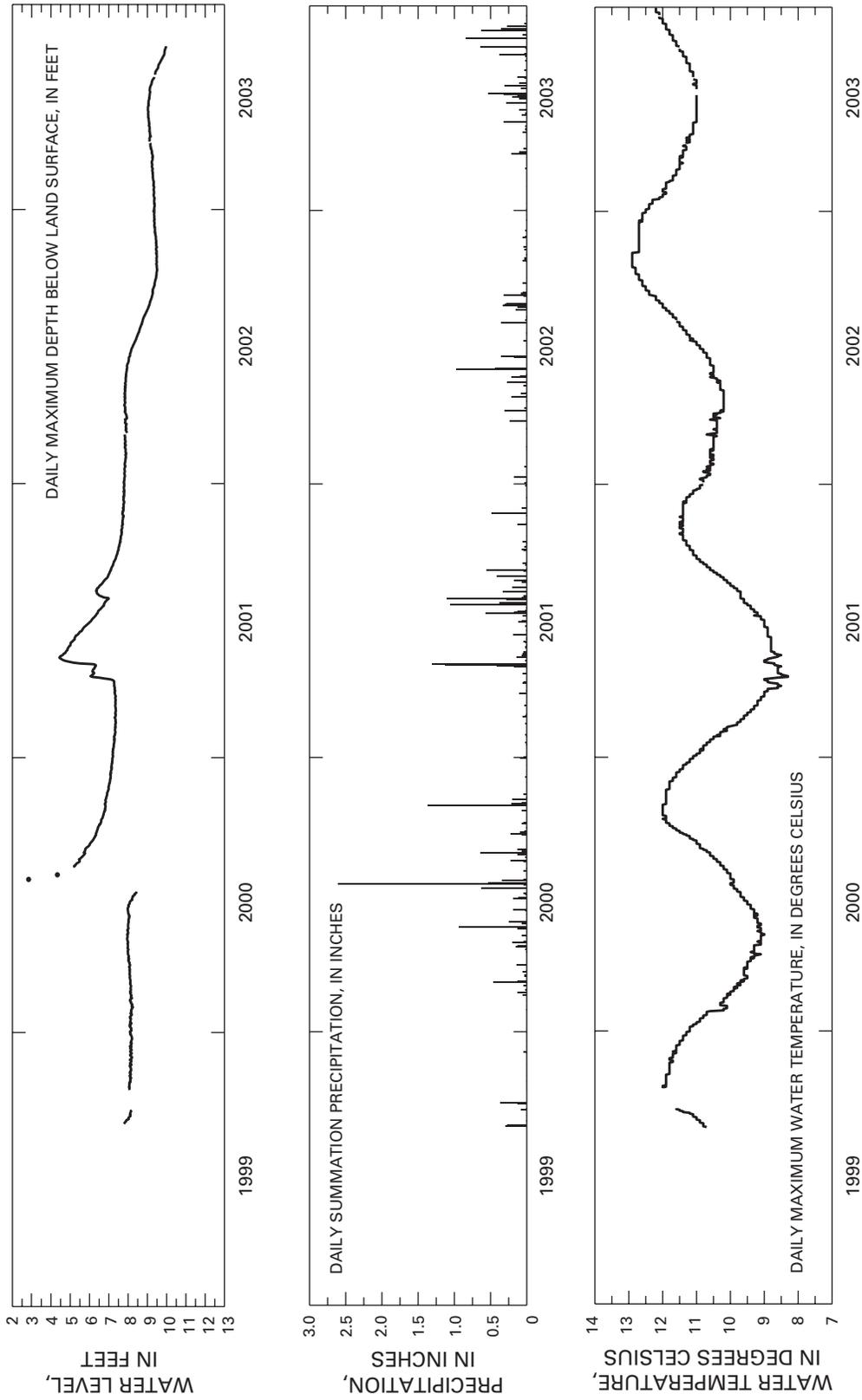


Figure 14. Continuous water-level, water-temperature, and precipitation data for well D25 near Deer Trail, Colorado, 1999–2003.

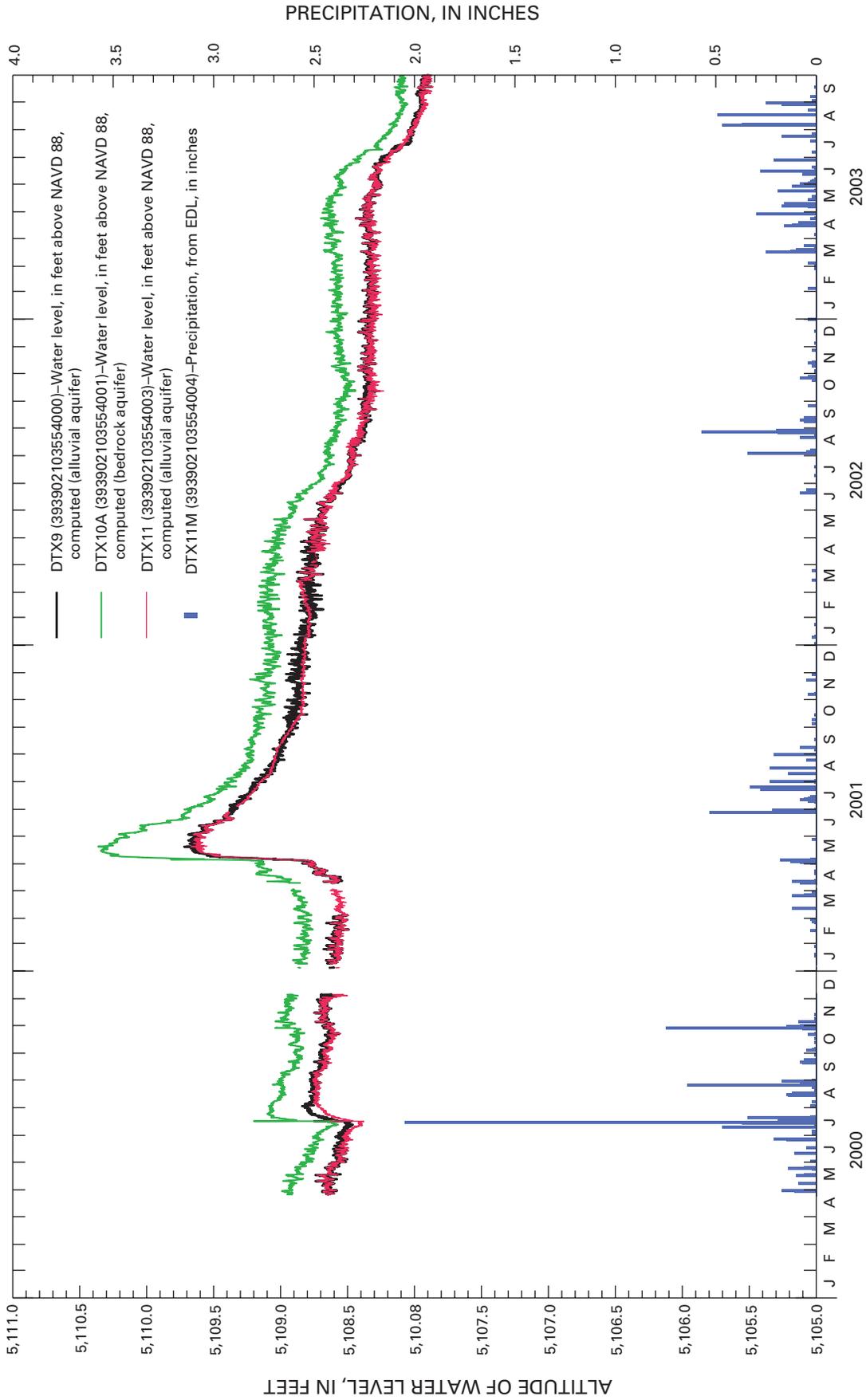


Figure 15. Continuous water-level altitudes for wells DTX9, DTX10, and DTX11, and precipitation data for a recharge-evaluation area near Deer Trail, Colorado, 2000–2003.

Ground-water recharge was evaluated through comparison of precipitation data with ground-water level data. Increased water levels are considered a sign of ground-water recharge. Data indicate that wells DTX1, DTX2, DTX4, DTX5, DTX6, DTX7, DTX8A, DTX9, DTX10A, D6, D6A, D13, and D25 respond to certain precipitation rates and quantities by rapid increased water levels (figs. 11–15). That could mean that precipitation infiltrates at the well, or that precipitation infiltrates elsewhere and causes corresponding increased ground-water pressure at the well, which results in increased water levels at the well. Yager and Arnold (2003) reported that age-dating of ground-water samples from wells D6 and D25 in 1998 indicated that ground water at those sites likely was much older than indicated by the quick water-level response to precipitation. That is, ground water in the study area (at these sites at least) likely recharges from precipitation or surface water a distance upgradient from the monitoring well. The quick water-level response to precipitation likely underestimates the traveltime of chemical constituents or contaminants vertically down through the unsaturated zone above the aquifers or even horizontally through the aquifer.

Continuous-recorder data for 1999 through 2003 indicate that episodic recharge from precipitation occasionally affected ground-water levels, but ground water was not recharged from every precipitation event. At well DTX2, episodic recharge increased the daily maximum depth to water a maximum of 2 ft and occurred each year monitored (fig. 12). At well DTX5, episodic recharge increased the daily maximum depth to water a maximum of about 8 ft and occurred only in 2001 and 2003 (fig. 13). At well D25, episodic recharge increased the daily maximum depth to water a maximum of about 5.5 ft and occurred only in 2000 and 2001 (fig. 14). At wells DTX9 and DTX11, episodic recharge increased the daily maximum depth to water a maximum of about 1 ft and occurred only in 2000 and 2001 (fig. 15). At DTX10A, episodic recharge increased the daily maximum depth to water a maximum of about 1.2 ft and occurred only in 2000 and 2001 (fig. 15). Episodic recharge at the continuous-recorder sites was immediately followed by a higher rate of water-level decline than during other periods of declining water levels, likely because higher water levels mean the ground water is closer to the land surface and therefore more subject to evapotranspiration.

Net recharge can be calculated as the seasonal water-level rises (periods where recharge exceeds evapotranspiration) minus the seasonal water-level declines (periods where evapotranspiration exceeds ground-water recharge). At well DTX2 during 1999 through 2003, seasonal water-level rises averaged about 2 ft/yr during an 8-month period, and seasonal water-level declines averaged about 2.5 ft/yr during a 4-month period (summer), which results in an average net recharge of about -0.5 ft/yr (fig. 12). At well DTX5 during 1999 through 2003, seasonal water-level rises averaged about 3.3 ft/yr during an 8-month period, and seasonal water-level declines averaged about 3.9 ft/yr during a 4 to 5 month season (summer), which results in an average net recharge of about -0.6 ft/yr (fig. 13). At well D25 during 1999 through 2003,

seasonal water-level increases averaged about 2.4 ft/yr during a 7 to 8 month period, and seasonal water-level decreases averaged about 2.6 ft/yr during a 5-month period (summer), which results in an average net recharge of about -0.2 ft/yr (fig. 14). At wells DTX9 and DTX11 during 2000 through 2003, seasonal water-level increases averaged about 0.4 ft/yr during a 7-month period, and seasonal water-level decreases averaged about 0.5 ft/yr during a 5-month period (summer), which results in an average net recharge of about -0.1 ft/yr (fig. 15). At DTX10A during 2000–2003, seasonal water-level increases averaged about 0.5 ft/yr during a 7-month period, and seasonal water-level decreases averaged about 0.7 ft/yr during a 5-month period (summer), which results in an average net recharge of about -0.2 ft/yr (fig. 15). Negative values for net recharge indicate that ground-water levels decreased year by year, mostly because of less episodic recharge during the later years of the study at most sites.

Ground-water recharge in the study area also was evaluated in more detail by comparing data for multiple aquifers and multiple zones within aquifers at the same location. Multiple wells in the same location enable different zones of ground water to be monitored without having to consider spatial variability and can enable inferences about vertical directions of ground-water flow between zones. Two recharge-evaluation areas were monitored: one containing wells DTX7 and DTX8, and one containing wells DTX9, DTX10, and DTX11 (fig. 1). Wells DTX7, DTX9, and DTX11 are alluvial-aquifer wells. Wells DTX8 and DTX10 are bedrock-aquifer wells. Each of the two bedrock-aquifer wells are nested, which means each borehole has two separate piezometers screened at two separate zones. Therefore, at least three different aquifer zones are monitored at each of the two recharge-evaluation areas in Muddy Creek downgradient from the MWRD properties (fig. 1). In 2000, EDL equipment was installed to continuously monitor precipitation and water levels in wells DTX9, DTX10, and DTX11 and to provide more detailed information about ground-water recharge at those locations.

The public was concerned that biosolids applications could contaminate alluvial aquifers, which then would contaminate the bedrock aquifer. In the study area, the alluvial aquifers generally are hydraulically connected to surface water and may be susceptible to surficial contamination. The sandy, shallow part (Fox Hills Formation) of the bedrock aquifer in the study area is used for domestic water supply. Data for 1999 through 2003 from the recharge-evaluation area that contains well DTX11 indicate that water-level altitudes of the shallow bedrock zone (DTX10A) always were slightly higher than those of both zones of the overlying alluvial aquifer (DTX9 and DTX11), which always were much higher than the water-level altitudes of the deep bedrock-aquifer zone (DTX10B) (figs. 11 and 15). Water-level data from 1999 through 2003 indicate that at this location, vertical gradients are more favorable for the shallow, sandy part of the bedrock aquifer to recharge (discharge to) the alluvial aquifer in the Muddy Creek flood plain, not for the alluvial aquifer to recharge (discharge to) the bedrock aquifer. Conversely,

data for 1999 through 2003 from the recharge-evaluation area that contains well DTX7 indicate that water-level altitudes of the deep bedrock-aquifer zone (DTX8B) were always much higher than those of the overlying alluvial aquifer (DTX7) and the shallow bedrock-aquifer zone (DTX8A) (fig. 11). During January through July each year, the shallow bedrock-aquifer zone water-level altitudes were slightly higher than the alluvial-aquifer water-level altitudes. During July through January, the alluvial-aquifer (DTX7) water-level altitudes were slightly higher than the shallow bedrock-aquifer zone (DTX8A) water-level altitudes. Water-level data from 1999 through 2003 indicate that at this location, vertical gradients are favorable for the alluvial aquifer to recharge (discharge to) the bedrock aquifer during July–January, despite confining pressures from the deeper parts of the bedrock aquifer. These gradients indicate that bedrock-aquifer quality is more vulnerable at DTX8 than at DTX10. Where lithologically possible, the shallower, more sandy part of the bedrock aquifer could recharge the deeper, more shaley part of the bedrock aquifer at DTX10 (fig. 11), and the deeper, more shaley part of the bedrock aquifer could recharge the shallower, more sandy part of the bedrock aquifer at DTX8 (fig. 11). Ground-water withdrawals from pumping the aquifers in the study area could completely change these gradients. At both sites, the data indicate that the water-supply part of the bedrock aquifer is in hydraulic connection with the alluvial aquifer. However, the recharge-evaluation area at DTX8, which is more vulnerable to bedrock-aquifer contamination from the alluvial aquifer, is considerably farther downstream from any MWRD property and downstream and downgradient from the recharge-evaluation area at DTX10, where the bedrock aquifer could be recharging the alluvial aquifer. Agricultural and range land near DTX8 therefore could have a larger effect on ground-water quality than the biosolids that are applied more than 4 mi upstream.

Effects of Biosolids on Ground Water

This expanded monitoring program directly considered only the chemical effects of biosolids on ground water of the study area; the effects of biosolids on ground water are expected to be mostly microbiological or chemical in nature. The chemical effects of biosolids could be inorganic (nutrients and trace elements) or organic (natural and synthetic carbon compounds). Only inorganic and radioactivity chemical effects were included in this monitoring program because the priority parameters identified by the stakeholders were inorganic elements or compounds and radioactivity measures. The priority parameters for ground water included the nine trace elements regulated for biosolids, nitrate, chromium, plutonium, and gross alpha and gross beta activity. However, most of these same elements and compounds are part of natural aquifer geochemical composition and variation. In order to state with confidence that ground-water composition for the priority parameters is affected by biosolids, the ground-water composition or variation must significantly exceed the natural aquifer geochemical composition and variation.

How can natural aquifer geochemical composition and variation be determined for the study area when only one of the wells in this monitoring program (D6) was installed before biosolids applications in the study area began in late 1993? Wells upgradient from the biosolids-applied property do not provide a viable approach to establish natural aquifer geochemical composition and variation for the priority parameters because the pre-biosolids sampling at 10 monitoring wells on the MWRD central property in 1993 indicated a substantial range in concentration of nutrients and trace elements over short distances (Tracy Yager, U.S. Geological Survey, unpublished data on file, Denver, Colo., office), and the priority parameters are not conservative along ground-water flow paths. Concentrations of most of these parameters increase and decrease naturally in the ground water because of dissolution and precipitation of minerals, chemical reactions, and microbiological transformations, and by inputs from sources that may include, but are not limited to, biosolids. Therefore, multiple approaches were used to discern possible biosolids effects on ground water in the study area.

Summary of Water Quality

A summary of ground-water quality data for all sites and all parameters monitored during 1999 through 2003 is included in table 5. Ground-water quality was evaluated by sampling different sites at the same time and by sampling the same sites at different times. Ground-water chemical data for 1999 through 2003 were reported for all parameters by Stevens and others (2003) and Yager and others (2004a, 2004b, 2004c). Alluvial-aquifer and bedrock-aquifer water generally were calcium/magnesium-sulfate type water, although proportions of sulfate were relatively less in well D17 (calcium/magnesium-bicarbonate type water) and proportions of calcium and magnesium were relatively less in well DTX8A (sodium-calcium-sulfate type water) (fig. 16). All ground-water samples were near neutral pH, but specific conductance (measure of ionic strength) ranged from about 500 $\mu\text{S}/\text{cm}$ at well D17 to about 18,000 $\mu\text{S}/\text{cm}$ at well D6, and dissolved-oxygen concentration ranged from about 0.2 mg/L at well DTX10 to about 7 mg/L at well DTX3. Concentrations of selected constituents (most of the priority parameters) in ground water during 1999 through 2003 are summarized by boxplots (fig. 17). Data for gross alpha and gross beta activity are reported by Stevens and others (2003) but are not included in figure 17. Only one ground-water sample from each well was analyzed for gross alpha and gross beta activity because high dissolved-solids concentrations in ground-water samples from the study area interfered with the laboratory analysis and precluded additional analyses for these parameters. Data for plutonium concentration in the ground-water samples are not included in figure 17 because only five samples (one each year of the monitoring program) from each well were analyzed for plutonium, and all plutonium concentrations were less than the contract-specified reporting limit of 0.1 pCi/L and had a distribution near zero.

Table 5. Summary of all ground-water-quality data collected near Deer Trail, Colorado, during 1999–2003, and ground-water regulatory limits.

[FAO, Food and Agricultural Organization of the United Nations (Pais and Jones, 1997, page 31); CaCO₃, calcium carbonate; lab, laboratory; µS/cm, microsiemens per centimeter; °C, degrees Celsius; ANC, acid neutralizing capacity; ROE, residue on evaporation; mg/L, milligrams per liter; µg/L, micrograms per liter; dissolved, passed through a 0.45-micron filter; NH₃+orgN, ammonia plus organic nitrogen; NO₂+NO₃, nitrite plus nitrate; P, phosphorus; pCi/L, exceeded a standard]

Parameter	Summary of data for all samples, all wells				Colorado regulatory standards for ground water				Well where standard or guideline was exceeded	
	Number of samples	Minimum for all samples	Maximum for all samples	Median for all samples	Human Health standard	Secondary drinking-water standard	Agricultural standard	Statewide standard		FAO-recommended maximum for irrigation water
Dissolved oxygen (field), mg/L	263	0.2	7.4	0.9	--	--	--	--	--	--
pH (field), standard units	279	6.4	7.7	7	--	6.5–8.5	--	--	--	DTX4 on 7/11/00
pH (laboratory), standard units	277	6.7	8	7.2	--	6.5–8.5	--	--	--	No data exceeded a standard
Specific conductance (lab), µS/cm at 25°C	278	430	16,700	3,870	--	--	--	--	--	--
Specific conductance (field), µS/cm at 25°C	281	447	18,000	3,920	--	--	--	--	--	--
Temperature of water (field), °C	281	6	23.1	12.1	--	--	--	--	--	--
Hardness, mg/L as CaCO ₃	279	210	12,000	2,000	--	--	--	--	--	--
Calcium, dissolved, mg/L	279	54.9	838	466	--	--	--	--	--	--
Magnesium, dissolved, mg/L	279	17.5	2,630	194	--	--	--	--	--	--
Potassium, dissolved, mg/L	279	1.39	15.4	7.01	--	--	--	--	--	--
Sodium adsorption ratio	279	0.4	9	2	--	--	--	--	--	--
Sodium, dissolved, mg/L	279	15.1	2,180	235	--	--	--	--	--	--
Sodium, percent	279	6	52	20	--	--	--	--	--	--
ANC (lab), mg/L as CaCO ₃	278	200	740	288.5	--	--	--	--	--	--
Alkalinity, dissolved (lab) mg/L as CaCO ₃	1	353	353	353	--	--	--	--	--	--
Bromide, dissolved, mg/L	279	0.05	4.69	0.26	--	--	--	--	--	--
Chloride, dissolved, mg/L	278	1.56	423	23.35	--	250	--	--	--	D6 and D6A (all data)
Fluoride, dissolved, mg/L	279	0.2	11.8	0.7	4	--	2	--	1	No data exceeded a standard!
Silica, dissolved, mg/L	279	9.87	35.7	17.3	--	--	--	--	--	--
Sulfate, dissolved, mg/L	279	39.9	13,600	2,350	--	250	--	--	--	All wells except D17
Residue, sum of dissolved constituents, mg/L	263	285	19,400	3,620	--	--	--	1.25 times background	--	--
Residue, dissolved, tons/acre-ft	263	0.38	30.6	5.41	--	--	--	--	--	--
Residue, ROE at 180°C, mg/L	279	280	22,500	4,000	--	--	--	--	--	--
NH ₃ +orgN, dissolved, mg/L as N	297	<0.06	1.8	0.29	--	--	--	--	--	--
NH ₃ +orgN, mg/L as N	275	<0.05	1.6	0.31	--	--	--	--	--	--
Ammonia, dissolved, mg/L as NH ₄	189	0.03	1.99	0.23	--	--	--	--	--	--
Ammonia, dissolved, mg/L as N	296	<0.014	1.55	0.058	--	--	--	--	--	--
NO ₂ +NO ₃ , dissolved, mg/L as N	296	<0.02	21.6	0.06	10	--	100	--	--	D6 and D6A (all data); DTX3 (10/10/01)
Nitrite, dissolved, mg/L as N	25	<0.01	0.017	0.01	1	--	10	--	--	No data exceeded a standard
Organic nitrogen, dissolved, mg/L	164	0	1.5	0.17	--	--	--	--	--	--
Organic nitrogen, mg/L	151	0.01	1.6	0.17	--	--	--	--	--	--
Orthophosphate, mg/L as P	25	<0.01	0.16	0.015	--	--	--	--	--	--
Phosphorus, dissolved, mg/L	296	<0.004	0.22	0.05	--	--	--	--	--	--
Phosphorus, mg/L	275	<0.02	<0.3	0.05	--	--	--	--	--	--
Total nitrogen, dissolved, mg/L	131	0.19	22	2.1	--	--	--	--	--	--
Total nitrogen, mg/L	126	0.18	23	2.05	--	--	--	--	--	--
Aluminum, dissolved, µg/L	279	<1	34	2	--	--	5,000	--	5,000	No data exceeded a standard
Antimony, dissolved, µg/L	279	<0.03	2<7	0.6	6	--	--	--	--	Possibly D6 (various) ²

Table 5. Summary of all ground-water-quality data collected near Deer Trail, Colorado, during 1999–2003, and ground-water regulatory limits.—Continued

[FAO, Food and Agricultural Organization of the United Nations (Pais and Jones, 1997, page 31); CaCO₃, calcium carbonate; lab, laboratory; µS/cm, microsiemens per centimeter; °C, degrees Celsius; ANC, acid neutralizing capacity; ROE, residue on evaporation; mg/L, milligrams per liter; µg/L, micrograms per liter; dissolved, passed through a 0.45-micron filter; NH₃+orgN, ammonia plus organic nitrogen; NO₂+NO₃, nitrite plus nitrate; P, phosphorus; pCi/L, exceeded a standard]

Parameter	Summary of data for all samples, all wells				Colorado regulatory standards for ground water				Well where standard or guideline was exceeded	
	Number of samples	Minimum for all samples	Maximum for all samples	Median for all samples	Human health standard	Secondary drinking-water standard	Agricultural standard	Statewide standard		FAO-recommended maximum for irrigation water
Arsenic, dissolved, µg/L	278	<0	11	2	50	--	100	--	100	No data exceeded a standard
Barium, dissolved, µg/L	279	<1	74	13	2,000	--	--	--	--	No data exceeded a standard
Beryllium, dissolved, µg/L	279	<0.03	2<7	0.12	4	--	100	--	100	Possibly D6 (various) ²
Boron, dissolved, µg/L	279	<50	1,030	310	--	--	750	--	--	D6 and D6A (all data)
Cadmium, dissolved, µg/L	279	<0.02	2<7	0.11	5	--	10	--	10	Possibly D6 (various) ²
Chromium, dissolved, µg/L	279	<0.4	27	0.8	100	--	100	--	100	No data exceeded a standard
Cobalt, dissolved, µg/L	279	<0.17	14.6	1.36	--	--	50	--	50	No data exceeded a standard
Copper, dissolved, µg/L	279	<0.4	103	6.9	--	1,000	200	--	200	No data exceeded a standard
Iron, dissolved, µg/L	279	<6	7,780	30	--	300	35,000	--	5,000	DTX2, DTX8A, DTX10A, DTX11, D6, D15, D23, D25A, ³ D29 (all data), and D30
Lead, dissolved, µg/L	279	<0.04	7	0.2	50	--	100	--	5,000	No data exceeded a standard
Manganese, dissolved, µg/L	279	<0.1	14,500	255	--	50	20	--	⁴ 200	All except DTX3, DTX4 (a few data), and DTX6 (all data) ⁴
Mercury, dissolved, µg/L	279	<0.01	<0.2	<0.02	2	--	10	--	--	No data exceeded a standard
Molybdenum, dissolved, µg/L	279	<0.4	13.7	2	--	--	--	--	10	D25
Nickel, dissolved, µg/L	279	<0.04	46.2	6.57	100	--	200	--	200	No data exceeded a standard
Selenium, dissolved, µg/L	279	<0.5	42.9	3	50	--	20	--	20	D6 on 10/10/01 and 10/03/03
Silver, dissolved, µg/L	278	<0	10	1	50	--	--	--	--	No data exceeded a standard
Strontium, dissolved, µg/L	279	<288	17,500	5,130	--	--	--	--	--	--
Zinc, dissolved, µg/L	279	<0	82	6	--	5,000	2,000	--	2,000	No data exceeded a standard
Uranium, dissolved, µg/L	279	<0.03	198	32.8	--	--	--	--	--	--
Gross alpha activity, dissolved, pCi/L	14	3	114.46	20.02	15	--	--	--	--	DTX1, DTX2, DTX4, DTX5, DTX6, D6, D25, D30
Gross beta activity, dissolved, pCi/L	14	4	71.35	30	--	--	--	--	--	--
Pu-238, dissolved, pCi/L	10	-0.016	0.001	-0.001	--	--	--	--	--	--
Pu-238, pCi/L	56	-0.010	0.085	0	--	--	--	--	--	--
Pu-239+240, dissolved, pCi/L	8	-0.010	0.012	0.001	--	--	--	0.15	--	No data exceeded a standard
Pu-239+240, pCi/L	56	-0.010	0.026	0.000	--	--	--	0.15	--	No data exceeded a standard

¹Fluoride data for wells D6, D13, D15, D17, and D25 (but not D6A or D25A) exceeded the FAO-recommended maximum for irrigation water.

²Antimony, beryllium, and cadmium concentrations reported by the laboratory for well D6 were "<6" for three samples and "<7" for one sample. Actual concentrations of antimony, beryllium, and cadmium could be substantially less than the standard.

³Iron data exceeded the Agricultural standard only at well D29.

⁴Manganese data exceeded the FAO-recommended maximum for irrigation water at all wells except DTX1, DTX3, DTX4, DTX5 (all but one sample), DTX6, and D13.

The chemistry of ground-water samples from one well (D6) was unique relative to that of the other monitoring wells in the study area (fig. 17). Specific conductance was at least three times higher at this well than at any other wells in the study, indicating that ion concentrations from dissolved salts are much higher at this location. The chemical data from ground-water samples during 1999 through 2003 confirm that dissolved solids (major elements and salts) were highest at this well (Stevens and others, 2003; Yager and others, 2004a, 2004b, 2004c). Nitrite plus nitrate concentrations (known to be primarily nitrate, and so hereinafter referred to as nitrate) at this well consistently were higher than at other wells (fig. 17). Trace-element concentrations at this well generally were high compared to those of other wells (fig. 17). The concentrated nature of this ground water means the laboratory had to dilute samples from this well more than other samples from the study, so laboratory uncertainty and reporting levels were higher for D6 data than for data from other wells. The USGS was informed that surface water at this location was considered poor quality for agricultural purposes even in the 1940s (Walter Keen, landowner, oral commun., July 2000).

Concentrations of priority parameters in ground water near Deer Trail varied spatially (different concentrations at different locations at the same time) (fig. 17) and temporally (different concentrations at the same locations at different times throughout 1999 through 2003) (fig. 18). Aquifer variation results from differences in chemistry between aquifers, differences in processes affecting chemistry at different locations of the same aquifer, and changes to the aquifers over time (such as the water-quantity changes at wells DTX3 and DTX4 mentioned in the Hydrology section). Ground-water chemical variation can be interpreted only if that variation is greater than the sample variability, and sample bias is minimal.

Sample bias in the ground-water data refers to a shift in concentration data that causes the concentration data to be reported as higher than actual or lower than actual for a certain span of time. These shifts in concentration usually are caused by sample collection, processing, or analysis and are not caused by aquifer changes. High bias in the low concentration range of ground-water data was evaluated by analysis of frequent field blanks as well as annual equipment blanks on the submersible pump. The data from these blanks indicate that sample collection and processing of samples at the alluvial-aquifer wells caused no bias, but sample collection at the three bedrock-aquifer wells (where the submersible pump was used) could result in a high bias in small concentrations of calcium, copper, nickel, and zinc, and occasionally iron, magnesium, manganese, sodium, and strontium. High or low bias in the low to middle concentration range of ground-water data was evaluated through laboratory standard-reference samples and performance data, and through reanalysis of selected samples. Rerun, reanalysis of the same selected samples at different times, is a feature of the USGS National Water Quality Laboratory (NWQL) that was used to verify unusual values (such as outliers or concentrations detected in blank samples), but most of the reanalysis information also provided at least a qualitative indication of sample bias caused by laboratory

analysis. Data for rerun samples indicate occasional bias in concentrations of aluminum, arsenic, and many other constituents because of sample analysis (at the laboratory). Quarterly sampling of the same sites during 5 years or more using the same equipment with analyses at the same laboratory (as in this monitoring program) enables significant sample bias to be recognized and rapidly corrected (where possible). Although laboratory quality assurance indicated periods of analytical bias (high or low) that could affect the data, no sustained or substantial bias was apparent in the laboratory data or other field data.

Sample variability in the ground-water data refers to noise in the data set; that is, differences in concentration values that do not represent aquifer changes but are an artifact of sample collection, processing, or analysis. Sample variability was evaluated by reruns, by graphical comparison of all concentration data for all sites over time, and by sample-replicate-pair analyses. Reanalysis of the same selected samples at different times is a feature of the USGS NWQL that was used to verify unusual values (such as outliers or concentration differences between replicate pairs), but most of the reanalysis information also provided at least a qualitative indication of sample variability caused by laboratory analytical uncertainty. Quarterly sampling of the same sites during 5 years or more using the same equipment with analyses at the same laboratory (as in this monitoring program) enables significant sample variability to be recognized rapidly and at least noted. Graphical comparison of all concentration data for all sites over time provides another qualitative indication of sample variability caused by laboratory analytical uncertainty. The replicate samples collected for this component of the monitoring program generally were concurrent (regular- and replicate-sample bottles for the same analysis were filled sequentially, then regular- and replicate-sample bottles for another analysis were filled sequentially, and so on). These replicate data provide quantitative measures of variability primarily from laboratory analytical uncertainty but also from aquifer heterogeneity.

Results indicate that sample variability was not constant during 1999 through 2003 but fluctuated over time, and sample variability mostly was an artifact of sample analysis caused by laboratory analytical uncertainty (largely a function of analysis technology and error introduced by diluting the samples for the appropriate analytical range). Reanalysis of samples indicated sample variability was greatest for concentrations of chromium, copper, nickel, zinc, and occasionally arsenic. Graphical comparison of all concentration data indicated that changes in nickel concentration most likely were from sample variability, not aquifer variation, because concentrations for all wells (regardless of aquifer type, geology, or depth to water) increased and decreased similarly during 1999 through 2003 (fig. 18). Results of replicate analysis are more detailed and were used to quantitatively evaluate sample variability. Sample variability for the 1999 through 2003 data was evaluated at two levels: (1) variability for samples at the time of each analysis as represented by variability measures calculated

A. Alluvial ground water near Deer Trail

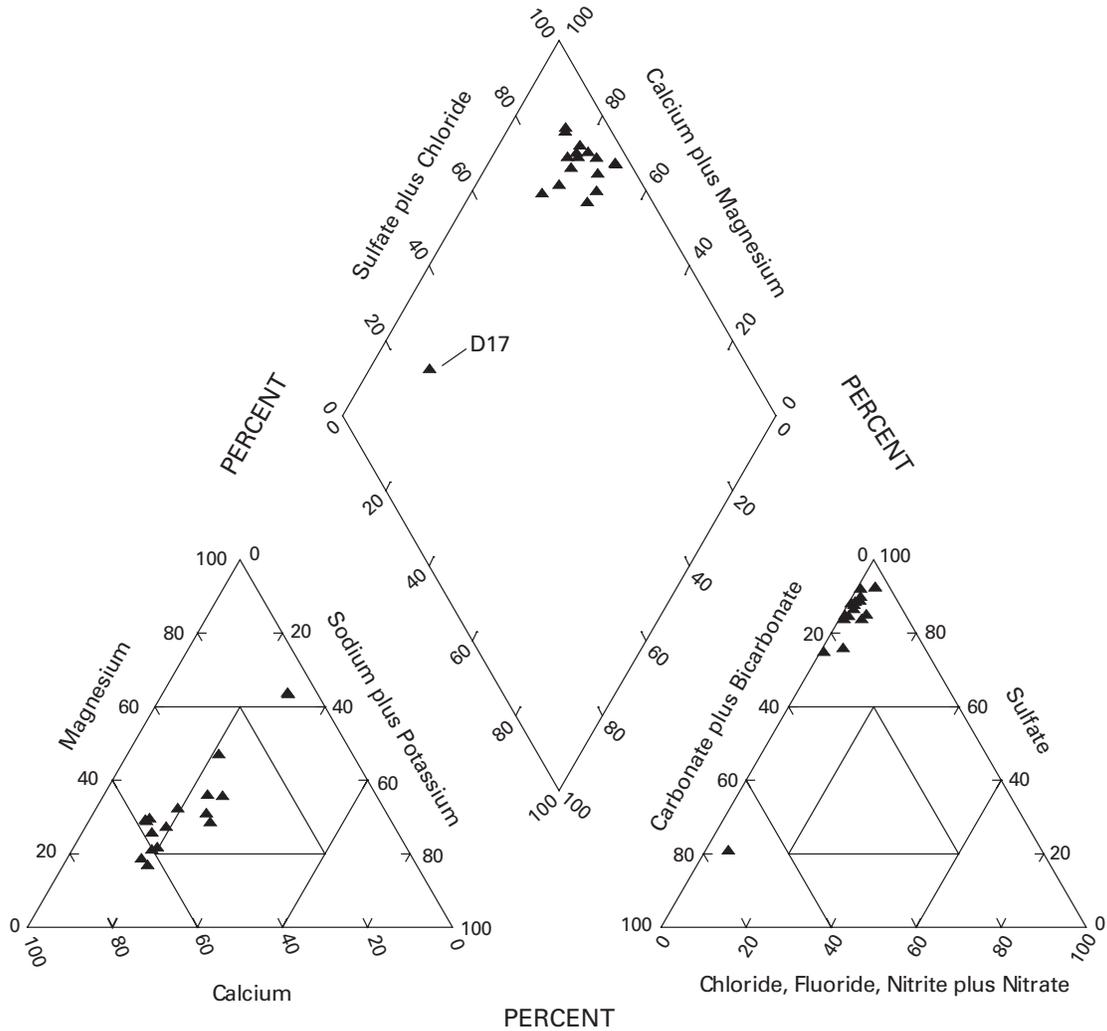


Figure 16. Trilinear diagrams showing water type for (A) alluvial-aquifer and (B) bedrock-aquifer wells near Deer Trail, Colorado, based on median data for 1999–2003.

for each sample-replicate pair and, (2) sample variability for the entire 1999 through 2003 ground-water data set as represented by summary values such as median absolute difference or median percent difference, as appropriate for the data (table 6). Note that median measures of variability are more conservative (not representative of the minimum or maximum variability indicated by sample-replicate pairs); variability or uncertainty in the sample data for a given analytical period could be substantially lower or higher than the median for any data pair. The data for the replicate pairs and relative percent difference were reported by Stevens and others (2003) and Yager and others (2004a, 2004b, 2004c); variability measures of relative standard deviation, absolute difference, and percent difference for each replicate pair (method from Terry Schertz, U.S. Geological Survey, written commun., February 10, 1997)

are listed in tables 12–14 (in the Supplemental Information section at the back of the report). Sample variability was greatest in the ground-water data for gross alpha activity, nickel, ammonia nitrogen, plutonium-239 and 240, and selenium (table 6). For most of the priority parameters and some other parameters, variability in the ground-water data was negligible (table 6). Sample variability for the priority parameters generally was less for the ground-water data than for aquifer variation; exceptions will be noted on a case-by-case basis in the tables and text of this section of the report. Water-quality data for selected priority parameters at selected sites (generally the highest concentrations) are shown in figure 18 along with associated variability estimates for 1999 through 2003. When concentrations for ground water in the study area were close to or exceeded the regulatory standard, the regulatory standard was included in figure 18.

B. Bedrock ground water near Deer Trail

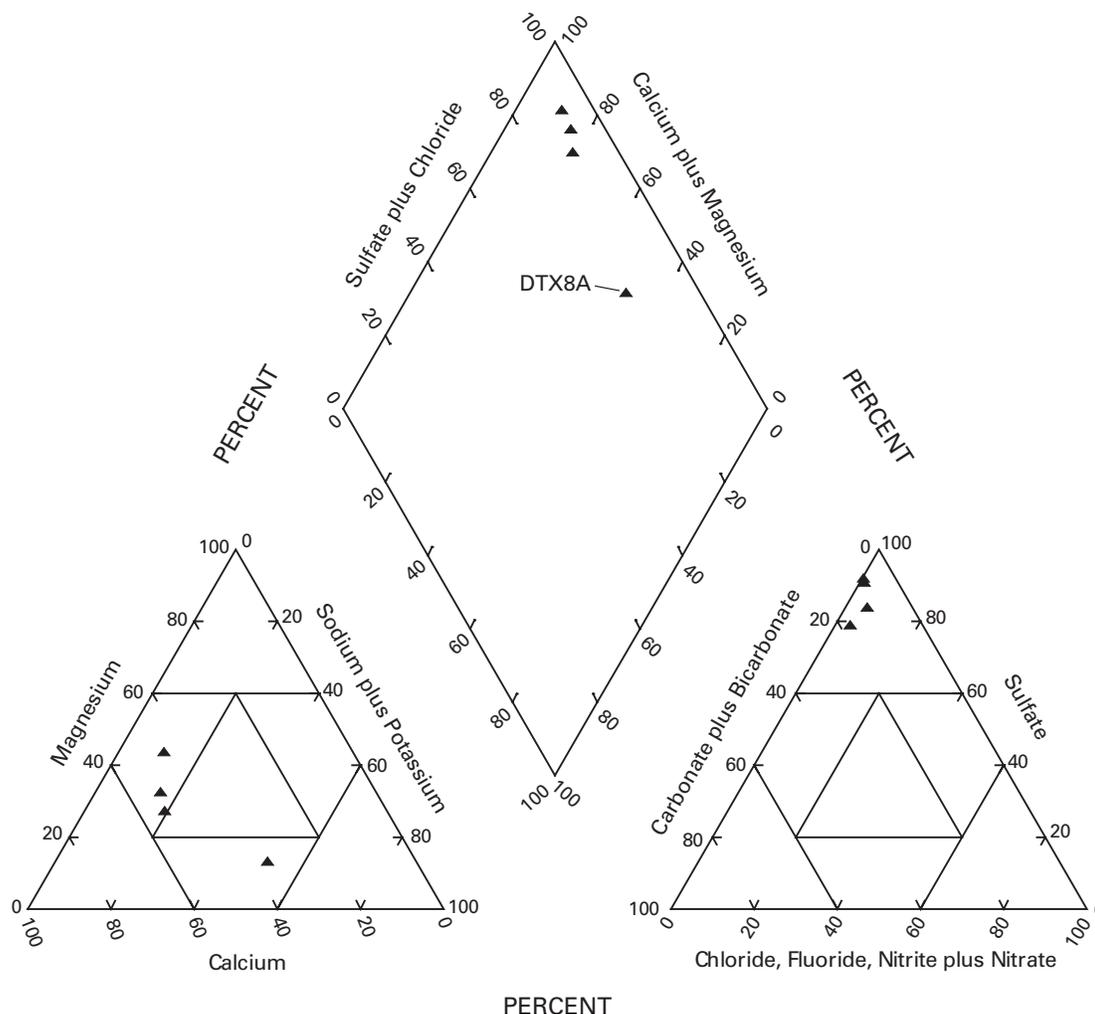


Figure 16. Trilinear diagrams showing water type for (A) alluvial-aquifer and (B) bedrock-aquifer wells near Deer Trail, Colorado, based on median data for 1999–2003.—Continued

Comparison with Regulatory Standards

Regulatory standards that might be used as guidelines to evaluate the ground-water quality in the study area are the human health standards and agricultural standards enforced by the State of Colorado (Colorado Department of Public Health and Environment, 1997a). Concentrations of priority parameters generally were less than Colorado regulatory limits for ground water (table 5). Ground-water concentrations for arsenic, chromium, copper, lead, mercury, nickel, zinc, and plutonium always met the Colorado standards (table 5). However, concentrations of nitrite plus nitrate during 1999 through 2003 at wells D6 and D6A all were higher than the Colorado Human Health standard of 10 mg/L. Cadmium concentrations for well D6 could have exceeded the Colorado Human Health standard; three samples were reported as less

than 7, and the standard is 5 $\mu\text{g/L}$. Selenium concentration for two samples at well D6 exceeded the Colorado Agricultural standard. Gross alpha activity for 8 of the 14 wells (all 8 are alluvial-aquifer wells) was greater than the Colorado Human Health standard of 15 pCi/L. The Colorado Human Health standard for gross alpha activity excludes radon and uranium (Colorado Department of Public Health and the Environment, 1997a, p. 22). Radon in the ground water near Deer Trail, has not been measured by the USGS, but uranium was analyzed in all the ground-water samples and is summarized in figure 17. Uranium concentration in ground water near Deer Trail in 1999 was of similar magnitude compared with gross alpha activity (Stevens and others, 2003), so at least some of the gross alpha activity could be caused by uranium concentration, in which case the Colorado standard may not have been exceeded for gross alpha activity.

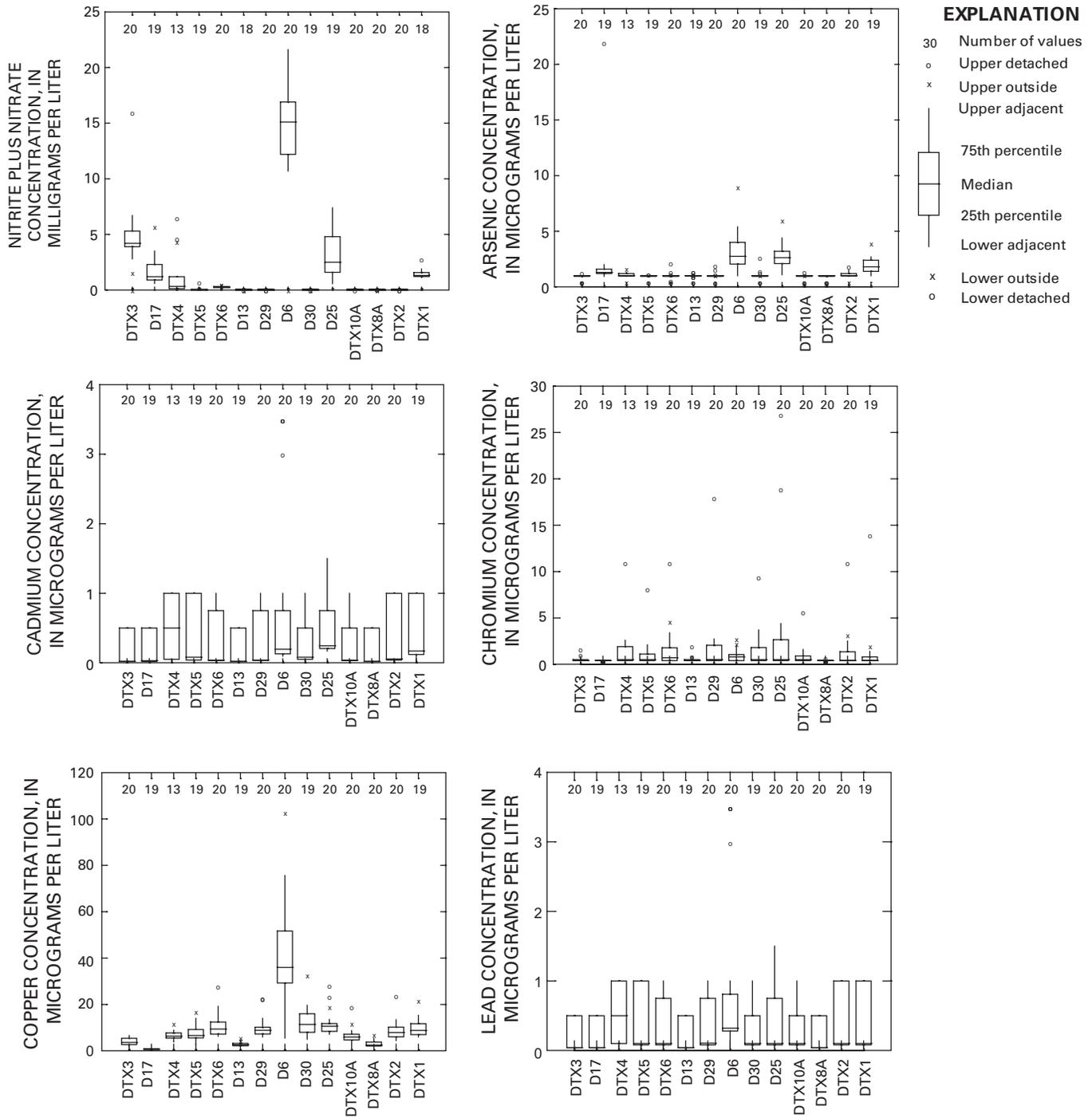


Figure 17. Boxplots summarizing ground-water concentrations near Deer Trail, Colorado, for selected constituents, 1999–2003.

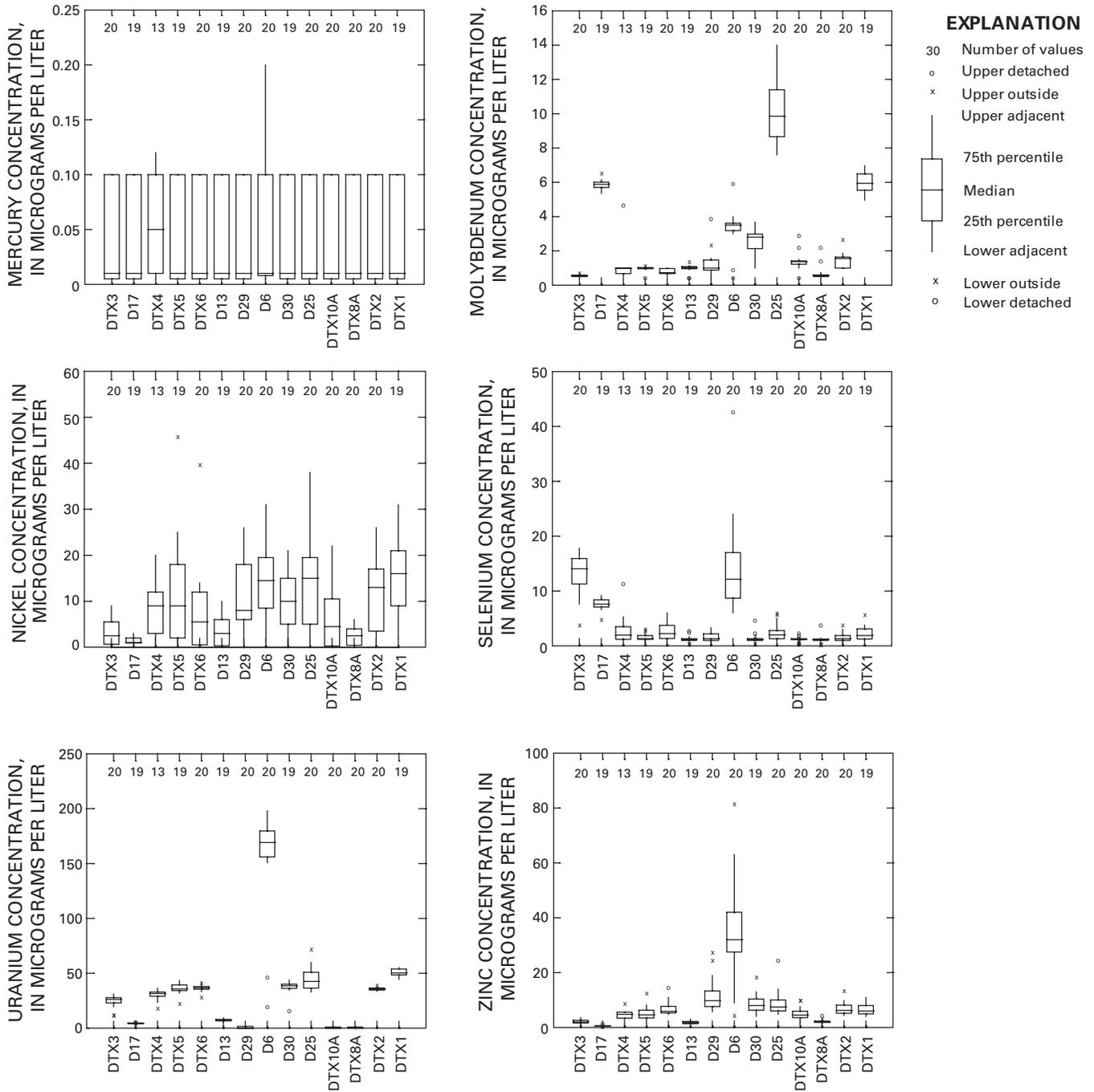


Figure 17. Boxplots summarizing ground-water concentrations near Deer Trail, Colorado, for selected constituents, 1999–2003.
—Continued

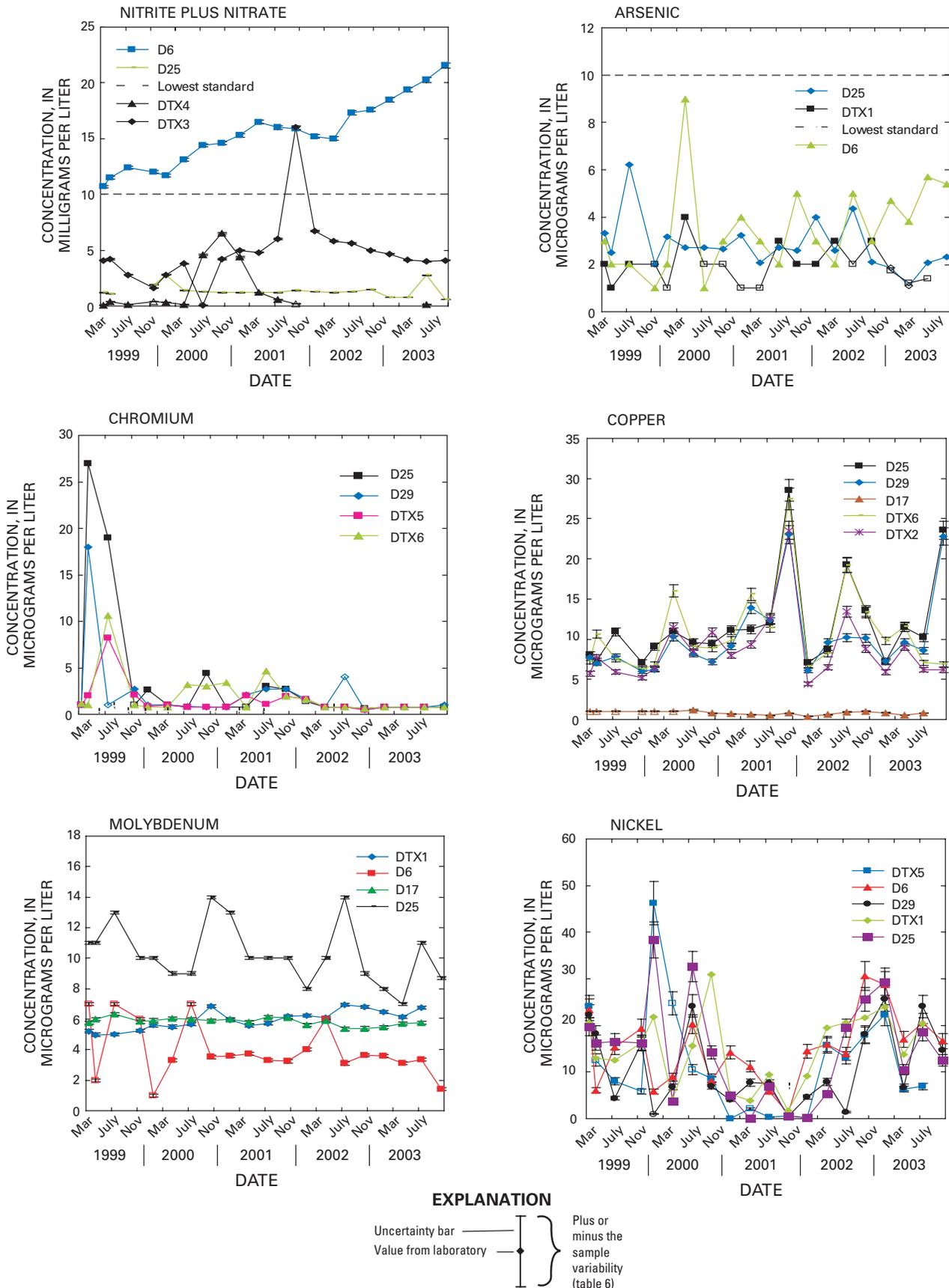


Figure 18. Ground-water concentrations near Deer Trail, Colorado, for selected constituents and selected wells, 1999–2003.

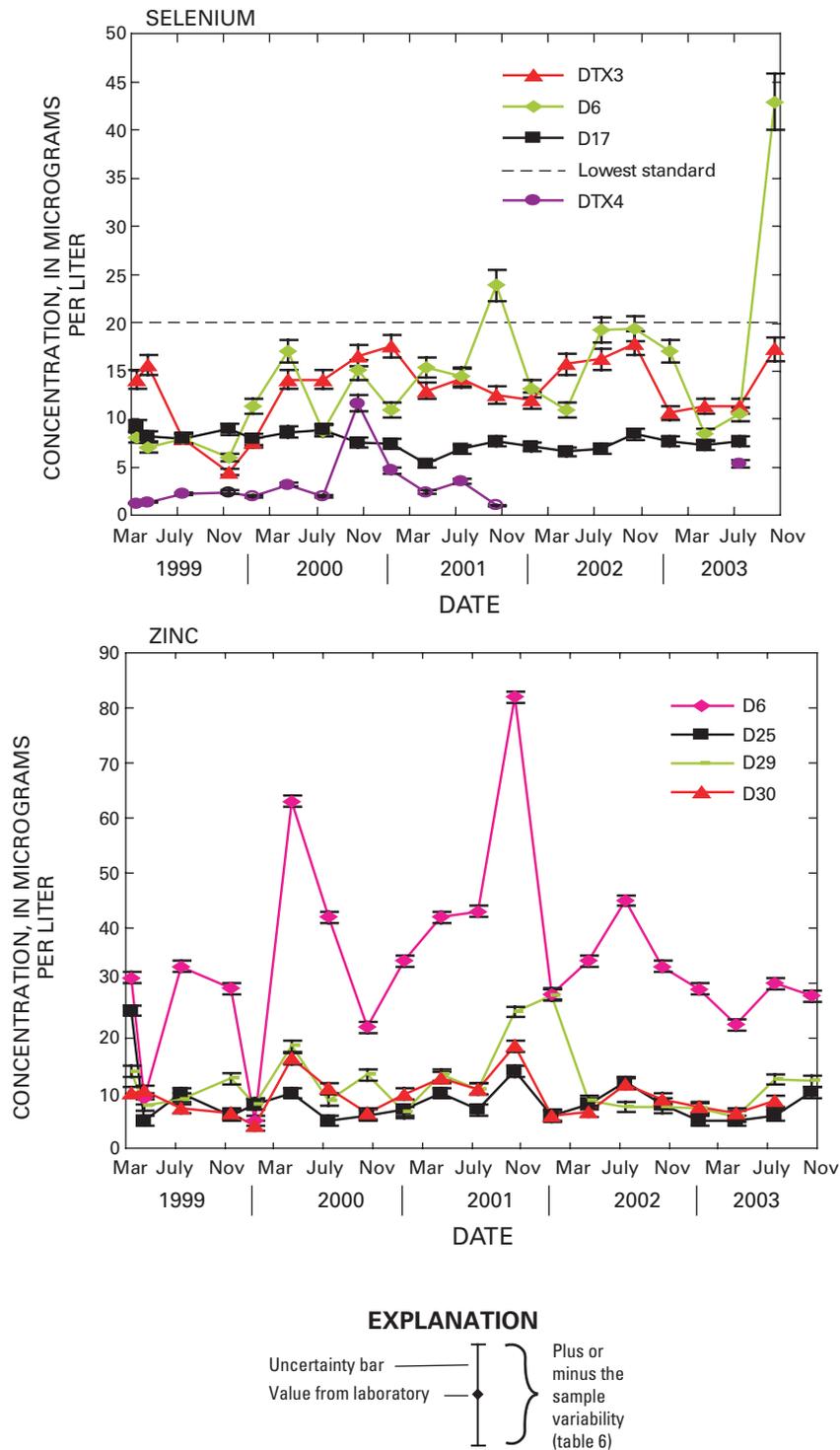


Figure 18. Ground-water concentrations near Deer Trail, Colorado, for selected constituents and selected wells, 1999–2003.—Continued

Table 6. Variability estimates for ground-water-quality data on the basis of comparisons of water-quality data for ground-water and replicate samples collected near Deer Trail, Colorado, 1999–2003.

[Shaded values indicate the measure and value of variability¹ selected to represent that constituent (shown graphically in fig. 18); values from tables 12 through 14 in the Supplemental Information section at the back of the report; for this analysis, all values that were less than the reporting limit were set equal to the reporting limit and estimated values were included; calculations done on unrounded data; --, no data; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; pCi/L , picocuries per liter]

Parameter	Median relative standard deviation	Median absolute difference	Median percent difference	Number of replicates
Specific conductance, laboratory ($\mu\text{S}/\text{cm}$)	0.28	10	0.41	39
pH, whole water, laboratory (standard units)	0	0	0	39
Calcium, dissolved (mg/L as Ca)	1.03	5.00	1.46	39
Magnesium, dissolved (mg/L as Mg)	1.30	6.33	1.84	39
Sodium, dissolved (mg/L as Na)	0.78	5.00	1.10	39
Potassium, dissolved (mg/L as K)	2.81	0.34	3.97	39
Acid neutralizing capacity, titration to 4.5, laboratory (mg/L as CaCO_3)	0.22	1.00	0.31	39
Sulfate, dissolved (mg/L as SO_4)	0.25	5.40	0.35	39
Chloride, dissolved (mg/L as Cl)	1.02	1.09	1.44	39
Fluoride, dissolved (mg/L as F)	0.16	0.002	0.23	39
Bromide, dissolved (mg/L as Br)	0.91	0.01	1.29	39
Silica, dissolved (mg/L as SiO_2)	0.89	0.26	1.25	39
Solids, residue on evaporation at 180°C, dissolved (mg/L)	0.44	40	0.63	39
Nitrite plus nitrate (mg/L as N)	0.74	0.04	1.04	38
Nitrogen ammonia, dissolved (mg/L as N)	5.55	0.01	7.84	38
Nitrogen ammonia plus organic, total (mg/L as N)	2.57	0.02	3.64	39
Nitrogen ammonia plus organic, dissolved (mg/L as N)	4.21	0.03	5.96	38
Phosphorus, total (mg/L as P)	1.79	0.00	2.53	39
Phosphorus, dissolved (mg/L as P)	0	0.0005	0	38
Aluminum, dissolved ($\mu\text{g}/\text{L}$ as Al)	0	0	0	39
Antimony, dissolved ($\mu\text{g}/\text{L}$ as Sb)	0	0	0	39
Arsenic, dissolved ($\mu\text{g}/\text{L}$ as As)	0	0	0	39
Barium, dissolved ($\mu\text{g}/\text{L}$ as Ba)	0	0	0	39
Beryllium, dissolved ($\mu\text{g}/\text{L}$ as Be)	0	0	0	39
Boron, dissolved ($\mu\text{g}/\text{L}$ as B)	2.58	20	3.66	39
Cadmium, dissolved ($\mu\text{g}/\text{L}$ as Cd)	0	0	0	39
Chromium, dissolved ($\mu\text{g}/\text{L}$ as Cr)	0	0	0	39
Cobalt, dissolved ($\mu\text{g}/\text{L}$ as Co)	1.15	0.07	1.62	39
Copper, dissolved ($\mu\text{g}/\text{L}$ as Cu)	3.39	1.00	4.79	39
Iron, dissolved ($\mu\text{g}/\text{L}$ as Fe)	0	0	0	39
Lead, dissolved ($\mu\text{g}/\text{L}$ as Pb)	0	0	0	39
Manganese, dissolved ($\mu\text{g}/\text{L}$ as Mn)	1.71	30	2.42	39
Mercury, dissolved ($\mu\text{g}/\text{L}$ as Hg)	0	0	0	39
Molybdenum, dissolved ($\mu\text{g}/\text{L}$ as Mo)	1.03	0.10	1.46	39
Nickel, dissolved ($\mu\text{g}/\text{L}$ as Ni)	7.07	0.90	10	39
Selenium, dissolved ($\mu\text{g}/\text{L}$ as Se)	5.86	0.70	8.28	39
Silver, dissolved ($\mu\text{g}/\text{L}$ as Ag)	0	0	0	39
Strontium, dissolved ($\mu\text{g}/\text{L}$ as Sr)	0.85	70	1.21	39
Zinc, dissolved ($\mu\text{g}/\text{L}$ as Zn)	3.37	1	4.76	39
Uranium, natural ($\mu\text{g}/\text{L}$ as U)	0.90	1	1.27	39
Gross alpha, dissolved (pCi/L)	14	3.95	19	2
Gross beta, dissolved (pCi/L)	3.64	2.5	5.15	2
Plutonium-238, whole water (pCi/L as Pu)	0	0.002	0	9
Plutonium-239+240, whole water (pCi/L as Pu)	141	0.004	200	9

¹Measures of variability (from Terry Schertz, U.S. Geological Survey, written commun., February 10, 1997) were calculated as follows: relative standard deviation = $100 \left(\frac{\sqrt{((C1-C2)^2/2)}}{(C1+C2)/2} \right)$; absolute difference = $|C1-C2|$; percent difference = $100 \left(\frac{|C1-C2|}{(C1+C2)/2} \right)$, which is the same as the absolute value of the relative percent difference calculated in Yager and others, 2004b and 2004c, where C1 is the concentration in the regular sample and C2 is the concentration in the replicate sample. Differences in pairs were not normally distributed, so nonparametric measures (absolute difference and percent difference) are the most appropriate measures. Absolute difference is the best measure when differences between pairs are not larger with larger concentrations. Percent difference is the best measure when differences between pairs are larger with larger concentrations.

Concentrations of other elements and compounds also generally were less than Colorado regulatory limits for ground water (table 5). Ground-water pH usually met the Colorado Secondary Drinking water standard. Ground-water concentrations for fluoride, nitrite, aluminum, barium, cobalt, and silver always met the Colorado standards. However, all chloride concentrations for wells D6 and D6A exceeded the Colorado Secondary Drinking-Water standard. Sulfate concentrations for all wells except D17 exceeded the Colorado Secondary Drinking-Water standard. Some antimony concentrations for well D6 might have exceeded the Colorado Human Health standard (some less-than values were greater than the standard). All boron concentrations for wells D6 and D6A exceeded the Colorado Agricultural standard. Iron concentrations for wells DTX2, DTX8A, DTX10A, DTX11, D6, D15, D23, D25A, D29, and D30 exceeded the Colorado Secondary Drinking-Water standard; iron concentrations for well D29 also exceeded the Colorado Agricultural standard. Manganese concentrations for all wells except DTX3, DTX4 and DTX6 (table 5) exceeded the Colorado Secondary Drinking Water and Agricultural standards.

Concentrations of the priority parameters were statistically tested against the Colorado regulatory standards, if the quantity of data was sufficient. For this report, a one-tailed Sign Test (Helsel and Hirsch, 2002) was used to indicate the level of statistical evidence that ground-water concentrations for selected constituents were significantly greater than regulatory standards.

A small p -value result from the Sign Test indicates more evidence that ground-water concentrations were significantly greater than the regulatory standards (table 15 in the Supplemental Information section at the back of the report). The closer the p -value to 1.0, the less evidence that ground-water concentrations were significantly greater than regulatory standards. For this test, only a p -value less than 0.025 (table 15) indicates that ground-water concentrations were significantly ($\alpha = 0.05$) greater than regulatory standards. The results of the statistical testing of the data for 11 alluvial-aquifer wells and 3 bedrock-aquifer wells for exceedance of regulatory standards for 11 of the priority parameters (not radioactivity) are listed in detail in table 15 and summarized in table 7. Nitrate concentrations at well D6 were the only data where the concentrations significantly ($\alpha < 0.001$) exceeded the regulatory standard. Data for gross alpha activity (only one sample for each well) and plutonium (only five samples for each well) were insufficient for statistical analysis.

Trends in Concentration

Upward trends in concentration mean that concentration for a parameter increases over time, although not necessarily in a straight line. These upward trends could indicate biosolids, other farm practices, grazing, or even natural processes such as geochemical dissolution are affecting ground water. For this report, the Kendall's tau statistic (Helsel and Hirsch, 2002) was used as a nonparametric measure of

correlation between concentration and time. Kendall's tau is a number between negative one and positive one where values approaching negative or positive one indicate increasing strength of the correlation and a number approaching zero indicates decreasing strength of correlation. Positive values of Kendall's tau indicate upward trends, and negative values indicate downward trends. The results of the statistical testing of the data for trends in 11 constituents identified as important by the public are summarized in table 7 and listed in detail in table 16 (in the Supplemental Information section in the back of the report). A p -value is included in table 16; the p -value must be less than or equal to 0.05 for tau to be significant ($\alpha = 0.05$) with at least 95-percent confidence.

The ground-water data evaluated for trend included many values that were less than the minimum reporting limit (MRL). If all data for a constituent were less than the MRL, or all data were greater than the MRL but were the same value, then the values were tied and no trend could be identified (such as for lead and mercury at most of the wells). Many of the reported concentrations included in the trend analysis were less than the MRL, and the MRL varied for most of the constituents. Initially, each value less than the MRL was evaluated at one-half the MRL (Stevens and others, 2003; Yager and others, 2004a, 2004b). With the previous approach, some of the trends evaluated by the statistical analyses likely were artificial—that is, the difference in MRL, not differences in concentration, resulted in an apparent trend. Another approach for data with multiple MRLs is to recensor all the estimated values below the MRL and the less-than data to the highest MRL for trend analysis. When the second approach was used (table 16), a few artificial trends likely remained (an apparent trend was caused by less-than values that were larger than the detected values). The trends were evaluated again with all values (less than and greater than an MRL) recensored to the highest MRL. Even after this third approach, some significant trends remained, although some trends likely still are artificial (table 16). Artificial trends also can result from changes in laboratory analytical precision and sensitivity during 1999 through 2003, which likely is the case for the downward chromium trend at well D25. For these reasons and because all 5 years of data now are included in the trend evaluation, the trend results in this report supersede the trends reported by Stevens and others (2003) and Yager and others (2004a, 2004b).

Radioactivity data were not statistically tested because only five radiochemical samples, which is an insufficient number of samples for statistical testing, have been collected at each well since the program began in 1999. However, considering 5 years of available data, there is no evidence that plutonium concentration increased in ground water.

The results of trend analysis on the 1999 through 2003 combined data set (table 16) indicate some statistically significant ($\alpha = 0.05$) upward trends in the ground-water-quality data. Of the constituents tested, only arsenic, cadmium, chromium, lead, mercury, nickel, and zinc data had no significant ($\alpha = 0.05$) upward trends (tables 7 and 16). The constituent tested that had the greatest number of significant ($\alpha = 0.05$) upward trends was selenium (for wells D6 and

Table 7. Summary of results for statistical evaluation of ground-water-quality data for wells near Deer Trail, Colorado, 1999–2003.

[Summary from information provided in tables 15 and 16 in the Supplemental Information section at the back of the report; values less than the reporting limit were set equal to the highest reporting limit for this evaluation; mg/L, milligrams per liter; µg/L, micrograms per liter; pCi/L, picocuries per liter; >, greater than]

Parameter, unit	Number of wells considered	Number of samples at each well considered (N)	Exceedance of standards		Trends	
			Are ground-water concentrations significantly higher than the lowest regulatory standard? (alpha = 0.05)	p-value	Are concentrations of ground water in the vicinity of biosolids application increasing significantly (alpha = 0.05) with time?	p-value
Nitrite plus nitrate, dissolved (mg/L as N)	14	13–20	Yes (at well D6)	0 for D6, N=20	Yes (at well D6)	0 for D6, N=20
Arsenic, dissolved (µg/L as As)	14	13–20	No	>0.3	No	>0.2
Cadmium, dissolved (µg/L as Cd)	14	13–20	No	>0.3	No ¹	>0.3
Chromium, dissolved (µg/L as Cr)	14	13–20	No	>0.3	No	>0.1
Copper, dissolved (µg/L as Cu)	14	13–20	No	>0.3	Yes (at well D25)	0.04 for D25, N=20
Lead, dissolved (µg/L as Pb)	14	13–20	No	>0.3	No ¹	>0.3
Mercury, dissolved (µg/L as Hg)	14	13–20	No	>0.3	No	>0.2
Molybdenum, dissolved (µg/L as Mo)	14	13–20	(No regulatory limit)	--	Yes (at well DTX1)	0 for DTX1, N=19
Nickel, dissolved (µg/L as Ni)	14	13–20	No	>0.3	No	>0.2
Selenium, dissolved (µg/L as Se)	14	13–20	No	>0.3	Yes (at wells D6, DTX4)	0.01 for D6, N=20; 0.02 for DTX4, N=13
Zinc, dissolved (µg/L as Zn)	14	13–20	No	>0.3	No	>0.3
Gross alpha activity, dissolved, pCi/L	14	1	-- ²	-- ²	-- ²	-- ²
Gross beta activity, dissolved, pCi/L	14	1	-- ³	-- ³	-- ³	-- ³
Plutonium-238, whole water (pCi/L as Pu)	14	5	-- ⁴	-- ⁴	-- ⁴	-- ⁴
Plutonium-239+240, whole water (pCi/L as Pu)	14	5	-- ⁵	-- ⁵	-- ⁵	-- ⁵

¹All or most concentration data were less than the reporting limit, so no trend in ground-water concentration at some wells.

²Data were insufficient for statistical evaluation because sample matrix caused

³Data were insufficient for statistical evaluation because sample matrix caused interference with laboratory analysis. No regulatory limit for Colorado.

⁴Data were insufficient for statistical evaluation and all data were less than the reporting limit of 0.1 pCi/L. No regulatory limit for Colorado.

⁵Data were insufficient for statistical evaluation and all data were less than the reporting limit of 0.1 pCi/L. All data were less than the Colorado statewide standard of 15 pCi/L.

DTX4) (tables 7 and 16). The well that had the greatest number of significant ($\alpha = 0.05$) upward concentration trends was D6 (for nitrate and selenium). The only other significant ($\alpha = 0.05$) upward trends were in copper concentration for well D25 and molybdenum concentration for well DTX1. The strongest upward trend was in nitrate concentration for well D6.

Biosolids could be contributing to the increasing nitrate concentration at well D6 by providing more nitrogen to soil and ground water than can be used by vegetation or microorganisms. However, the upward trend in nitrate concentration at well D6 may not be caused solely by biosolids applications. There is little indication of a temporal response in concentration corresponding to individual applications of biosolids (fig. 18). Upgradient nitrate sources related to land uses before biosolids applications began have not been ruled out. Moreover, the combination of dissolved oxygen and dissolved solids naturally in the ground water at well D6 may be inhibiting microbial denitrification at this location. At other sites, such as along the Muddy Creek alluvial aquifer, redox sampling done in 1999 indicates that vegetation and microorganisms consume more nitrate nitrogen than is supplied from the various sources; additional nitrogen from biosolids applications has not significantly ($\alpha = 0.05$) increased ground-water nitrate concentrations.

The results of trend analysis on the 1999 through 2003 combined data set (table 16) also indicate a number of statistically significant ($\alpha = 0.05$) downward trends in the ground-water-quality data. The constituents tested that had no significant ($\alpha = 0.05$) downward trends were arsenic, cadmium, copper, lead, mercury, selenium, and zinc (table 16). The constituent tested that had the greatest number of significant ($\alpha = 0.05$) downward trends was molybdenum (for wells DTX8A and DTX10A) (table 16). The well that had the greatest number of significant ($\alpha = 0.05$) downward concentration trends was well D25 (nitrate and chromium). The only other significant ($\alpha = 0.05$) downward trend was in nickel concentration for well DTX4. The strongest downward trend was in molybdenum concentration for well DTX8A.

The results of trend analysis on the 1999 through 2003 combined data set (table 16) commonly were different than the results of the previous trend analyses on only the 1999 data set (Stevens and others, 2003), the 1999 through 2000 combined data set (Yager and others, 2004a), or the 1999 through 2001 combined data set (Yager and others, 2004b). Some of the trend directions changed from upward to downward trends or from downward to upward trends when the data were combined and retested each year, and significance of the trend result increased. Some of these changes may have been caused by the low power of the test when few data are used in the test (as in 1999–2001 and for DTX4 trends in this report), or by changes in the MRL or trend calculation as mentioned previously in this same section. Where quarterly samples were collected for all 5 years, the power of the trend test increased and has now reached a minimum acceptable level for interpretation (Dennis Helsel, U.S. Geological Survey, written commun., September 2004).

Are trends in ground-water concentration related to water level and, therefore, to climate or recharge? As stated previously in the Hydrology section, water levels in the alluvial aquifers generally declined during 1999 through 2003 (fig. 17). Did concentrations of the priority parameters in the alluvial aquifers significantly increase or decrease during the same period? The most consistent decreasing water levels were at well DTX3, which had no significant water-quality trends. Thus, trends in concentration do not directly correlate with water level in this study area. Additional information about water-quality trends related to climate or recharge is provided in figure 18. Concentrations of nitrate at well D6, molybdenum at well D25, nickel at most wells, and selenium at well DTX3 were relatively lower during the wet year (2001) and higher during the dry year (2002) (fig. 18). These concentrations are consistent with ground water that is diluted by recharge. The recharge water likely had lower concentrations of these constituents than the ground water already in contact with rock and soil at those locations. Conversely, concentrations of nitrate at well DTX3, selenium at well D6, and zinc at wells D6, D25, and D30 were relatively higher during the wet year (2001) and lower during the dry year (2002). These concentrations are consistent with ground water that is affected by recharge (that is, recharge water is a source of these constituents). However, ground-water quality did not correlate with climate (wet or dry years) or water levels at all sites or for all parameters.

Seasonal patterns in the time-series data may be present for molybdenum, selenium, and zinc at some sites. For example, molybdenum data for well D25 have an undulating pattern where higher concentrations occur in July 1999, October 2000, July 2002, and July 2003 and lower concentrations occur in intervening months (fig. 18). This pattern could be caused by seasonal effects that generally prevailed except during the exceptionally wet year (2001). However, too few data (a maximum of five samples at each site) are available to statistically test for seasonal trends. Seasonal patterns in the water-quality data are less indicative of biosolids effects than of natural geochemical processes because biosolids are not applied to the same locations within the study area on an annual schedule. Biosolids applications to any specific location within the study area were done, at most, every 2 years, sometimes less frequently. If sampling continues, the power of the statistical tests will increase and the amount of data available will enable further evaluation of trends and seasonal effects.

Biosolids Signature

The mere presence of inorganic chemical constituents in the ground water does not indicate effects from biosolids. The priority parameters and many of the other constituents monitored are naturally occurring elements and compounds in rocks and soil (table 1; Drever, 1988) and so have geochemical sources as well as a potential biosolids source. Another possible source for most of the priority parameters is inorganic fertilizer used in agriculture. Also, some constituents were

present in high concentrations in ground water of the study area before biosolids were applied to the study area (Tracy Yager, U.S. Geological Survey, unpublished data on file at Denver, Colo., office). Upward trends in ground-water concentrations of the priority parameters could result from natural processes completely unrelated to biosolids. Many of these constituents are present in the rocks and soils of the study area in about the same concentrations as in biosolids applied to the study area (table 1), but the water of the study area has more contact with soil and rock than biosolids (consider the volume of biosolids indicated by figure 2 compared to the volume of rock and soil at the study area). The biosolids signature elements for soil and sediment primarily are bismuth, mercury, phosphorus, and silver, and to a lesser extent cadmium, copper, molybdenum, selenium, uranium, and zinc (table 1). However, bismuth, silver and some of the other elements highlighted in yellow in table 1 are not very soluble (table 10), so these elements are not the best inorganic biosolids signature for water in the study area.

The preliminary water leach tests on biosolids (mentioned previously in the Biosolids and Soil sections of this report) provide information about which inorganic elements and compounds are sufficiently mobile in biosolids and soil to move into pore water in the unsaturated zone, surface water (ponds or runoff), or ground water. Leachate concentrations from biosolids were compared with leachate concentrations from soil to determine biosolids signature elements for water (table 10 in the Supplemental Information section at the back of the report). The results of the leach tests indicate that the inorganic biosolids signature elements for water of the study area primarily are molybdenum and tungsten, and to a lesser extent antimony, cadmium, cobalt, copper, mercury, nickel, phosphorus, and selenium (table 10); note that the leachate samples were not analyzed for any nitrogen species.

The ground-water samples collected near Deer Trail during 1999 through 2003 were not analyzed for tungsten, but they were analyzed for antimony, cadmium, cobalt, copper, mercury, molybdenum, nickel, phosphorus, and selenium (table 5). Tungsten is expected to act geochemically similar to molybdenum, so relative concentrations could be similar for molybdenum and tungsten in the ground water (Pais and Jones, 1997). Antimony concentrations generally were less than detection or about equal to the reporting limit, but three values were substantially higher: 2.9 $\mu\text{g/L}$ at DTX2 on 10/16/02, 2.8 $\mu\text{g/L}$ at DTX4 on 10/11/01, and 1.3 $\mu\text{g/L}$ at DTX5 on 04/09/02 (and D6 was < 7 on 07/06/99). Cadmium concentrations generally were less than detection or about equal to the reporting limit at most sites but were substantially higher at three sites: D25, D6, and DTX1, and one value on 10/16/02 at well DTX2. Cobalt concentrations were highest at wells D15, D6A, D6, DTX2, and D25. Copper concentrations were considerably higher at well D6 but also relatively high at wells D25, D29, DTX2, and DTX6 (fig. 18). Mercury concentrations all were less than the reporting level (all less than 0.2 $\mu\text{g/L}$); the only detection was 0.1 $\mu\text{g/L}$ at well D29 on 04/16/99. Molybdenum concentrations were highest at

wells D25, DTX1, D17, and D6 (fig. 18). As mentioned previously, nickel concentration was too variable to pick many patterns in the data, but concentrations generally were highest at wells D25, D6, DTX1, and DTX5 (fig. 18). Phosphorus concentrations generally were less than the reporting limit, except for 0.2 mg/L (dissolved phosphorus) at D25A; concentrations were highest at wells D25A, D25, D17, and DTX1. Selenium concentrations were highest at wells DTX3, DTX4, D6, and D17 (fig. 18). These data are reported by Stevens and others (2003) and Yager and others (2004a, 2004b, 2004c).

What do the leach-test data tell us? The signature elements from the leach tests are not always present at high concentrations in ground water of the study area, and the higher concentrations of these elements are not always at the same wells. However, ground water from wells D6 and D25 had relatively high concentrations of six of the biosolids signature elements compared to other ground water in the study area. Ground water from wells DTX1 and DTX2 had relatively high concentrations of four of the biosolids signature elements compared to other ground water in the study area. Ground water from well D17 had relatively high concentrations of three of the biosolids signature elements compared to other ground water in the study area. Moreover, ground-water concentrations increased significantly ($\alpha = 0.05$) during 1999 through 2003 for nitrate and selenium at well D6, for copper at well D25, and for molybdenum at well DTX1 (table 7). Therefore, these data indicate that ground water at wells D6, D25, DTX1, and possibly DTX2 and D17, are more likely affected by biosolids applications than ground water at the other monitoring wells of the study area.

These results are not conclusive, however. All these trace elements have natural geochemical sources. Geochemical sources and natural processes still could account for all the inorganic trace-element concentrations in the ground water. Consider that age dating of ground-water samples from wells D6, D17, and D25 in 1998 indicated that ground water recharged too slowly at those sites to be affected yet by biosolids applications, although the USGS has only moderate confidence in the results for D6 and D25 because old and young ground water seemed to be mixing at these sites (Yager and Arnold, 2003, p. 26). Further age dating of the ground water of the study area would be helpful for understanding ground-water ages and flow paths and for determining whether biosolids effects are possible at this time.

Streambed Sediment

Animal waste related to grazing livestock and applications of pesticides, herbicides, or fertilizers (including biosolids) to the land surface could affect surface-water quality directly by contaminated inflow or by runoff over contaminated soils or sediments (remobilization). These applications also can affect surface-water quality indirectly by tilling that mobilizes or changes surface constituents or surface

characteristics; by inflow, base flow, or recharge to surface water from contaminated ground water; or by contributions to natural processes such as nitrification. Contaminated surface water could contaminate downstream, previously uncontaminated ponds, streams, streambed sediments, alluvial aquifers, or bedrock water-supply aquifers in aquifer-recharge zones.

Surface-water contamination from biosolids applications is a public concern. However, because streams flow off the MWRD properties only after intense thunderstorms, surface-water sampling is impractical, and monitoring extreme surface-water events is difficult. Monitoring streambed-sediment chemistry is more practical and cost effective and offers greater opportunity to establish comparison or baseline sites than monitoring surface-water chemistry. For the expanded monitoring program, streambed sediment is defined as the fine-grained alluvium freshly deposited in the drainage bottoms by surface-water flow (runoff) after rainstorms.

Sediment affected by the applications of biosolids could be transported off MWRD property into streambeds when precipitation is intense enough to cause overland flow. Therefore, streambed-sediment chemistry was evaluated to indicate chemistry of particles transported by surface water. Contaminants in the streambed sediment could cause contamination in ground water or surface water if the contaminants are resuspended in water or leached from the bed sediment. Furthermore, concentrations of trace elements and plutonium and gross alpha and gross beta activity may be higher in the bed sediment than in dissolved form in the surface water.

Objectives of Monitoring Streambed Sediment

Streambed sediments were monitored to determine if concentrations of nitrogen, phosphorus, organic carbon, arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, zinc, plutonium, and gross alpha and gross beta radioactivity in sediments derived from (or transported through) biosolids-application areas are significantly higher than in bed sediments derived from nearby farmland that did not receive biosolids applications.

Approach for Monitoring Streambed Sediment

Two small drainage basins were selected for comparison of streambed-sediment chemistry (fig. 1). The basins had similar physical characteristics, but one basin (known as the biosolids-applied basin) receives biosolids applications and is part of the MWRD farming program, and the other basin (known as the control basin) receives no biosolids applications and is farmed privately. A complete comparison of basin characteristics and a description of basin-selection criteria are included in Stevens and others (2003).

A DCP site (with a rain gage) was at DTX2 (fig. 1) near the biosolids-applied basin. The DCP data were transmitted remotely to enable the USGS to determine when rainfall of sufficient intensity and duration had occurred near the basins.

For sampling to take place, sufficient rainfall was needed to cause the fine-grained materials and dissolved constituents to wash off the hillsides of the drainage basins into down-gradient streambeds. Paired streambed-sediment samples were collected when freshly deposited streambed sediment was available from both the biosolids-applied basin and the control basin at the same time (after the same storm). The USGS learned that at least 0.50 inch of rain in a single hour had to be received by the tipping-bucket rain gage at DTX2 before runoff in the biosolids-applied basin was enough for a streambed-sediment sample to be collected. This rainfall scenario rarely occurred during 1999 through 2003; the USGS was able to collect only nine paired samples during this 5-year monitoring period. The streambed-sediment samples were collected using standard USGS protocols (U.S. Geological Survey, variously dated).

Streambed-sediment samples were collected as field composites. That is, the upper 1–2 cm of freshly deposited sediment was collected from various locations within the basin and combined into a single bag for that basin. Usually, samples were collected from different locations within the basin each time because areas of fresh sediment deposits were limited and were not in the same area of the basin every time. The composite sample for each basin was processed substantially in the USGS laboratory (Denver, Colo.) before analysis. The sample for each basin was processed exactly the same way, at the same time, using the same type of dedicated equipment. The composite sample for each basin was stirred with deionized water to homogenize, then wet sieved to less than 63 μm for trace-element analysis and to less than 2 mm for nutrient, carbon, and radioactivity analysis. Runoff deposits commonly did not yield enough material to enable collection of field duplicates (completely separate samples). Therefore, replicate samples and regular samples were prepared from the same bag of sediment but sieved separately from the composite material, not split from sieved subsamples.

Streambed-sediment samples were analyzed for priority parameters (ammonia plus organic nitrogen, phosphorus, arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, zinc, carbon, gross alpha and gross beta radioactivity, and plutonium) and other selected parameters. The radioactivity analyses were included in response to public concerns that biosolids radioactivity concentrations could increase from the transfer of treated water from the Lowry Landfill Superfund site to the MWRD treatment plant. During 2002 through 2003, additional trace elements (including silver and uranium) were included in the analyses. Sampling, processing, and analytical methods are described by Stevens and others (2003) and Yager and others (2004a, 2004b, 2004c).

Effects of Biosolids on Streambed Sediment

Effects of biosolids on streambed sediment can be physical or chemical in type. This monitoring program was not designed to address the physical effects of biosolids on streambed sediment. However, the USGS observed that

runoff-produced streambed sediment usually was less in the biosolids-applied basin than in the control basin. Possible explanations for this observed difference include differences in rainfall intensity or duration, differences in farming practices, or slight differences in soil type or chemistry. Another possible explanation is that biosolids are primarily composed of organic matter and may include synthetic polymers used to separate the liquid effluent from the solid effluent during wastewater treatment. These organic compounds may decrease soil erosion from wind and water and, therefore, result in less soil and sediment moved by runoff and redeposited in alluvial channels of the biosolids-applied basin. Another possibility is that the biosolids act as a crude ground cover that decreases erosion and runoff. More study would be needed to verify these hypotheses.

Comparison with Regulatory Standards or Guidelines

Chemical effects of biosolids on streambed sediment were not evaluated by comparison of the chemical data to regulatory standards. These sediment samples were collected near Deer Trail, Colo., instead of surface-water samples because collection of representative surface-water samples was impractical. Comparison of the sediment data to surface-water standards would not be appropriate. Streambed-sediment regulatory standards or guidelines do exist but generally are not applicable to the sediment data collected near Deer Trail. These standards and guidelines usually presume that a water column is present above the sediment or that sediment is in the water column, which was not the case near Deer Trail at the time of sampling. These standards and guidelines also are not designed for the sediment fraction that is less than 63 μm , the size fraction of sample likely to yield the highest trace-element concentrations. Other standards that relate to sediment from erosion are written in terms of sediment quantity or sediment amount in a water column, not sediment chemistry, so no comparison is possible. Some standards relate sediment chemistry to toxicity effects on aquatic life, but no aquatic life has been identified at the sediment-sampling locations of this study. Because no water column is present with the sediment sampled in this study, soil standards or guidelines (tables 2 and 3) are the most appropriate comparison, although these also were not designed for the sediment fraction that is less than 63 μm . Comparison of the sediment data collected near Deer Trail (fig. 19) to the soil cleanup value standards for Colorado (table 2) indicates that, like the soil samples from this study, concentrations of arsenic in sediment from both the biosolids-applied and control basins were considerably higher than the standard (see Soil section in this report). Concentrations of lead and mercury in sediment (fig. 19) were less than the lowest standards in table 2. Lead concentrations (fig. 19) sometimes exceeded the Ecological soil screening level for birds (table 3) in sediment from both basins, but cadmium concentrations (fig. 19) never exceeded the lowest screening level in either basin (table 3).

Comparison of Sites

Chemical effects of biosolids on streambed sediment were determined through comparison of the sample data for the biosolids-applied basin with that for the control basin and through comparison of sample data with corresponding replicate data. Trends in concentration were not used to indicate biosolids effects because too few samples (only 5–10) were available for analysis. In order to state with confidence that streambed-sediment composition is affected by biosolids, the difference in chemical composition between the two basins for a given parameter must significantly exceed the variability in data for that parameter.

Variability in the streambed-sediment data for this program was evaluated by replicate analyses. The runoff deposits usually were not plentiful enough to collect two independent samples as replicates. Replicate samples and regular samples were prepared from the same bag of sediment but sieved separately from the composite material, not split from sieved subsamples. Still, the replicates for this program are more of a split sample than a sequential sample. Therefore, the sample variability indicated by the replicate data is partially from natural chemical heterogeneity in the sediment deposits and sediment-sample matrix but mostly from laboratory analytical uncertainty. Collection of field duplicates (completely separate samples) would be necessary to evaluate the true variability (sample variability from laboratory analytical uncertainty plus natural chemical heterogeneity). Note that the variability caused by natural chemical heterogeneity in the sediment likely is much larger than the variability caused by laboratory uncertainty and could be 20 percent or more, although for some elements the laboratory variability may exceed the sampling variability (Crock and others, 1992, 1994; Mausbach and others, 1980; Severson and others, 1990; Stewart and others, 1993).

Variability in the data was evaluated at two levels: (1) variability for each sample at the time of analysis as represented by the relative percent difference calculated for each sample-replicate pair (reported for all sample-replicate pairs by Stevens and others [2003] and Yager and others [2004a, 2004b, 2004c]) and (2) variability for the entire 1999 through 2003 sediment data set as represented by a summary value (mean or median percent difference or median absolute difference, as appropriate for the data). Variability measures for each sample-replicate pair (method from Terry Schertz, U.S. Geological Survey, written commun., February 10, 1997) and the corresponding summary values are listed for each priority parameter in table 17 (in the Supplemental Information section at the back of the report). Difference measures for each biosolids-applied basin/control-basin sample pair and the corresponding summary values are listed for each priority parameter in table 18 (in the Supplemental Information section at the back of the report). The reason for including silver and uranium in the tables are explained later in this section.

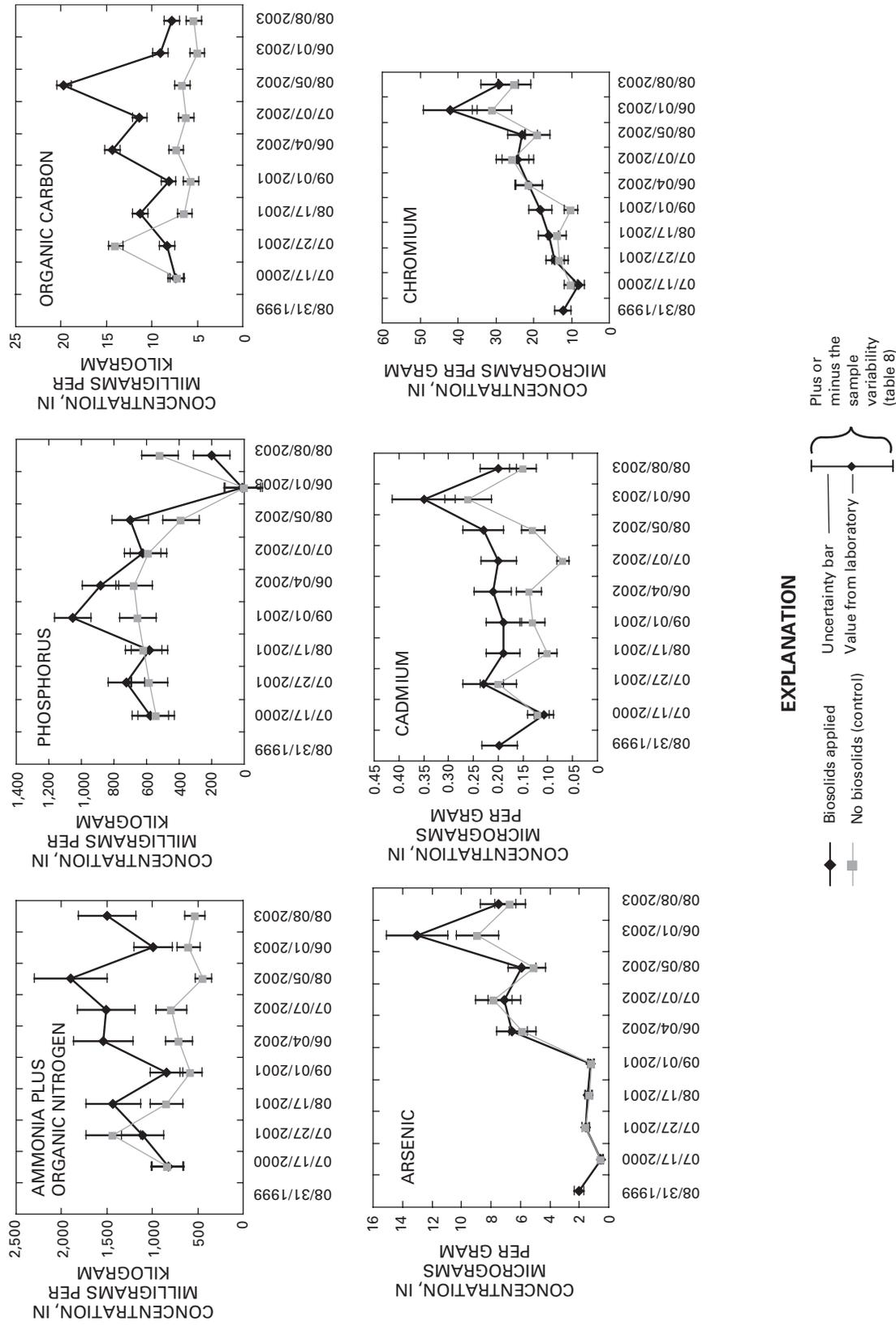


Figure 19. Streambed-sediment concentrations near Deer Trail, Colorado, for selected constituents, 1999–2003.

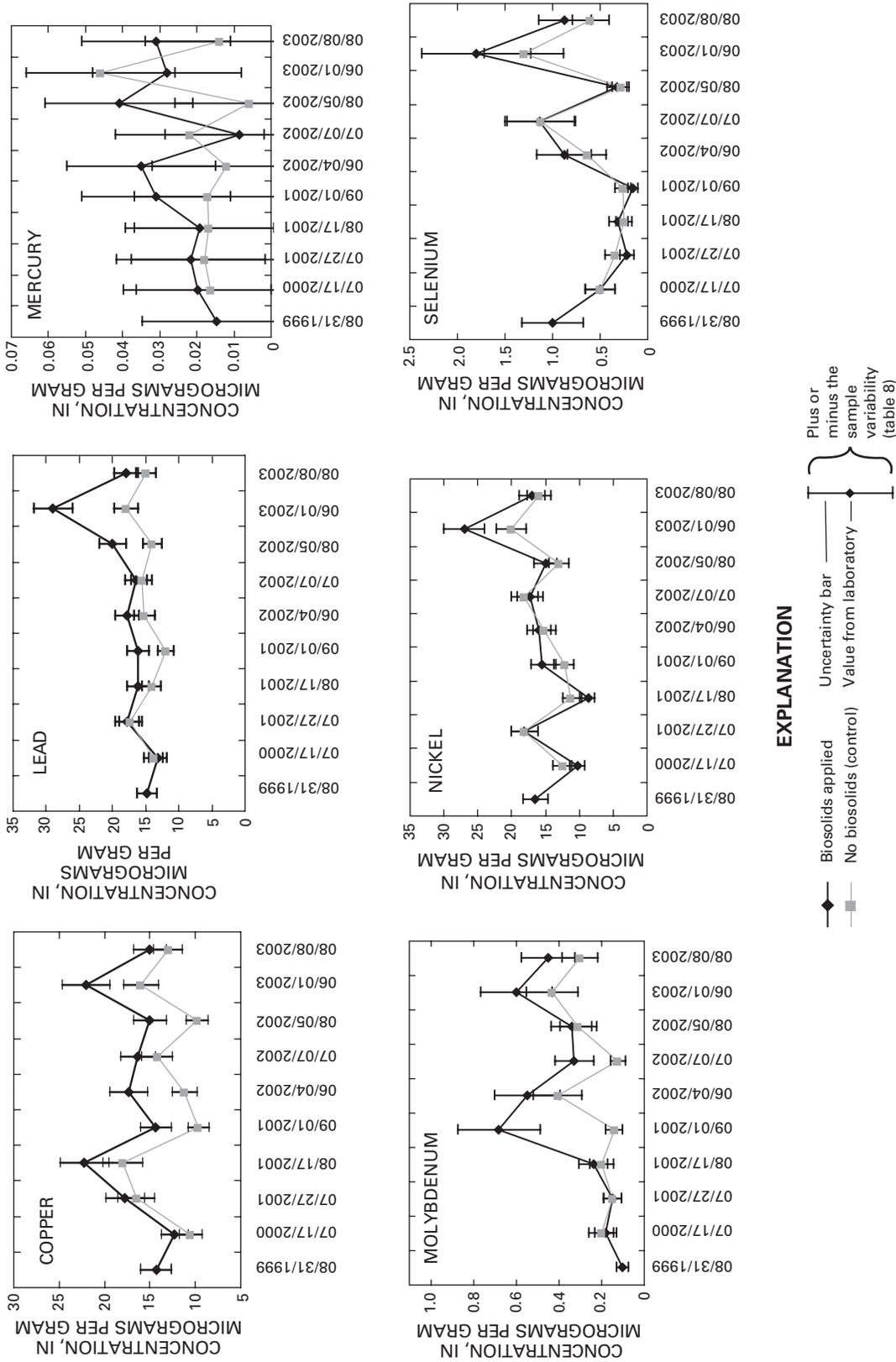


Figure 19. Streambed-sediment concentrations near Deer Trail, Colorado, for selected constituents, 1999–2003.—Continued

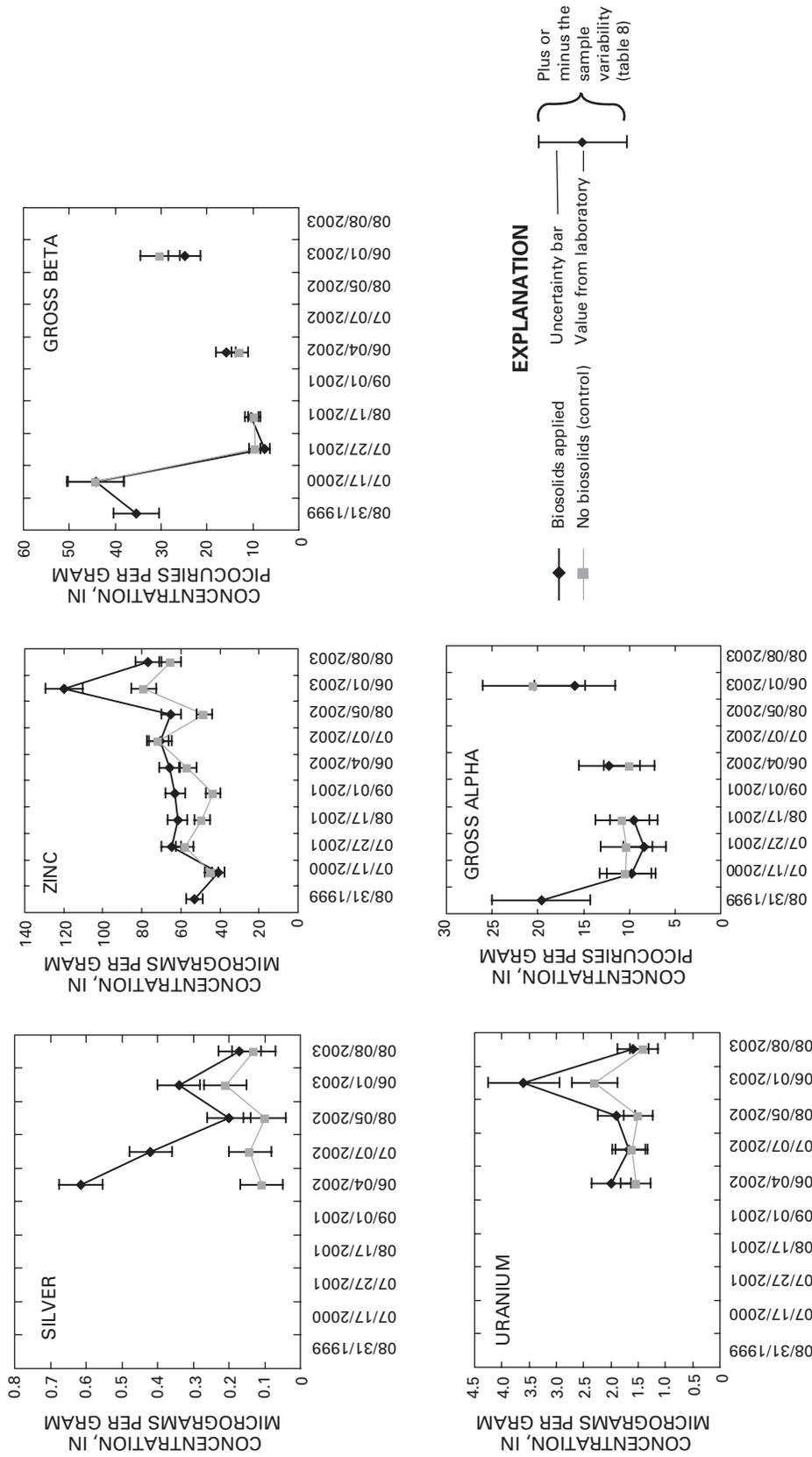


Figure 19. Streambed-sediment concentrations near Deer Trail, Colorado, for selected constituents, 1999–2003.—Continued

Summary values for sample variability and differences between basins for each parameter of interest during 1999 through 2003 are listed in table 8 (method from Terry Schertz, U.S. Geological Survey, written commun., February 10, 1997). Note that median measures of variability usually are smaller than mean measures because the median does not consider extreme high or low values (tables 8 and 17). The median as a variability estimate for many constituents, such as arsenic, cadmium, and copper concentrations, does not represent the central tendency and grossly underestimates the true variability because the individual variability estimates have so many extreme values in a small data set (table 17). For this reason, the mean was selected as the summary value to represent sample variability, regardless of the data distribution. Actual variability or uncertainty in the sample data could be substantially lower or higher than the summary values for any specific sample pair (table 17). Note that differences between pairs are not always substantial and may be well within the precision of the laboratory method. Because different measures of variability are appropriate for different parameters, the variability values are difficult to compare. The summary values in table 8 indicate that sample variability (mean percent difference) was greatest in the sediment data for phosphorus, mercury, and selenium. Variability (mean percent difference) was smallest in the sediment data for zinc, lead, and nickel. A comparison of the summary values in table 8 also indicates that differences between basins (mean percent difference) were greatest for silver, mercury, and nitrogen and smallest for arsenic, nickel, and gross beta. Differences between basins (mean percent difference) generally were greater than sample variability for most priority parameters. Differences between basins (mean percent difference) exceeded sample variability most for silver, organic carbon, and nitrogen. For parameters such as chromium, nickel, and uranium, the differences between basins (mean percent difference) are almost the same as the sample variability; in those instances, differences between basins are not substantial (table 8). Differences between basins (mean percent difference) were about the same or even less than sample variability for phosphorus, arsenic, selenium, and gross alpha activity (table 8). However, this numeric comparison (table 8) does not provide an objective answer to the question, “Are the differences between the basins significantly greater than the sample variability?”

Differences in chemical concentration between the biosolids-applied basin and the control basin can be evaluated several other ways. For all biosolids-applied basin/control-basin sample pairs, the concentration of each priority parameter is graphed in figure 19 along with uncertainty bars that represent the variability estimate (shaded values in table 8). Plutonium data were not graphed because concentrations were not above detection, and the distribution of data were near zero. The graphical distribution of point concentrations indicates that concentrations are higher in the biosolids-applied basin than in the control basin for most of the priority parameters; concentrations are the same or lower in the biosolids-applied basin than in the control basin for gross alpha and

gross beta radioactivity (fig. 19). Biosolids were applied directly to the sediment-sampling areas of the biosolids-applied basin, so concentrations of constituents in the streambed sediment likely are not representative of (are higher than) sediment that is transported off the MWRD property. The paired data points also were statistically evaluated by using the Sign Test (Helsel and Hirsch, 2002). The statistical evaluation considers sample variability and still indicates that concentrations of ammonia plus organic nitrogen, organic carbon, copper, lead, mercury, and silver were significantly ($\alpha < 0.10$) higher in sediment of the biosolids-applied basin (table 9). Biosolids applications likely contribute to the significantly higher concentrations of nitrogen and organic carbon, which are major components of biosolids. The source of significantly higher concentrations of trace elements is more difficult to determine because of natural sources in soils.

Biosolids Signature

Differences in trace-element composition between the two basins could be caused by natural geochemical differences between the two basins; that is, a larger component of shale in the soil parent material at the biosolids-applied basin could cause higher trace-element concentrations in the sediment deposits sampled at the biosolids-applied basin (the reader is referred to the discussion of natural geochemical variability in the Soil section of this report). The streambed-sediment deposits sampled actually are soil and pond sediment originating in the sampled basin that are washed downgradient by storm runoff and redeposited, so soil geochemistry can have a major effect on the chemical composition of the streambed-sediment samples of both basins. Biosolids already had been applied in at least parts of all basins of the MWRD property before the start of this expanded monitoring program (the control basin is not on MWRD property and never received biosolids), so a baseline (or prebiosolids) chemical composition of soil or sediment in the monitored basin was not available. A biosolids chemical signature would help to distinguish biosolids effects from the natural geochemical signature of soil and sediment where baseline data are not available.

An inorganic-chemical signature for biosolids can be determined from the data summary in table 1. The Arapahoe County soil plots are closest in distance to the sediment-monitored basins (fig. 1) but may not be chemically identical, so data from both soil-monitoring plots are considered. By comparing chemical data for biosolids with chemical data for the various soil-control plots (soil-sampling areas where biosolids are never applied), the only elements for which biosolids concentrations are substantially greater than natural soil concentrations are bismuth, cadmium, copper, mercury, molybdenum, phosphorus, selenium, silver, uranium, and zinc (table 1). The largest concentration differences are seen for bismuth, mercury, phosphorus, and silver. Unfortunately, the sediment samples were not analyzed for bismuth, and only five of the nine sample pairs were analyzed for silver and uranium. Concentrations of some (copper, mercury, and silver) but

Table 8. Comparison of variability in chemical data from sediment-replicate samples with differences in chemical data between biosolids-applied and control-basin samples collected near Deer Trail, Colorado, 1999–2003.

[Shaded values indicate the measure and value of variability selected to represent that constituent (shown graphically in fig. 19); values summarized from tables 17 and 18 in the Supplemental Information section at the back of the report; values less than the reporting level were set equal to the reporting level for this evaluation; calculations done on unrounded data; <, less than; mm, millimeters; μm , micrometers; mg/kg, milligrams per kilogram; g/kg, grams per kilogram; $\mu\text{g/g}$, micrograms per gram; pCi/g, picocuries per gram]

Measure ¹	Sample variability		Basin difference	
	Median	Mean	Median	Mean
Ammonia plus organic nitrogen in sediment <2 mm, mg/kg as N				
Relative standard deviation	6	15	36	41
Absolute difference	106	189	583	617
Percent difference	8	21	51	58
Phosphorus in sediment <2 mm, mg/kg				
Relative standard deviation	13	45	19	31
Absolute difference	62	112	142	166
Percent difference	18	63	26	43
Organic carbon in sediment <2 mm, g/kg				
Relative standard deviation	9	8	39	36
Absolute difference	1.01	0.82	5	5
Percent difference	13	12	56	51
Arsenic in sediment <63 μm, $\mu\text{g/g}$				
Relative standard deviation	1.32	11	7	7
Absolute difference	0.12	0.71	0.71	0.81
Percent difference	2	16	10	10
Cadmium in sediment <63 μm, $\mu\text{g/g}$				
Relative standard deviation	6	12	27	30
Absolute difference	0.01	0.03	0.07	0.07
Percent difference	8	18	38	42
Chromium in sediment <63 μm, $\mu\text{g/g}$				
Relative standard deviation	4	12	11	14
Absolute difference	0.57	3.41	2	4
Percent difference	5	17	15	19
Copper in sediment <63 μm, $\mu\text{g/g}$				
Relative standard deviation	5	9	15	18
Absolute difference	1.00	2.04	4	4
Percent difference	6	12	21	25
Lead in sediment <63 μm, $\mu\text{g/g}$				
Relative standard deviation	5	7	11	14
Absolute difference	1.00	1.93	2.6	3.5
Percent difference	7	10	16	19
Mercury in sediment <63 μm, $\mu\text{g/g}$				
Relative standard deviation	41	38	41	45
Absolute difference	0.01	0.02	0.01	0.01
Percent difference	58	53	58	63

Table 8.—Continued

Measure ¹	Sample variability		Basin difference	
	Median	Mean	Median	Mean
Molybdenum in sediment <63 μm, $\mu\text{g/g}$				
Relative standard deviation	18	20	21	28
Absolute difference	0.08	0.10	0.14	0.14
Percent difference	25	28	30	40
Nickel in sediment <63 μm, $\mu\text{g/g}$				
Relative standard deviation	4	8	10	10
Absolute difference	1.00	1.87	2	2
Percent difference	6	11	14	14
Selenium in sediment <63 μm, $\mu\text{g/g}$				
Relative standard deviation	16	23	23	18
Absolute difference	0.18	0.25	0.10	0.15
Percent difference	23	32	32	25
Silver in sediment <63 μm, $\mu\text{g/g}$				
Relative standard deviation	12	14	47	54
Absolute difference	0.05	0.06	0.13	0.21
Percent difference	18	19	67	76
Uranium in sediment <63 μm, $\mu\text{g/g}$				
Relative standard deviation	4	13	17	15
Absolute difference	0.10	0.55	0.40	0.48
Percent difference	6	18	24	22
Zinc in sediment <63 μm, $\mu\text{g/g}$				
Relative standard deviation	2	6	12	14
Absolute difference	2	6	12	14
Percent difference	3	8	17	20
Gross alpha activity in sediment <2mm, pCi/g				
Relative standard deviation	19	20	14	12
Absolute difference	3	3	1.97	2.08
Percent difference	28	28	20	17
Gross beta activity in sediment <2mm, pCi/g				
Relative standard deviation	5	10	14	10
Absolute difference	0.63	2.98	2.17	2.24
Percent difference	7	14	20	14

¹Measures of variability (from Terry Schertz, U.S. Geological Survey, written commun., February 10, 1997) were calculated as follows: relative standard deviation = $100 \left(\frac{\text{square root } (C1-C2)^2/2}{(C1+C2)/2} \right)$; absolute difference = $|C1-C2|$; percent difference = $100 \left(\frac{|C1-C2|}{(C1+C2)/2} \right)$, which is the same as the absolute value of the relative percent difference calculated in Yager and others, 2004b and 2004c, where C1 is the concentration in the regular sample (or biosolids-applied basin) and C2 is the concentration in the replicate sample (or control basin). Differences in pairs were not normally distributed, so nonparametric measures (absolute difference and percent difference) are the most appropriate measures. Absolute difference is the best measure when differences between pairs are not larger with larger concentrations. Percent difference is the best measure when differences between pairs are larger with larger concentrations. Mean values were selected to represent sample variability because median values did not represent the broad range of concentration differences.

Table 9. Results of statistical comparison of chemical data including variability for paired streambed-sediment samples collected from biosolids-applied and control basins near Deer Trail, Colorado, 1999–2003.

[Statistical comparison was Sign Test described by Helsel and Hirsch (2002); concentration ranges are compared graphically in figure 19; number of sample pairs in parentheses is that used for the statistical comparison because tied pairs cannot be counted in the Sign Test; <, less than; mm, millimeters; μm , micrometers; mg/kg, milligrams per kilogram; g/kg, grams per kilogram; $\mu\text{g/g}$, micrograms per gram; pCi/g, picocuries per gram]

Parameter, unit	Number of sample pairs considered	Median value		p-value	Confidence level of result (percent)	Are sediment concentrations from the biosolids-applied basin significantly ($\alpha < 0.10$) higher than that of the control basin?
		Biosolids- applied basin	Control basin			
Ammonia plus organic nitrogen in sediment <2 mm, mg/kg as N	9 (9)	1,430	706	0.04	96	Yes
Phosphorus in sediment <2 mm, mg/kg	9 (9)	625	582	0.18	82	No
Organic carbon in sediment <2 mm, g/kg	9 (9)	9.10	6.39	0.04	96	Yes
Arsenic in sediment <63 μm , $\mu\text{g/g}$	9 (6)	3.96	5.10	0.22	78	No
Cadmium in sediment <63 μm , $\mu\text{g/g}$	9 (7)	0.200	0.138	0.22	78	No
Chromium in sediment <63 μm , $\mu\text{g/g}$	9 (8)	19.7	19.0	0.29	71	No
Copper in sediment <63 μm , $\mu\text{g/g}$	9 (9)	15.7	13.0	0.004	99.6	Yes
Lead in sediment <63 μm , $\mu\text{g/g}$	9 (9)	17.2	15.0	0.04	96	Yes
Mercury in sediment <63 μm , $\mu\text{g/g}$	9 (8)	0.025	0.017	0.07	93	Yes
Molybdenum in sediment <63 μm , $\mu\text{g/g}$	9 (7)	0.334	0.300	0.13	87	No
Nickel in sediment <63 μm , $\mu\text{g/g}$	9 (8)	16.3	15.2	0.73	27	No
Selenium in sediment <63 μm , $\mu\text{g/g}$	9 (6)	0.875	0.600	0.69	31	No
Silver in sediment <63 μm , $\mu\text{g/g}$	5 (5)	0.340	0.130	0.06	94	Yes
Uranium in sediment <63 μm , $\mu\text{g/g}$	5 (4)	1.90	1.54	0.12	88	No
Zinc in sediment <63 μm , $\mu\text{g/g}$	9 (9)	65.0	56.6	0.18	82	No
Gross alpha activity in sediment <2mm, pCi/g	5 (5)	11.0	10.4	1.00	0	No
Gross beta activity in sediment <2mm, pCi/g	5 (4)	20.4	12.9	1.00	0	No
Plutonium (Pu-238) in sediment <2mm, pCi/g	5 (5)	0.003	0	-- ¹	-- ¹	-- ¹
Plutonium (Pu-239+240) in sediment <2mm, pCi/g	5 (5)	0.007	0.005	-- ¹	-- ¹	-- ¹

¹Concentrations were not above the reporting limit and the distribution of plutonium concentrations was near zero, so this parameter was not evaluated.

not all of the biosolids-signature elements were significantly ($\alpha < 0.10$) higher in sediment samples from the biosolids-applied basin than in sediment samples from the control basin. Biosolids applications likely contribute to the significantly higher concentrations of mercury and silver (and possibly copper) in the sediment (table 1). Based on the leach-test results (fig. 5), biosolids could have contributed to molybdenum and selenium concentrations in the sediment that decreased by the mass lost to water that either continued downstream or infiltrated the subsurface and thus did not result in significantly higher concentrations in the sediment. Therefore, comparison of the sediment results to the inorganic biosolids signature elements in table 1 indicates that at least some of the chemical differences between the control and the biosolids-applied basins could be attributed to biosolids applications.

A signature based not on inorganic or radioactive constituent concentrations is needed to more confidently differentiate the effects of biosolids from the effects of natural geochemistry. Cadmium, copper, molybdenum, selenium, and zinc are elements that are present in soil and sediment because of natural rock weathering (geochemistry) (Drever, 1988; Pais and Jones, 1997). Concentrations of these elements in the sediment samples from this expanded monitoring program are consistent with concentrations in uncontaminated soil (Pais and Jones, 1997). Natural geochemical causes of increased concentrations in these elements for the biosolids-applied basin cannot be easily verified or discounted by a mass-loading calculation, as was done previously in this report for soil, because the mobility of the biosolids (or these elements within biosolids) relative to the mobility of soil that results in the sediment deposits is not known.

Summary and Conclusions

The U.S. Geological Survey (USGS), in cooperation with Metro Wastewater Reclamation District (MWRD) and North Kiowa Bijou Groundwater Management District, studied natural geochemical effects and the effects of biosolids applications to the MWRD properties near Deer Trail, Colo., during 1999 through 2003. This study was conducted in response to public concern about potential contamination of soil, crops, ground water, and surface water from biosolids applications. In this study, biosolids, soil, crops, ground water, and streambed sediment (in place of surface water) were separate monitoring components. Priority parameters were identified by stakeholders and were slightly different for each monitoring component. Priority parameters for each monitoring component included the nine trace elements regulated by Colorado for biosolids (arsenic, cadmium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc), gross alpha and gross beta radioactivity, and plutonium. Other constituents and parameters also were analyzed for each monitoring component.

Chemical data for biosolids collected from the MWRD plant over approximately 5 years (1999 through 2003) show that all nine of the regulated trace elements for biosolids maintained relatively uniform concentrations and never exceeded the maximum allowable levels for Table 3 (Grade I) biosolids. Elevated concentrations of bismuth, mercury, phosphorus, and silver, and to a lesser extent, cadmium, copper, molybdenum, selenium, uranium, and zinc, would be the most likely inorganic biosolids signature to indicate that soil or streambed sediment have been affected by biosolids. Measurements of gross alpha activity have a high degree of uncertainty but generally were below the now-outdated limit of 40 picocuries per gram (pCi/g). No regulatory limits have been established for plutonium, but all values were below the minimum detectable level and were near zero.

Preliminary experiments in which biosolids were leached with distilled-deionized water indicate that antimony, cadmium, cobalt, copper, mercury, molybdenum, nickel, phosphorus, selenium, and tungsten have the highest biosolids to soil leachate-concentration ratio and may be useful indicators of biosolids effects on ground and surface water. The elements leached at the highest percentage of their total concentration in biosolids are arsenic, molybdenum, nickel, phosphorus, and selenium. This high percentage indicates that these elements occur in biosolids in a more soluble form.

Chemical data for soil samples collected in 1999, 2000/2001, and 2002 from monitoring sites in Arapahoe and Elbert Counties, Colo., show that biosolids have had no measurable effect on the concentration of the priority parameters. Each of the trace-element concentrations show variation over the course of the three sampling events that is consistent with the natural variation expected from estimating the composition of soil in a large field by taking a limited number of subsamples. Plutonium concentration of these soil samples is below the minimum detectable level, and gross alpha and gross beta activity show no significant change.

Arsenic concentrations in soil of both Arapahoe and Elbert County monitoring sites exceed the soil remediation objectives and soil cleanup value standards issues by the Colorado Department of Public Health and Environment in 1997. This is a function of the manner in which the cleanup value standards were determined by back-calculating a soil concentration equivalent to a one-in-a-million cumulative cancer risk.

Lead concentrations in soil from Arapahoe and Elbert County slightly exceed the U.S. Environmental Protection Agency toxicity-derived ecological soil screening levels for birds. This is true for those fields receiving biosolids as well as for the control fields, which never receive biosolids.

Wheat grain was sampled on the Arapahoe County and Elbert County monitoring sites after the 2000 and 2002 harvests. With only two data points, it is impossible to draw conclusions about trends in crop composition that might be related to application of biosolids. Comparison with data on winter wheat from other parts of North America where biosolids were not applied shows that wheat from the monitoring fields has very similar concentrations of elements in common with the other localities. Nickel is the exception to this statement; the monitoring fields had higher nickel values in both the biosolids-applied fields and the control fields. Plutonium content of the wheat is below detection for all samples with the distribution near zero.

Ground-water levels generally declined at all alluvial-aquifer wells during 1999 through 2003, but ground-water levels at two bedrock-aquifer wells increased slightly during 1999 through 2003. Water levels steadily declined at one alluvial-aquifer well to the extent that the well was dry after the study, possibly because of upgradient withdrawals. At another alluvial-aquifer well, water levels declined to the extent that the well was dry in fall 2001, but the well periodically recharged.

Water-level data for 1999 through 2003 indicate that at the DTX9, DTX10, DTX11 recharge area, vertical gradients are more favorable for the shallow, sandy part of the bedrock aquifer to recharge (discharge to) the alluvial aquifer in the Muddy Creek flood plain, not for the alluvial aquifer to recharge (discharge to) the bedrock aquifer. Conversely, data indicate that at the DTX7, DTX8 recharge area, vertical gradients are favorable for the alluvial aquifer to recharge (discharge to) and possibly contaminate the bedrock aquifer during July–January, despite confining pressures from the deeper parts of the bedrock aquifer. Vertical gradients also indicate that agricultural and range land uses in this part of Muddy Creek (near DTX7, DTX8) could have a larger effect on ground-water quality than the biosolids applications that are more than 4 miles upstream. At both sites, the data indicate that the water-supply part of the bedrock aquifer is in hydraulic connection with the alluvial aquifer. However, any ground-water withdrawals from pumping the aquifers in the study area could completely change these vertical gradients.

Ground-water quality throughout the study area varied over time at each site (some sites more than others) and from site to site at the same time. The USGS data indicate that concentrations of most parameters differed widely throughout

the study area. Laboratory quality assurance indicated periods of slight analytical bias (high or low) that could affect the data, but no sustained or substantial bias was apparent in the laboratory data or other field data for the ground-water samples. Sample variability from the laboratory was greatest in the ground-water data for plutonium-239+240, gross alpha activity, nickel, ammonia nitrogen, and selenium, but for most of the priority parameters and some other parameters, variability in the ground-water data was negligible compared to aquifer variation. Plutonium concentrations in the ground water were less than the reporting limit for all samples with the distribution near zero. Concentrations of many constituents at well D6 were relatively high; this ground water had more dissolved ions than other ground water of the study.

Concentrations of all the constituents monitored, including the priority parameters, generally were less than Colorado regulatory limits for ground water. Ground-water pH usually met the Colorado standard. Concentrations of fluoride, nitrite, aluminum, arsenic, barium, chromium, cobalt, copper, lead, mercury, nickel, silver, zinc, and plutonium in the ground water of the study area always met the Colorado standards. However, concentrations of some parameters did not meet the Colorado standards: chloride (wells D6 and D6A), sulfate (all wells except D17), nitrate (wells D6, D6A, and DTX3), antimony, beryllium, and boron (wells D6 and D6A), possibly cadmium (well D6), iron (wells DTX2, DTX8A, DTX10A, DTX11, D6, D15, D23, D25A, D29, and D30), manganese (all wells except DTX3, DTX4, and DTX6), selenium (two samples at well D6), and possibly gross alpha activity (8 alluvial-aquifer wells). Nitrate concentrations at well D6 were the only priority-parameter data where the concentrations significantly ($\alpha = 0.05$) exceeded the regulatory standard.

Few significant ($\alpha = 0.05$) upward trends are seen in the 1999 through 2003 ground-water data for the study area. Concentrations of arsenic, cadmium, chromium, lead, mercury, nickel, and zinc had no significant upward trends. Concentrations of selenium had the most upward trends (wells D6 and DTX4). Ground-water samples from well D25 showed a significant upward trend in copper concentration, and DTX1 had a significant upward trend in molybdenum concentration. Ground-water samples from well D6 had the greatest number of significant upward trends (nitrate and selenium). Biosolids could be contributing to the upward trend in nitrate concentration at well D6, but biosolids applications likely are not the only cause of this upward trend. Trends in ground-water quality did not correlate directly with ground-water levels, but concentrations of some constituents did relate to climate and possibly recharge fluctuations.

Preliminary results from the distilled-deionized water-leach tests on biosolids and soil samples indicate that the inorganic biosolids signature elements for water of the study area primarily are molybdenum and tungsten, and to a lesser extent antimony, cadmium, cobalt, copper, mercury, nickel, phosphorus, and selenium. Biosolids signature elements were present in relatively high concentrations (compared to other ground water from the study area) at wells D6 and D25 (for six of the

biosolids signature elements), wells DTX1 and DTX2 (for four of the biosolids signature elements) and well D17 (for three of the biosolids signature elements). These data indicate that ground water at wells D6, D25, DTX1, and possibly DTX2 and D17 are more likely affected by biosolids applications than ground water at the other monitoring wells of the study area. However, these results are not conclusive because the same elements have multiple sources including natural geochemical sources that could result in such concentrations. In addition, age-dating results for ground-water samples from wells D6, D17, and D25 in 1998 raise questions about whether the ground water at these sites is young enough to be affected by biosolids applications to the study area. Additional age dating of the ground water could further indicate whether biosolids could have affected ground-water concentrations.

Few paired streambed-sediment samples could be collected during 1999 through 2003 because runoff was not common in the designated biosolids-applied basin or control basin. By observation, less sediment usually was deposited from runoff in the biosolids-applied basin than in the control basin. Sample variability was estimated from comparison of data for replicate samples, but this measure of variability is produced mostly from laboratory analysis and does not fully consider natural chemical heterogeneity. True variability likely is greater, so uncertainty in the sediment data needs to be considered when evaluating the data for effects from biosolids. Plutonium concentrations in the streambed sediment were below detection for all samples with the distribution near zero. No appropriate sediment regulatory standards are available for the sediment data. Comparison of the sediment data with the soil standards and screening levels yields similar results as the comparison with the soil data for arsenic and lead concentrations, but all cadmium and mercury data were less than the soil screening levels. Concentrations of ammonia plus organic nitrogen, organic carbon, copper, lead, mercury, and silver were significantly ($\alpha < 0.10$) greater in sediment of the biosolids-applied basin than in sediment of the control basin. Trace-element-concentration differences between the basins usually were small but consistent. Biosolids were applied directly to the sediment-sampling areas of the biosolids-applied basin, so concentrations of constituents in the streambed sediment likely are not representative of (are higher than) sediment that is transported off the MWRD property. Apparent differences in trace-element concentration between the two basins could be caused by natural geochemical differences between the two basins. Concentrations of the priority parameters in all the sediment samples from this monitoring program are consistent with concentrations in uncontaminated soil.

A biosolids chemical signature could help distinguish biosolids effects from the natural geochemical signature of soil and sediment. An inorganic-chemical signature for biosolids was determined by comparing summary data for soil to that for biosolids. The only elements for which biosolids concentrations were substantially greater than natural study-area soil concentrations were bismuth, cadmium, copper,

mercury, molybdenum, phosphorus, selenium, silver, uranium, and zinc; the largest differences were in bismuth, mercury, phosphorus, and silver concentrations. Copper, mercury, and silver are biosolids-signature elements that were significantly ($\alpha < 0.10$) higher in sediment samples from the biosolids-applied basin than in sediment samples from the control basin, although no samples were analyzed for bismuth and only about one-half the sample pairs were analyzed for silver and uranium. The preliminary leach results for biosolids and soil samples indicate that selenium and molybdenum concentrations could be diminished in the sediment deposits by the mass lost to water that either continued downstream or infiltrated the sub-surface. Most of the priority parameters (not plutonium) can be present in soil, crops, ground water, and sediment because of natural rock weathering (geochemistry). Thus, a clear biosolids signature is not evident in the sediment data.

A signature based not on inorganic- or radioactive-constituent concentrations is needed to help differentiate the effects of biosolids from the effects of geochemistry on all the monitoring components. Some other property or chemical presence that is not possibly characteristic of natural soil, rock, crops, ground water, surface water, or sediment of the area is needed to determine if biosolids could possibly have affected concentrations in the study area. Current (2004) USGS research is evaluating pharmaceutical and other anthropogenic organic compounds as indicators of biosolids or other wastewater effects (<http://water.usgs.gov/nrp/proj.bib/barber.html>, accessed on July 13, 2004; <http://toxics.usgs.gov/regional/emc.html>, accessed on July 19, 2004). Some of the compounds in this suite of organic chemicals associated with wastewater may prove sufficiently conservative in the environment to act as a more definitive biosolids signature than inorganic compounds and even indicate the presence or absence of biosolids or wastewater in monitoring components.

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Supplemental Information

Table 10. Preliminary results from laboratory leach test of biosolids from the Metro Wastewater Reclamation District and soil collected from the soil-monitoring plots near Deer Trail, Colorado.

[Leach test described by Hageman and Briggs (2000); zero values result because data were blank corrected by subtracting processing-blank values; RL, reporting limits, which are the data for the processing blank; four biosolids samples from 2000–2001 were leached; six soil samples were leached, all collected during 1999 before biosolids were applied; $\mu\text{g/L}$, micrograms per liter; mg/L , milligrams per liter; <, less than; $\mu\text{S/cm}$, microsiemens per centimeter at 25 degrees Celsius; -, no data; the color orange indicates biosolids-leachate data generally were about two orders of magnitude greater than that for soil leachate; the color yellow indicates biosolids-leachate data generally were about one order of magnitude greater than that for soil leachate; the color green indicates soil-leachate data generally were at least one order of magnitude greater than that for biosolids leachate]

Parameter	Concentration data for biosolids leachate		Concentration data for soil leachate		RL
	Median	\pm 2 standard deviations	Median	\pm 2 standard deviations	
Priority parameters ¹					
Arsenic, $\mu\text{g/L}$	6	\pm 6	0	\pm 1	<1
Cadmium, $\mu\text{g/L}$	0.27	\pm 0.35	0.01	\pm 0.03	<0.02
Chromium, $\mu\text{g/L}$	2.7	\pm 4.8	0	\pm 0.8	<1
Copper, $\mu\text{g/L}$	42.4	\pm 148.1	3.1	\pm 1.3	<0.5
Lead, $\mu\text{g/L}$	0.6	\pm 2.0	0.2	\pm 0.6	0.1
Mercury, $\mu\text{g/L}$	0.06	\pm 0.14	0	\pm 0.00	0.01
Molybdenum, $\mu\text{g/L}$	183	\pm 260	0	\pm 1.36	1.24
Nickel, $\mu\text{g/L}$	72.2	\pm 106.4	2.4	\pm 0.8	0.1
Selenium, $\mu\text{g/L}$	4.3	\pm 7.3	0.4	\pm 0.5	<1
Zinc, $\mu\text{g/L}$	22	\pm 40	1	\pm 2	1
Other parameters					
Specific conductance, $\mu\text{S/cm}$	1,335	\pm 269	273	\pm 302	--
pH, standard units	7.8	\pm 0.6	8.7	\pm 0.6	--
Aluminum, $\mu\text{g/L}$	34.71	\pm 29.11	86.16	\pm 300.99	2.69
Antimony, $\mu\text{g/L}$	2.21	\pm 2.84	0	\pm 0.1	<0.1
Barium, $\mu\text{g/L}$	1.96	\pm 2.10	56.45	\pm 76.14	0.1
Beryllium, $\mu\text{g/L}$	0	\pm 0	0	\pm 0	<0.05
Bismuth, $\mu\text{g/L}$	0.01	\pm 0.18	0	\pm 0	<0.005
Calcium, mg/L	4.02	\pm 4.71	31.62	\pm 45.68	0.08
Cerium, $\mu\text{g/L}$	0.03	\pm 0.11	0.43	\pm 0.88	<0.01
Cesium, $\mu\text{g/L}$	0.08	\pm 0.13	0.005	\pm 0.01	<0.01
Cobalt, $\mu\text{g/L}$	9.39	\pm 15.51	0.24	\pm 0.05	<0.02
Dysprosium, $\mu\text{g/L}$	0	\pm 0	0.05	\pm 0.09	<0.005
Erbium, $\mu\text{g/L}$	0	\pm 0	0.02	\pm 0.05	<0.005
Europium, $\mu\text{g/L}$	0	\pm 0	0.01	\pm 0.02	<0.005
Gadolinium, $\mu\text{g/L}$	0.002	\pm 0.005	0.06	\pm 0.11	<0.005
Gallium, $\mu\text{g/L}$	0.54	\pm 0.89	0.07	\pm 0.16	<0.02
Germanium, $\mu\text{g/L}$	0.06	\pm 0.14	0	\pm 0	<0.02
Holmium, $\mu\text{g/L}$	0	\pm 0	0.01	\pm 0.02	<0.005
Iron, $\mu\text{g/L}$	157	\pm 376	50	\pm 137	<50
Lanthanum, $\mu\text{g/L}$	0.02	\pm 0.06	0.30	\pm 0.63	<0.01
Lithium, $\mu\text{g/L}$	2.9	\pm 3.9	3.9	\pm 3.5	<0.1
Lutetium, $\mu\text{g/L}$	0	\pm 0	0	\pm 0	<0.1
Magnesium, mg/L	1.80	\pm 2.74	3.82	\pm 4.94	<0.01
Manganese, $\mu\text{g/L}$	7.0	\pm 11.3	4.1	\pm 1.3	0.2
Neodymium, $\mu\text{g/L}$	0.005	\pm 0.03	0.31	\pm 0.62	<0.01
Niobium, $\mu\text{g/L}$	0.01	\pm 0.07	0.02	\pm 0.07	<0.02
Phosphorus, mg/L	17.94	\pm 34.08	0.09	\pm 0.11	0.01
Potassium, mg/L	19.37	\pm 11.35	5.87	\pm 2.98	<0.03
Praseodymium, $\mu\text{g/L}$	0	\pm 0	0.07	\pm 0.16	<0.01
Rubidium, $\mu\text{g/L}$	10.80	\pm 7.48	3.07	\pm 1.84	0.01
Samarium, $\mu\text{g/L}$	0	\pm 0	0.06	\pm 0.13	<0.01
Scandium, $\mu\text{g/L}$	0.2	\pm 0.2	0.4	\pm 0.1	<0.1
Silica, mg/L	1.6	\pm 2.0	2.3	\pm 1.4	<0.2

Table 10. Preliminary results from laboratory leach test of biosolids from the Metro Wastewater Reclamation District and soil collected from the soil-monitoring plots near Deer Trail, Colorado.
—Continued

[Leach test described by Hageman and Briggs (2000); zero values result because data were blank corrected by subtracting processing-blank values; RL, reporting limits, which are the data for the processing blank; four biosolids samples from 2000–2001 were leached; six soil samples were leached, all collected during 1999 before biosolids were applied; $\mu\text{g/L}$, micrograms per liter; mg/L , milligrams per liter; <, less than; $\mu\text{S/cm}$, microsiemens per centimeter at 25 degrees Celsius; -, no data; the color orange indicates biosolids-leachate data generally were about two orders of magnitude greater than that for soil leachate; the color yellow indicates biosolids-leachate data generally were about one order of magnitude greater than that for soil leachate; the color green indicates soil-leachate data generally were at least one order of magnitude greater than that for biosolids leachate]

Parameter	Concentration data for biosolids leachate		Concentration data for soil leachate		RL
	Median	\pm 2 standard deviations	Median	\pm 2 standard deviations	
Other parameters—Continued					
Silver, $\mu\text{g/L}$	0	\pm 1	0	\pm 0	<3
Sodium, mg/L	8.14	\pm 6.97	1.14	\pm 3.61	0.1
Strontium, $\mu\text{g/L}$	10.5	\pm 10.0	215.0	\pm 298.2	<0.5
Sulfate, mg/L	127	\pm 94	90	\pm 148	<2
Tantalum, $\mu\text{g/L}$	0	\pm 0	0	\pm 0	<0.02
Terbium, $\mu\text{g/L}$	0	\pm 0	0.008	\pm 0.016	<0.005
Thallium, $\mu\text{g/L}$	0	\pm 0	0	\pm 0	<0.05
Thorium, $\mu\text{g/L}$	0.008	\pm 0.017	0.115	\pm 0.249	<0.005
Thulium, $\mu\text{g/L}$	0	\pm 0	0	\pm 0	<0.005
Titanium, $\mu\text{g/L}$	1.6	\pm 1.9	6.2	\pm 12.5	0.4
Tungsten, $\mu\text{g/L}$	8.22	\pm 9.23	0.03	\pm 0.04	0.06
Uranium, $\mu\text{g/L}$	0.42	\pm 1.06	0.31	\pm 0.15	<0.005
Vanadium, $\mu\text{g/L}$	30.9	\pm 65.1	2.3	\pm 8.2	<0.1
Ytterbium, $\mu\text{g/L}$	0	\pm 0	0.01	\pm 0.04	<0.005
Yttrium, $\mu\text{g/L}$	0	\pm 0.01	0.32	\pm 0.47	<0.01
Zirconium, $\mu\text{g/L}$	0.01	\pm 0.32	0.27	\pm 0.82	0.08

¹For ground water, although samples were not analyzed for nitrate or radioactivity parameters.

Table 11. Information for U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1999–2003.

[Latitude and longitude are in the format degrees minutes seconds referenced to NAD 83; bmp, below measuring point (stickup); wells shown in bold routinely are sampled for water quality; Elev., elevation in feet above NAVD 88; Metro, Metro Wastewater Reclamation District; A, alluvial aquifer; B, bedrock aquifer; HUC, Hydrologic Unit Code (Seaber and others, 1987); NWS, USGS National Water Information System database; ID, identification number]

Well identifier (fig. 1)	Latitude	Longitude	Elev. of stickup (feet)	Elev. of land surface (feet)	Property owner	County	Drill date	Current stickup (feet)	Total depth (feet bmp)	Screen top (feet bmp)	Screen bottom (feet bmp)	Screen size (feet)	Screen length (feet)	Sump length (feet)	Well diameter (inches)	Aquifer at screen	HUC	NWS station ID
DTX1	39 43 33	103 52 51	4,909	4,906	Metro	Arapahoe	02/16/99	2.56	25.50	20.59	22.19	0.010	1.60	3.31	2	A	10190012	394333103525100
DTX2	39 41 49	103 51 38	4,903	4,900	Metro	Arapahoe	02/16/99	3.23	20.50	15.59	17.19	0.010	1.60	3.31	2	A	10190012	394148103513300
DTX3	39 30 24	103 43 28	5,195	5,192	Metro	Elbert	02/12/99	3.11	18.71	13.80	15.40	0.010	1.60	3.31	2	A	10190013	393024103432800
DTX4	39 33 58	103 43 42	4,957	4,954	Metro	Elbert	02/10/99	2.70	16.72	11.81	13.41	0.010	1.60	3.31	2	A	10190013	3933358103434200
DTX5	39 33 58	103 45 48	4,975	4,973	Metro	Elbert	02/10/99	2.30	20.90	16.09	17.69	0.010	1.60	3.21	2	A	10190013	3933358103454800
DTX6	39 33 58	103 46 48	4,970	4,968	Metro	Elbert	02/09/99	2.36	39	34	36	0.010	1.60	3.31	2	A	10190013	3933358103464800
DTX7	39 40 54	103 56 46	5,076	5,073	Price	Arapahoe	02/18/99	2.77	16.10	11.19	12.79	0.010	1.60	3.31	2	A	10190011	394054103564600
DTX8A	39 40 54	103 56 45	5,076	5,074	Price	Arapahoe	03/02/99	2.46	77.52	67.56	71.83	0.010	4.27	5.69	2	B	10190011	394054103564501
DTX8B	39 40 54	103 56 45	5,076	5,074	Price	Arapahoe	03/02/99	2.49	177.48	167.52	171.79	0.010	4.27	5.69	2	B	10190011	394054103564502
DTX9	39 39 02	103 55 40	5,121	5,119	Weissensee	Arapahoe	02/17/99	2.46	30.15	22.72	24.32	0.010	1.60	5.83	2	A	10190011	393902103554000
DTX10A	39 39 02	103 55 40	5,122	5,120	Weissensee	Arapahoe	03/04/99	2.03	61.97	52.01	56.28	0.010	4.27	5.69	2	B	10190011	393902103554001
DTX10B	39 39 02	103 55 40	5,122	5,120	Weissensee	Arapahoe	03/04/99	2.11	121.73	111.77	116.04	0.010	4.27	5.69	2	B	10190011	393902103554002
DTX11	39 39 02	103 55 40	5,122	5,120	Weissensee	Arapahoe	01/19/00	2.24	32	28	30	0.020	2	2.35	2	A	10190011	393902103554003
D6	39 36 33	103 51 22	5,128.78	5,126	Metro	Arapahoe	09/12/93	2.65	25	15	25	0.010	10	0.3	2	A	10190013	393633103512300
D6A	39 36 33	103 51 22	5,129	5,126	Metro	Arapahoe	02/06/02	2.42	32.96	28.42	30.71	0.010	2.29	2.25	2	A	10190013	393633103512301
D11a	39 33 45	103 54 23	5,377	5,374	Metro	Elbert	10/23/97	2.46	143	113	123	0.010	10	20.38	2	B	10190011	393334103543600
D13	39 34 42	103 54 38	5,235.33	5,234	Metro	Arapahoe	04/04/94	1.81	16	6	16	0.010	10	0.3	2	A	10190011	393439103543400
D15	39 33 59	103 54 54.2	5,246.77	5,245	Keen	Elbert	04/07/94	1.86	25	15	25	0.010	10	0.3	2	A	10190011	3933357103545200
D17	39 33 34	103 54 36	5,277.73	5,276	Metro	Elbert	04/05/94	1.90	21	11	21	0.010	10	0.3	2	A	10190011	393327103541200
D19	39 33 17	103 54 18.1	5,304.24	5,303	Metro	Elbert	04/05/94	1.69	30	20	30	0.010	10	0.3	2	B	10190011	3933311103541800
D23	39 33 42	103 55 01.1	5,256.05	5,254	Keen	Elbert	04/08/94	2.54	15	10	15	0.010	5	0.3	2	A	10190011	393330103545300
D25	39 37 02	103 54 42	5,167.13	5,165	Metro	Arapahoe	05/01/95	2.23	23	13	23	0.010	10	0.3	2	A	10190011	393702103544100
D25A	39 37 02	103 54 42	5,167	5,165	Metro	Arapahoe	02/05/02	2.57	24.67	20.13	22.42	0.010	2.29	2.25	2	A	10190011	393702103544102
D29	39 36 41	103 52 48	5,371	5,369	Metro	Arapahoe	11/04/97	2.38	183	148	158	0.010	10	25.38	2	B	10190013	393632103524300
D30	39 36 55	103 51 22	5,096.43	5,094	Metro	Arapahoe	05/05/95	1.98	19	9	19	0.010	10	0.3	2	A	10190013	393655103512200

¹Wells having continuous-recorder equipment.

²DTX6 stickup went from 2.43 to 2.36 ft between mid-October 2002 and early November 2002.

70 Effects of Surface Applications of Biosolids near Deer Trail, Colorado, 1999–2003

Table 12. Relative standard deviation for replicate ground-water samples collected near Deer Trail, Colorado, 1999–2003.

[Relative standard deviation is defined as ((square root ((sample value – replicate value)²)/((sample value + replicate value)/2)) × 100; for this analysis, all values that were less than the reporting limit were set equal to the reporting limit and estimated values were included; calculations done on unrounded data; --, no data; μS/cm, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; μg/L, micrograms per liter; pCi/L, picocuries per liter]

Parameter	DTX6 03/18/99	D6 03/19/99	D30 04/12/99	DTX5 04/13/99	DTX1 07/07/99	DTX3 07/09/99	DTX1 11/08/99	D6 11/12/99	D29 01/07/00	DTX3 01/10/00
Specific conductance, laboratory (μS/cm)	0.17	0.00	0.28	0.45	0.00	1.17	0.17	5.99	0.18	0.00
pH, whole water, laboratory (standard units)	0.00	0.00	0.00	0.00	0.00	0.94	0.00	0.00	0.78	0.26
Calcium, dissolved (mg/L as Ca)	0.00	4.66	1.59	1.03	1.46	0.00	1.49	0.00	1.20	5.10
Magnesium, dissolved (mg/L as Mg)	2.77	3.14	0.00	1.47	3.29	1.49	0.00	0.00	3.96	6.71
Sodium, dissolved (mg/L as Na)	0.00	0.00	1.84	0.78	1.94	0.00	2.05	0.00	1.41	5.33
Potassium, dissolved (mg/L as K)	5.66	15.71	3.45	1.37	6.15	1.32	2.05	5.66	2.81	2.08
Acid neutralizing capacity, titration to 4.5, laboratory (mg/L as CaCO ₃)	0.00	0.11	0.73	0.00	0.23	0.00	0.23	0.11	0.29	0.09
Sulfate, dissolved (mg/L as SO ₄)	0.00	0.00	2.24	0.00	0.00	0.00	0.00	0.00	0.52	0.12
Chloride, dissolved (mg/L as Cl)	3.45	0.00	5.66	0.00	1.37	6.73	1.43	1.70	0.49	0.54
Fluoride, dissolved (mg/L as F)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	8.87	7.53
Bromide, dissolved (mg/L as Br)	0.00	3.45	1.08	0.00	1.08	7.44	0.94	0.00	3.82	0.00
Silica, dissolved (mg/L as SiO ₂)	0.00	9.43	3.29	0.00	2.11	0.00	2.11	0.00	0.89	1.36
Solids, residue on evaporation at 180 degrees Celsius, dissolved (mg/L)	0.34	0.35	0.27	0.44	0.51	0.33	0.86	0.68	0.20	0.00
Nitrite plus nitrate (mg/L as N)	3.01	0.00	0.00	0.00	--	0.00	3.82	0.00	3.29	0.00
Nitrogen ammonia, dissolved (mg/L as N)	20	0.00	9.43	9.43	--	0.00	0.00	28	0.00	49
Nitrogen ammonia plus organic, total (mg/L as N)	0.00	0.00	0.00	0.00	0.00	0.00	47.14	5.24	1.68	6.96
Nitrogen ammonia plus organic, dissolved (mg/L as N)	0.00	0.00	0.00	16	--	9.43	3.63	40	4.56	22
Phosphorus, total (mg/L as P)	0.00	20	16	0.00	0.00	0.00	11	16	1.79	0.00
Phosphorus, dissolved (mg/L as P)	0.00	20	31	0.00	--	0.00	16	0.00	7.44	0.00
Aluminum, dissolved (μg/L as Al)	28	0.00	47	57	20	0.00	0.00	35.36	12.86	47
Antimony, dissolved (μg/L as Sb)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	35.36	0.00	0.00
Arsenic, dissolved (μg/L as As)	0.00	0.00	0.00	0.00	28	0.00	0.00	47	0.00	0.00
Barium, dissolved (μg/L as Ba)	0.00	0.00	6.73	3.82	0.00	0.00	0.00	35	0.00	0.00
Beryllium, dissolved (μg/L as Be)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	35	0.00	0.00
Boron, dissolved (μg/L as B)	1.71	2.39	5.30	0.00	5.12	0.73	2.25	14	1.92	1.33
Cadmium, dissolved (μg/L as Cd)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	35	0.00	0.00
Chromium, dissolved (μg/L as Cr)	5.66	79	0.00	0.00	0.00	0.00	16	0.00	0.00	20
Cobalt, dissolved (μg/L as Co)	11	0.00	28	0.00	0.00	0.00	0.00	35	0.00	0.00
Copper, dissolved (μg/L as Cu)	9.43	2.40	0.00	8.32	9.43	0.00	0.00	5.05	11	28
Iron, dissolved (μg/L as Fe)	0.00	0.00	35	0.00	28	0.00	0.00	0.00	0.99	0.00
Lead, dissolved (μg/L as Pb)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	35	0.00	0.00
Manganese, dissolved (μg/L as Mn)	6.15	0.20	2.22	2.96	2.77	0.00	1.63	1.68	0.09	0.00
Mercury, dissolved (μg/L as Hg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molybdenum, dissolved (μg/L as Mo)	0.00	0.00	28	0.00	0.00	0.00	0.00	35	0.00	0.00
Nickel, dissolved (μg/L as Ni)	31	3.14	5.24	10	104	0.00	4.56	7.07	0.00	0.00
Selenium, dissolved (μg/L as Se)	0.00	9.43	0.00	0.00	16	0.00	0.00	13	13	0.00
Silver, dissolved (μg/L as Ag)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	35	0.00	0.00
Strontium, dissolved (μg/L as Sr)	2.53	0.00	1.15	1.21	1.23	9.43	1.25	0.00	0.85	2.08
Zinc, dissolved (μg/L as Zn)	47	12	13	13	13	0.00	13	9.12	0.00	0.00
Uranium, natural (μg/L as U)	0.00	0.90	1.79	1.66	1.37	0.00	0.00	0.91	0.00	0.00
Gross alpha, dissolved (pCi/L)	--	--	--	--	7.31	20	--	--	--	--
Gross beta, dissolved (pCi/L)	--	--	--	--	7.29	0.00	--	--	--	--
Plutonium-238, whole water (pCi/L as Pu)	--	--	--	--	-141	-141	--	--	-141	141
Plutonium-239+240, whole water (pCi/L as Pu)	--	--	--	--	20	283	--	--	141	141

Table 12. Relative standard deviation for replicate ground-water samples collected near Deer Trail, Colorado, 1999–2003.—Continued

[Relative standard deviation is defined as $((\text{square root } ((\text{sample value} - \text{replicate value})^2/2)))/((\text{sample value} + \text{replicate value})/2)) \times 100$; for this analysis, all values that were less than the reporting limit were set equal to the reporting limit and estimated values were included; calculations done on unrounded data; --, no data; $\mu\text{S/cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; $\mu\text{g/L}$, micrograms per liter; pCi/L , picocuries per liter]

Parameter	DTX3	D6	D25	D6	D25	D6	D25	D6	D6	D25
	04/11/00	04/13/00	07/06/00	07/11/00	10/10/00	10/12/00	01/03/01	01/08/01	04/04/01	04/10/01
Specific conductance, laboratory ($\mu\text{S/cm}$)	0.00	0.00	0.31	0.00	0.14	0.44	0.43	0.43	0.42	0.29
pH, whole water, laboratory (standard units)	0.01	0.27	0.00	0.00	0.00	0.28	0.00	0.99	1.99	0.00
Calcium, dissolved (mg/L as Ca)	2.30	2.39	1.57	0.49	0.27	0.30	0.10	4.35	0.81	0.31
Magnesium, dissolved (mg/L as Mg)	2.40	2.80	2.80	0.33	0.32	0.32	0.28	1.00	0.33	1.50
Sodium, dissolved (mg/L as Na)	0.44	3.45	3.81	0.00	0.00	0.34	1.23	1.40	0.71	2.92
Potassium, dissolved (mg/L as K)	3.07	1.94	14	3.45	0.86	2.63	3.04	5.15	4.49	10
Acid neutralizing capacity, titration to 4.5, laboratory (mg/L as CaCO_3)	0.00	0.11	1.44	0.08	15	0.00	2.00	0.00	0.11	1.01
Sulfate, dissolved (mg/L as SO_4)	0.73	1.09	0.28	0.54	0.25	1.08	0.25	0.54	0.00	0.52
Chloride, dissolved (mg/L as Cl)	2.49	0.74	0.14	0.18	2.11	0.17	1.34	2.11	1.45	1.45
Fluoride, dissolved (mg/L as F)	0.00	4.85	2.37	6.28	6.73	0.00	6.73	0.00	0.00	7.44
Bromide, dissolved (mg/L as Br)	0.00	1.94	13	0.18	0.51	0.17	1.46	0.17	0.48	0.00
Silica, dissolved (mg/L as SiO_2)	2.70	0.33	2.01	1.02	0.49	0.72	6.23	0.97	0.67	1.60
Solids, residue on evaporation at 180 degrees Celsius, dissolved (mg/L)	0.92	1.72	0.76	0.33	1.35	2.00	0.27	1.00	0.34	0.58
Nitrite plus nitrate (mg/L as N)	0.06	3.88	0.23	5.20	1.28	0.00	0.87	0.46	2.62	2.53
Nitrogen ammonia, dissolved (mg/L as N)	0.00	19	4.94	0.00	0.00	2.13	6.15	2.48	14	11
Nitrogen ammonia plus organic, total (mg/L as N)	4.73	11	1.81	0.00	13	0.00	2.37	0.00	6.02	10.04
Nitrogen ammonia plus organic, dissolved (mg/L as N)	0.00	0.00	3.93	0.00	108	8.16	0.80	0.00	11	5.98
Phosphorus, total (mg/L as P)	0.00	12	1.92	5.11	3.75	0.00	3.56	47	0.00	8.81
Phosphorus, dissolved (mg/L as P)	0.00	25	0.46	33	0.63	0.00	11	2.11	27	9.17
Aluminum, dissolved ($\mu\text{g/L}$ as Al)	101	5.66	0.00	0.00	0.00	0.00	0.00	0.00	47	0.00
Antimony, dissolved ($\mu\text{g/L}$ as Sb)	0.00	0.00	0.00	0.00	0.00	0.00	4.56	13	8.84	0.00
Arsenic, dissolved ($\mu\text{g/L}$ as As)	0.00	18	18	28	0.00	2.24	0.00	0.00	0.00	7.07
Barium, dissolved ($\mu\text{g/L}$ as Ba)	0.00	0.00	0.00	0.00	0.00	0.00	0.36	1.25	3.97	0.78
Beryllium, dissolved ($\mu\text{g/L}$ as Be)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Boron, dissolved ($\mu\text{g/L}$ as B)	0.32	0.00	4.99	1.57	4.00	0.00	2.06	5.68	5.31	11
Cadmium, dissolved ($\mu\text{g/L}$ as Cd)	0.00	0.00	0.00	0.00	0.00	0.00	2.89	13	13	0.00
Chromium, dissolved ($\mu\text{g/L}$ as Cr)	16	16	20	0.00	3.14	0.00	0.00	63	0.00	0.00
Cobalt, dissolved ($\mu\text{g/L}$ as Co)	0.00	0.00	0.00	0.00	0.00	11	2.46	2.59	1.34	2.59
Copper, dissolved ($\mu\text{g/L}$ as Cu)	0.00	2.28	7.44	16	0.00	4.16	1.26	2.57	0.73	0.63
Iron, dissolved ($\mu\text{g/L}$ as Fe)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lead, dissolved ($\mu\text{g/L}$ as Pb)	0.00	0.00	0.00	0.00	0.00	131	11	5.89	7.29	9.43
Manganese, dissolved ($\mu\text{g/L}$ as Mn)	0.00	1.71	9.40	9.91	1.48	0.57	0.65	2.92	2.23	13
Mercury, dissolved ($\mu\text{g/L}$ as Hg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molybdenum, dissolved ($\mu\text{g/L}$ as Mo)	0.00	0.00	0.00	0.00	5.24	20	2.75	0.00	3.72	0.71
Nickel, dissolved ($\mu\text{g/L}$ as Ni)	0.00	0.00	57	3.45	11	22	7.94	11	5.87	135
Selenium, dissolved ($\mu\text{g/L}$ as Se)	3.60	77	13	5.86	0.00	4.88	21	11	2.35	11
Silver, dissolved ($\mu\text{g/L}$ as Ag)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium, dissolved ($\mu\text{g/L}$ as Sr)	0.76	2.47	3.00	0.43	0.00	0.00	0.00	0.00	0.00	1.04
Zinc, dissolved ($\mu\text{g/L}$ as Zn)	71	3.29	13	11	0.00	6.15	0.00	2.05	1.66	0.00
Uranium, natural ($\mu\text{g/L}$ as U)	0.00	0.00	0.00	2.38	2.40	0.83	1.32	1.12	0.40	4.63
Gross alpha, dissolved (pCi/L)	--	--	--	--	--	--	--	--	--	--
Gross beta, dissolved (pCi/L)	--	--	--	--	--	--	--	--	--	--
Plutonium-238, whole water (pCi/L as Pu)	--	--	--	--	141	0.00	--	--	--	--
Plutonium-239+240, whole water (pCi/L as Pu)	--	--	--	--	707	-424	--	--	--	--

Table 12. Relative standard deviation for replicate ground-water samples collected near Deer Trail, Colorado, 1999–2003.—Continued

[Relative standard deviation is defined as $((\text{square root } ((\text{sample value} - \text{replicate value})^2/2)))/((\text{sample value} + \text{replicate value})/2)) \times 100$; for this analysis, all values that were less than the reporting limit were set equal to the reporting limit and estimated values were included; calculations done on unrounded data; --, no data; $\mu\text{S/cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; $\mu\text{g/L}$, micrograms per liter; pCi/L , picocuries per liter]

Parameter	D25 07/09/01	D6 07/10/01	D6 10/10/01	D25 10/15/01	D6 01/14/02	D25 01/07/02	DTX3 04/09/02	D6R 04/04/02	D6 07/09/02	DTX2 07/10/02
Specific conductance, laboratory ($\mu\text{S/cm}$)	1.21	1.29	0.00	0.31	0.00	0.00	0.00	0.45	0.45	0.00
pH, whole water, laboratory (standard units)	0.00	0.00	0.00	0.00	0.05	0.29	0.10	0.09	0.99	0.00
Calcium, dissolved (mg/L as Ca)	0.78	0.83	1.34	6.26	1.42	0.17	1.20	3.37	0.83	0.43
Magnesium, dissolved (mg/L as Mg)	0.28	0.30	2.61	2.12	1.16	1.41	2.93	1.30	0.31	1.09
Sodium, dissolved (mg/L as Na)	0.45	0.34	2.19	1.56	0.49	0.22	2.80	4.37	1.05	0.68
Potassium, dissolved (mg/L as K)	1.44	2.53	2.28	18	1.50	3.28	6.71	0.28	5.33	3.46
Acid neutralizing capacity, titration to 4.5, laboratory (mg/L as CaCO_3)	1.07	0.22	0.11	0.81	0.27	0.27	0.02	0.35	0.00	0.00
Sulfate, dissolved (mg/L as SO_4)	0.54	0.00	0.00	1.04	0.62	0.02	0.41	0.20	0.00	0.03
Chloride, dissolved (mg/L as Cl)	1.22	1.79	1.86	0.96	0.20	0.94	4.14	1.02	1.05	0.16
Fluoride, dissolved (mg/L as F)	0.00	9.43	8.32	0.00	1.75	1.47	3.68	0.16	0.00	0.00
Bromide, dissolved (mg/L as Br)	4.82	1.98	0.91	0.83	1.49	0.39	1.61	1.05	0.67	1.17
Silica, dissolved (mg/L as SiO_2)	0.76	1.99	5.43	4.29	0.36	0.58	2.01	3.99	0.65	0.85
Solids, residue on evaporation at 180 degrees Celsius, dissolved (mg/L)	4.08	3.58	0.00	0.44	0.66	0.60	0.80	1.77	0.33	0.03
Nitrite plus nitrate (mg/L as N)	1.72	0.88	0.44	2.24	0.60	1.18	0.57	1.42	2.07	0.00
Nitrogen ammonia, dissolved (mg/L as N)	12.12	10.10	2.77	26	10	9.12	0.00	42	0.00	1.56
Nitrogen ammonia plus organic, total (mg/L as N)	2.21	2.57	4.56	3.10	15	0.97	9.38	4.10	0.00	0.72
Nitrogen ammonia plus organic, dissolved (mg/L as N)	5.55	4.04	34	1.02	10.51	4.14	2.50	10.13	0.00	0.73
Phosphorus, total (mg/L as P)	1.47	0.00	39	3.10	0.00	8.38	0.00	33.53	0.00	0.00
Phosphorus, dissolved (mg/L as P)	0.00	0.00	0.00	1.10	0.00	2.50	0.00	0.00	20	0.00
Aluminum, dissolved ($\mu\text{g/L}$ as Al)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.05	0.00	0.00
Antimony, dissolved ($\mu\text{g/L}$ as Sb)	3.82	0.00	0.00	0.00	0.00	3.45	57	9.50	13.86	0.00
Arsenic, dissolved ($\mu\text{g/L}$ as As)	5.05	13.34	19	2.67	13	5.73	0.00	14	16	47
Barium, dissolved ($\mu\text{g/L}$ as Ba)	0.00	0.00	0.00	0.00	0.00	0.26	3.95	3.86	0.00	2.27
Beryllium, dissolved ($\mu\text{g/L}$ as Be)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Boron, dissolved ($\mu\text{g/L}$ as B)	5.01	0.00	6.35	5.44	2.12	6.48	9.70	10	1.68	0.22
Cadmium, dissolved ($\mu\text{g/L}$ as Cd)	43.51	3.14	12	3.14	0.00	0.00	20	6.73	18	0.00
Chromium, dissolved ($\mu\text{g/L}$ as Cr)	4.56	11.79	0.00	2.67	0.12	0.00	0.00	0.00	47	0.00
Cobalt, dissolved ($\mu\text{g/L}$ as Co)	1.84	0.90	2.20	8.26	8.06	1.45	7.01	5.36	1.24	0.40
Copper, dissolved ($\mu\text{g/L}$ as Cu)	18.45	2.14	5.92	12	3.39	3.15	5.57	0.77	6.35	1.57
Iron, dissolved ($\mu\text{g/L}$ as Fe)	0.00	0.00	0.00	0.00	0.00	71	0.00	0.00	0.00	0.56
Lead, dissolved ($\mu\text{g/L}$ as Pb)	0.00	5.48	30	0.00	49	0.00	0.00	0.00	0.00	0.00
Manganese, dissolved ($\mu\text{g/L}$ as Mn)	2.32	1.54	1.17	4.74	6.12	2.08	35.49	3.04	0.71	0.26
Mercury, dissolved ($\mu\text{g/L}$ as Hg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molybdenum, dissolved ($\mu\text{g/L}$ as Mo)	2.20	4.42	0.00	0.68	5.86	2.04	0.13	4.01	4.42	4.29
Nickel, dissolved ($\mu\text{g/L}$ as Ni)	137.44	15.95	35	7	0.10	107	92	2.33	3.96	0.44
Selenium, dissolved ($\mu\text{g/L}$ as Se)	3.82	3.36	20	2.67	4.76	0.00	8.22	4.89	7.86	0.00
Silver, dissolved ($\mu\text{g/L}$ as Ag)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium, dissolved ($\mu\text{g/L}$ as Sr)	0.00	0.42	2.20	1.35	0.99	0.55	1.02	4.21	1.34	0.66
Zinc, dissolved ($\mu\text{g/L}$ as Zn)	31.43	1.63	3.37	5.24	0.78	6.55	10	1.76	3.21	0.00
Uranium, natural ($\mu\text{g/L}$ as U)	4.43	0.00	1.25	0.86	3.43	2.33	0.90	1.58	0.84	0.21
Gross alpha, dissolved (pCi/L)	--	--	--	--	--	--	--	--	--	--
Gross beta, dissolved (pCi/L)	--	--	--	--	--	--	--	--	--	--
Plutonium-238, whole water (pCi/L as Pu)	--	--	--	--	73.91	50.75	--	--	--	--
Plutonium-239+240, whole water (pCi/L as Pu)	--	--	--	--	141.42	-141.42	--	--	--	--

Table 12. Relative standard deviation for replicate ground-water samples collected near Deer Trail, Colorado, 1999–2003.—Continued

[Relative standard deviation is defined as $((\text{square root}((\text{sample value} - \text{replicate value})^2/2))/(\text{sample value} + \text{replicate value}/2)) \times 100$; for this analysis, all values that were less than the reporting limit were set equal to the reporting limit and estimated values were included; calculations done on unrounded data; --, no data; $\mu\text{S/cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; $\mu\text{g/L}$, micrograms per liter; pCi/L, picocuries per liter]

Parameter	D6 10/17/02	DTX3 10/21/02	D6 01/03/03	DTX6 01/07/03	D6 04/04/03	DTX6 04/03/03	D6 07/10/03	DTX4 07/08/03	DTX8A 10/06/03	Median relative standard deviation	Number of replicate pairs
Specific conductance, laboratory ($\mu\text{S/cm}$)	0.00	0.34	0.00	0.00	1.79	0.48	0.60	0.34	0.00	0.28	39
pH, whole water, laboratory (standard units)	0.00	0.96	0.88	0.99	0.00	0.00	0.00	1.00	0.00	0.00	39
Calcium, dissolved (mg/L as Ca)	0.64	1.04	0.00	0.00	1.70	0.00	1.42	3.34	0.47	1.03	39
Magnesium, dissolved (mg/L as Mg)	0.94	0.70	0.00	0.00	3.14	0.00	7.48	3.64	1.31	1.30	39
Sodium, dissolved (mg/L as Na)	0.99	1.16	3.45	0.00	0.00	0.00	0.65	3.38	0.59	0.78	39
Potassium, dissolved (mg/L as K)	0.63	0.39	0.00	0.00	1.44	1.00	10.10	3.45	2.18	2.81	39
Acid neutralizing capacity, titration to 4.5, laboratory (mg/L as CaCO_3)	0.22	10.71	0.11	0.27	0.22	0.28	0.00	0.00	0.33	0.22	39
Sulfate, dissolved (mg/L as SO_4)	0.52	0.14	0.55	0.00	3.07	0.00	2.67	0.00	0.47	0.25	39
Chloride, dissolved (mg/L as Cl)	0.18	0.69	0.58	0.00	0.39	4.26	0.17	2.02	1.01	1.02	39
Fluoride, dissolved (mg/L as F)	7.44	0.00	0.00	2.49	0.59	0.00	1.27	2.57	2.11	0.16	39
Bromide, dissolved (mg/L as Br)	0.98	0.00	0.17	0.00	0.00	1.91	3.15	1.42	0.45	0.91	39
Silica, dissolved (mg/L as SiO_2)	0.95	0.78	3.29	0.00	0.00	0.00	0.00	0.68	1.01	0.89	39
Solids, residue on evaporation at 180 degrees Celsius, dissolved (mg/L)	0.00	0.00	0.68	0.16	3.63	0.00	0.33	1.14	0.00	0.44	39
Nitrite plus nitrate (mg/L as N)	1.22	0.29	0.38	2.93	0.37	1.24	0.00	3.38	0.00	0.74	38
Nitrogen ammonia, dissolved (mg/L as N)	0.00	40	9.43	20	20	0.00	4.39	0.00	1.46	5.55	38
Nitrogen ammonia plus organic, total (mg/L as N)	4.88	6.43	66	25	0.00	0.00	43.04	0.00	4.88	2.57	39
Nitrogen ammonia plus organic, dissolved (mg/L as N)	19	0.00	0.00	9.53	4.29	35	9.66	5.24	0.00	4.21	38
Phosphorus, total (mg/L as P)	20.20	0.00	32.64	0.00	12.86	18.00	0.00	0.00	0.00	1.79	39
Phosphorus, dissolved (mg/L as P)	0.00	0.00	15.71	0.00	0.00	0.00	2.18	0.00	0.00	0.00	38
Aluminum, dissolved ($\mu\text{g/L}$ as Al)	0.00	0.00	0.00	0.00	0.00	0.00	1.27	0.00	4.56	0.00	39
Antimony, dissolved ($\mu\text{g/L}$ as Sb)	0.00	0.00	21.76	0.00	0.00	0.00	3.45	0.00	0.00	0.00	39
Arsenic, dissolved ($\mu\text{g/L}$ as As)	28.28	0.00	7.95	0.00	0.00	0.00	0.00	0.00	28	0.00	39
Barium, dissolved ($\mu\text{g/L}$ as Ba)	0.00	0.00	3.03	0.00	4.17	0.36	8.79	0.00	0.55	0.00	39
Beryllium, dissolved ($\mu\text{g/L}$ as Be)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	39
Boron, dissolved ($\mu\text{g/L}$ as B)	1.54	2.67	3.99	2.58	4.03	3.56	11.31	1.64	0.28	2.58	39
Cadmium, dissolved ($\mu\text{g/L}$ as Cd)	47	0.00	0.00	0.00	0.00	0.00	6.15	8.57	0.00	0.00	39
Chromium, dissolved ($\mu\text{g/L}$ as Cr)	0.00	0.00	0.00	0.00	0.00	0.00	16	0.00	0.00	0.00	39
Cobalt, dissolved ($\mu\text{g/L}$ as Co)	5.90	4.20	0.74	12.02	0.41	0.00	1.15	0.93	0.23	1.15	39
Copper, dissolved ($\mu\text{g/L}$ as Cu)	12	5.34	3.03	9.00	1.45	1.87	5.37	3.06	3.63	3.39	39
Iron, dissolved ($\mu\text{g/L}$ as Fe)	0.00	0.00	0.00	0.00	0.00	71	61	0.00	1.40	0.00	39
Lead, dissolved ($\mu\text{g/L}$ as Pb)	0.00	0.00	0.00	16	0.00	0.00	0.00	0.00	0.00	0.00	39
Manganese, dissolved ($\mu\text{g/L}$ as Mn)	1.90	0.00	1.69	44	0.00	0.00	0.81	13	6.46	1.71	39
Mercury, dissolved ($\mu\text{g/L}$ as Hg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	39
Molybdenum, dissolved ($\mu\text{g/L}$ as Mo)	6.15	13	5.76	3.04	4.18	0.98	2.68	1.03	0.00	1.03	39
Nickel, dissolved ($\mu\text{g/L}$ as Ni)	12	7.46	2.25	11	1.68	2.63	3.04	0.85	8.71	7.07	39
Selenium, dissolved ($\mu\text{g/L}$ as Se)	7.07	8.32	2.11	30	3.29	42	6.33	6.37	16	5.86	39
Silver, dissolved ($\mu\text{g/L}$ as Ag)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	39
Strontium, dissolved ($\mu\text{g/L}$ as Sr)	0.83	0.23	0.00	0.00	0.00	1.21	2.82	3.22	0.81	0.85	39
Zinc, dissolved ($\mu\text{g/L}$ as Zn)	0.00	0.00	3.80	1.46	0.31	5.44	4.14	5.24	0.00	3.37	39
Uranium, natural ($\mu\text{g/L}$ as U)	8.86	0.90	0.72	0.98	0.00	0.58	0.44	0.37	3.63	0.90	39
Gross alpha, dissolved (pCi/L)	--	--	--	--	--	--	--	--	--	14	2
Gross beta, dissolved (pCi/L)	--	--	--	--	--	--	--	--	--	3.64	2
Plutonium-238, whole water (pCi/L as Pu)	--	--	--	0.00	--	--	--	--	--	0.00	9
Plutonium-239+240, whole water (pCi/L as Pu)	--	--	--	141.42	--	--	--	--	--	141	9

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Table 13. Absolute difference for replicate ground-water samples collected near Deer Trail, Colorado, 1999–2003.

[Absolute difference is defined as (sample value – replicate value)]; for this analysis, all values that were less than the reporting limit were set equal to the reporting limit and estimated values were included; calculations done on unrounded data; --, no data; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; pCi/L , picocuries per liter]

Parameter	DTX6 03/18/99	D6 03/19/99	D30 04/12/99	DTX5 04/13/99	DTX1 07/07/99	DTX3 07/09/99	DTX1 11/08/99	D6 11/12/99	D29 01/07/00	DTX3 01/10/00	DTX3 04/11/00
Specific conductance, laboratory ($\mu\text{S}/\text{cm}$)	10	0	20	20	0	20	10	1,300	10	0	0
pH, whole water, laboratory (standard units)	0	0	0	0	0	0.1	0	0	0.076	0.027	0.001
Calcium, dissolved (mg/L as Ca)	0	30	10	10	10	0	10	0	9	11.83	7.68
Magnesium, dissolved (mg/L as Mg)	10	100	0	2	10	1	0	0	18.84	6.331	3.146
Sodium, dissolved (mg/L as Na)	0	0	10	1	10	0	10	0	2.82	4.226	0.452
Potassium, dissolved (mg/L as K)	1	3	0.2	0.1	0.3	0.1	0.1	1	0.45	0.18	0.31
Acid neutralizing capacity, titration to 4.5, laboratory (mg/L as CaCO_3)	0	1	4	0	1	0	1	1	1.21	0.34	0
Sulfate, dissolved (mg/L as SO_4)	0	0	100	0	0	0	0	0	20	0.86	7.91
Chloride, dissolved (mg/L as Cl)	1	0	4	0	1	1	1	10	0.08	0.13	0.9
Fluoride, dissolved (mg/L as F)	0	0	0	0	0	0	0	0	0.059	0.045	0
Bromide, dissolved (mg/L as Br)	0	0.2	0.01	0	0.01	0.01	0.01	0	0.01	0	0
Silica, dissolved (mg/L as SiO_2)	0	3	1	0	1	0	1	0	0.263	0.3	0.621
Solids, residue on evaporation at 180 degrees Celsius, dissolved (mg/L)	20	100	20	20	30	4	50	200	12	0	20
Nitrite plus nitrate (mg/L as N)	0.01	0	0	0	--	0	0.1	0	0.001	0	0.003
Nitrogen ammonia, dissolved (mg/L as N)	0.01	0	0.01	0.01	--	0	0	0.03	0	0.015	0
Nitrogen ammonia plus organic, total (mg/L as N)	0	0	0	0	0	0	0.1	0.1	0.012	0.015	0.011
Nitrogen ammonia plus organic, dissolved (mg/L as N)	0	0	0	0.04	--	0.2	0.01	0.24	0.03	0.052	0
Phosphorus, total (mg/L as P)	0	0.01	0.01	0	0	0	0.01	0.01	0.001	0	0
Phosphorus, dissolved (mg/L as P)	0	0.01	0.018	0	--	0	0.02	0	0.005	0	0
Aluminum, dissolved ($\mu\text{g}/\text{L}$ as Al)	1	0	5	4	1	0	0	4	1	1	5
Antimony, dissolved ($\mu\text{g}/\text{L}$ as Sb)	0	0	0	0	0	0	0	4	0	0	0
Arsenic, dissolved ($\mu\text{g}/\text{L}$ as As)	0	0	0	0	1	0	0	1	0	0	0
Barium, dissolved ($\mu\text{g}/\text{L}$ as Ba)	0	0	1	1	0	0	0	4	0	0	0
Beryllium, dissolved ($\mu\text{g}/\text{L}$ as Be)	0	0	0	0	0	0	0	4	0	0	0
Boron, dissolved ($\mu\text{g}/\text{L}$ as B)	9	29	37	0	42	2	20	190	5	4	1
Cadmium, dissolved ($\mu\text{g}/\text{L}$ as Cd)	0	0	0	0	0	0	0	4	0	0	0
Chromium, dissolved ($\mu\text{g}/\text{L}$ as Cr)	0.1	5	0	0	0	0	0.2	0	0	0.2	0.2
Cobalt, dissolved ($\mu\text{g}/\text{L}$ as Co)	1	0	1	0	0	0	0	4	0	0	0
Copper, dissolved ($\mu\text{g}/\text{L}$ as Cu)	1	1	0	1	1	0	0	2	1	1	0
Iron, dissolved ($\mu\text{g}/\text{L}$ as Fe)	0	0	26	0	15	0	0	0	100	0	0
Lead, dissolved ($\mu\text{g}/\text{L}$ as Pb)	0	0	0	0	0	0	0	4	0	0	0
Manganese, dissolved ($\mu\text{g}/\text{L}$ as Mn)	1	10	10	5	3	0	2	90	1	0	0
Mercury, dissolved ($\mu\text{g}/\text{L}$ as Hg)	0	0	0	0	0	0	0	0	0	0	0
Molybdenum, dissolved ($\mu\text{g}/\text{L}$ as Mo)	0	0	1	0	0	0	0	4	0	0	0
Nickel, dissolved ($\mu\text{g}/\text{L}$ as Ni)	4	1	1	2	11	0	1	2	0	0	0
Selenium, dissolved ($\mu\text{g}/\text{L}$ as Se)	0	1	0	0	1	0	0	1	0.4	0	0.7
Silver, dissolved ($\mu\text{g}/\text{L}$ as Ag)	0	0	0	0	0	0	0	4	0	0	0
Strontium, dissolved ($\mu\text{g}/\text{L}$ as Sr)	200	0	100	100	100	200	100	0	70	60	30
Zinc, dissolved ($\mu\text{g}/\text{L}$ as Zn)	6	6	2	1	1	0	1	4	0	0	2
Uranium, natural ($\mu\text{g}/\text{L}$ as U)	0	2	1	1	1	0	0	2	0	0	0
Gross alpha, dissolved (pCi/L)	--	--	--	--	6	1.9	--	--	--	--	--
Gross beta, dissolved (pCi/L)	--	--	--	--	5	0	--	--	--	--	--
Plutonium-238, whole water (pCi/L as Pu)	--	--	--	--	0.001	0.003	--	--	0.002	0.001	--
Plutonium-239+240, whole water (pCi/L as Pu)	--	--	--	--	0.002	0.004	--	--	0.006	0.002	--

Table 13. Absolute difference for replicate ground-water samples collected near Deer Trail, Colorado, 1999–2003.—Continued

[Absolute difference is defined as (sample value – replicate value)]; for this analysis, all values that were less than the reporting limit were set equal to the reporting limit and estimated values were included; calculations done on unrounded data; --, no data; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; pCi/L , picocuries per liter]

Parameter	D6	D25	D6	D25	D6	D25	D6	D6	D25	D25
	04/13/00	07/06/00	07/11/00	10/10/00	10/12/00	01/03/01	01/08/01	04/04/01	04/10/01	07/09/01
Specific conductance, laboratory ($\mu\text{S}/\text{cm}$)	0	20	0	10	100	30	100	100	20	80
pH, whole water, laboratory (standard units)	0.027	0	0	0	0.028	0	0.1	0.2	0	0
Calcium, dissolved (mg/L as Ca)	14.82	14	2.9	3	1.85	1	28	5	3	7
Magnesium, dissolved (mg/L as Mg)	90	9	10	1	10	1	30	10	5	1
Sodium, dissolved (mg/L as Na)	100	15	0	0	10	6	40	20	13	2
Potassium, dissolved (mg/L as K)	0.35	1.3	0.6	0.1	0.38	0.33	0.9	0.8	0.86	0.13
Acid neutralizing capacity, titration to 4.5, laboratory (mg/L as CaCO_3)	1	10	0.73	112	0	17	0	1	8	7
Sulfate, dissolved (mg/L as SO_4)	200	10	100	10	202	10	100	0	20	20
Chloride, dissolved (mg/L as Cl)	4	0.2	1	2.4	1	1.6	11	8	2	2
Fluoride, dissolved (mg/L as F)	0.053	0.033	0.068	0.1	0	0.1	0	0	0.1	0
Bromide, dissolved (mg/L as Br)	0.12	0.01	0.01	0.01	0.01	0.03	0.01	0.03	0	0.11
Silica, dissolved (mg/L as SiO_2)	0.1	0.8	0.3	0.2	0.2	2.7	0.3	0.2	0.6	0.3
Solids, residue on evaporation at 180 degrees Celsius, dissolved (mg/L)	500	50	100	100	600	20	300	100	40	270
Nitrite plus nitrate (mg/L as N)	0.7	0.01	1.1	0.09	0	0.05	0.1	0.6	0.09	0.04
Nitrogen ammonia, dissolved (mg/L as N)	0.014	0.01	0	0	0.004	0.003	0.002	0.011	0.005	0.006
Nitrogen ammonia plus organic, total (mg/L as N)	0.2	0.02	0	0.15	0	0.03	0	0.08	0.11	0.04
Nitrogen ammonia plus organic, dissolved (mg/L as N)	0	0.04	0	0.72	0.12	0.01	0	0.12	0.06	0.02
Phosphorus, total (mg/L as P)	0.006	0.004	0.003	0.006	0	0.008	0	0.08	0.017	0.02
Phosphorus, dissolved (mg/L as P)	0.015	0.001	0.019	0.001	0	0.025	0	0.12	0.019	0.04
Aluminum, dissolved ($\mu\text{g}/\text{L}$ as Al)	0.1	0	0	0	0	0	0	1	0	0
Antimony, dissolved ($\mu\text{g}/\text{L}$ as Sb)	0	0	0	0	0	0.01	0.04	0.02	0	0.01
Arsenic, dissolved ($\mu\text{g}/\text{L}$ as As)	2	0.8	0.5	0	0.1	0	0	0	0.2	0.2
Barium, dissolved ($\mu\text{g}/\text{L}$ as Ba)	0	0	0	0	0	0.1	0.1	0.3	0.2	0
Beryllium, dissolved ($\mu\text{g}/\text{L}$ as Be)	0	0	0	0	0	0	0	0	0	0
Boron, dissolved ($\mu\text{g}/\text{L}$ as B)	0	30	18	23	0	16	66	70	64	31
Cadmium, dissolved ($\mu\text{g}/\text{L}$ as Cd)	0	0	0	0	0	0.01	0.02	0.02	0	0.08
Chromium, dissolved ($\mu\text{g}/\text{L}$ as Cr)	0.2	0.2	0	0.2	0	0	1.3	0	0	0.2
Cobalt, dissolved ($\mu\text{g}/\text{L}$ as Co)	0	0	0	0	1	0.12	0.27	0.14	0.1	0.08
Copper, dissolved ($\mu\text{g}/\text{L}$ as Cu)	2	1	7	0	2	0.2	1.4	0.6	0.1	3.6
Iron, dissolved ($\mu\text{g}/\text{L}$ as Fe)	0	0	0	0	0	0	0	0	0	0
Lead, dissolved ($\mu\text{g}/\text{L}$ as Pb)	0	0	0	0	0.96	0.01	0.02	0.05	0.01	0
Manganese, dissolved ($\mu\text{g}/\text{L}$ as Mn)	90	410	520	80	30	30	180	130	600	90
Mercury, dissolved ($\mu\text{g}/\text{L}$ as Hg)	0	0	0	0	0	0	0	0	0	0
Molybdenum, dissolved ($\mu\text{g}/\text{L}$ as Mo)	0	0	0	1	1	0.5	0	0.2	0.1	0.3
Nickel, dissolved ($\mu\text{g}/\text{L}$ as Ni)	0	19	1	2	3	0.59	2.3	0.9	2.36	6.9
Selenium, dissolved ($\mu\text{g}/\text{L}$ as Se)	12	0.5	0.7	0	1	1.3	1.8	0.5	0.2	0.1
Silver, dissolved ($\mu\text{g}/\text{L}$ as Ag)	0	0	0	0	0	0	0	0	0	0
Strontium, dissolved ($\mu\text{g}/\text{L}$ as Sr)	600	140	100	0	0	0	0	0	50	0
Zinc, dissolved ($\mu\text{g}/\text{L}$ as Zn)	3	1	7	0	2	0	1	1	0	4
Uranium, natural ($\mu\text{g}/\text{L}$ as U)	0	0	5	2	2	1	3	1	3.3	2.8
Gross alpha, dissolved (pCi/L)	--	--	--	--	--	--	--	--	--	--
Gross beta, dissolved (pCi/L)	--	--	--	--	--	--	--	--	--	--
Plutonium-238, whole water (pCi/L as Pu)	--	--	--	0.002	0	--	--	--	--	--
Plutonium-239+240, whole water (pCi/L as Pu)	--	--	--	0.005	0.003	--	--	--	--	--

Table 13. Absolute difference for replicate ground-water samples collected near Deer Trail, Colorado, 1999–2003.—Continued

[Absolute difference is defined as (sample value – replicate value)]; for this analysis, all values that were less than the reporting limit were set equal to the reporting limit and estimated values were included; calculations done on unrounded data; --, no data; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; pCi/L , picocuries per liter]

Parameter	D6 07/10/01	D6 10/10/01	D25 10/15/01	D6 01/14/02	D25 01/07/02	DTX3 04/09/02	D6R 04/04/02	D6 07/09/02	DTX2 07/10/02	D6 10/17/02
Specific conductance, laboratory ($\mu\text{S}/\text{cm}$)	300	0	20	0	0	0	100	100	0	0
pH, whole water, laboratory (standard units)	0	0	0	0.005	0.03	0.01	0.009	0.1	0	0
Calcium, dissolved (mg/L as Ca)	5	8	71	8.27	1.67	4.28	19.76	5	3	4
Magnesium, dissolved (mg/L as Mg)	10	80	7	34.91	4.23	4.09	42.71	10	3	30
Sodium, dissolved (mg/L as Na)	10	60	7	13.37	0.86	4.23	125.49	30	4	30
Potassium, dissolved (mg/L as K)	0.4	0.4	1.82	0.25	0.34	0.63	0.05	0.9	0.35	0.1
Acid neutralizing capacity, titration to 4.5, laboratory (mg/L as CaCO_3)	2	1	6	2.45	1.69	0.06	3.16	0	0	2
Sulfate, dissolved (mg/L as SO_4)	0	0	40	118.742	0.639	5.4	37.26	0	1	100
Chloride, dissolved (mg/L as Cl)	10	11	1.3	1.094	1.571	1.73	5.68	6	0.1	1
Fluoride, dissolved (mg/L as F)	0.1	0.1	0	0.021	0.022	0.017	0.002	0	0	0.1
Bromide, dissolved (mg/L as Br)	0.12	0.06	0.02	0.094	0.009	0.005	0.068	0.04	0.01	0.06
Silica, dissolved (mg/L as SiO_2)	0.6	1.5	1.9	0.11	0.23	0.44	1.18	0.2	0.2	0.3
Solids, residue on evaporation at 180 degrees Celsius, dissolved (mg/L)	1,100	0	30	200	40	20.21	543.75	100	2	0
Nitrite plus nitrate (mg/L as N)	0.2	0.1	0.15	0.129	0.039	0.047	0.304	0.5	0	0.3
Nitrogen ammonia, dissolved (mg/L as N)	0.008	0.002	0.017	0.015	0.008	0	0.023	0	0.01	0.1
Nitrogen ammonia plus organic, total (mg/L as N)	0.02	0.5	0.01	0.11	0.01	0.028	0.075	0	0.01	0.21
Nitrogen ammonia plus organic, dissolved (mg/L as N)	0.02	0.1	0.03	0.079	0.04	0.008	0.153	0	0.01	0.1
Phosphorus, total (mg/L as P)	0	0.1	0.03	0	0.015	0	0.023	0	0	0.01
Phosphorus, dissolved (mg/L as P)	0.02	0.5	0.01	0	0.004	0	0	0.01	0	0
Aluminum, dissolved ($\mu\text{g}/\text{L}$ as Al)	0	0	0	0	0	0	0.28	0	0	0
Antimony, dissolved ($\mu\text{g}/\text{L}$ as Sb)	0	0	0	0	0.01	0.034	0.18	0.05	0	0
Arsenic, dissolved ($\mu\text{g}/\text{L}$ as As)	0.5	1.2	0.1	0.55	0.31	0	0.42	1	1	1
Barium, dissolved ($\mu\text{g}/\text{L}$ as Ba)	0	0	0	0	0.07	0.896	0.3	0	0.41	0
Beryllium, dissolved ($\mu\text{g}/\text{L}$ as Be)	0	0	0	0	0	0	0	0	0	0
Boron, dissolved ($\mu\text{g}/\text{L}$ as B)	0	63	34	21	35	30	126	20	1	20
Cadmium, dissolved ($\mu\text{g}/\text{L}$ as Cd)	0.01	0.04	0.01	0	0	0.007	0.01	0.05	0	0.13
Chromium, dissolved ($\mu\text{g}/\text{L}$ as Cr)	0.2	0	0.1	0.005	0	0	0	0.8	0	0
Cobalt, dissolved ($\mu\text{g}/\text{L}$ as Co)	0.09	0.21	0.35	0.85	0.07	0.058	0.61	0.12	0.03	0.62
Copper, dissolved ($\mu\text{g}/\text{L}$ as Cu)	1.8	9	4.4	1.15	0.31	0.271	0.49	6.5	0.3	7.8
Iron, dissolved ($\mu\text{g}/\text{L}$ as Fe)	0	0	0	0	20	0	0	0	4	0
Lead, dissolved ($\mu\text{g}/\text{L}$ as Pb)	0.05	0.17	0	0.31	0	0	0	0	0	0
Manganese, dissolved ($\mu\text{g}/\text{L}$ as Mn)	90	70	220	389	93	0.067	203	40	16	120
Mercury, dissolved ($\mu\text{g}/\text{L}$ as Hg)	0	0	0	0	0	0	0	0	0	0
Molybdenum, dissolved ($\mu\text{g}/\text{L}$ as Mo)	0.2	0	0.1	0.32	0.24	0.001	0.33	0.2	0.1	0.3
Nickel, dissolved ($\mu\text{g}/\text{L}$ as Ni)	1.5	0.75	0.06	0.02	0.62	3.964	0.52	0.8	0.1	4.9
Selenium, dissolved ($\mu\text{g}/\text{L}$ as Se)	0.7	5.8	0.1	0.92	0	1.93	0.73	2	0	2
Silver, dissolved ($\mu\text{g}/\text{L}$ as Ag)	0	0	0	0	0	0	0	0	0	0
Strontium, dissolved ($\mu\text{g}/\text{L}$ as Sr)	100	500	70	224	26	43	1,004	300	48	200
Zinc, dissolved ($\mu\text{g}/\text{L}$ as Zn)	1	4	1	0.29	0.52	0.231	0.83	2	0	0
Uranium, natural ($\mu\text{g}/\text{L}$ as U)	0	3	0.6	9.31	1.25	0.36	4.07	2	0.1	23
Gross alpha, dissolved (pCi/L)	--	--	--	--	--	--	--	--	--	--
Gross beta, dissolved (pCi/L)	--	--	--	--	--	--	--	--	--	--
Plutonium-238, whole water (pCi/L as Pu)	--	--	--	0.059	0.005	--	--	--	--	--
Plutonium-239+240, whole water (pCi/L as Pu)	--	--	--	0.027	0.003	--	--	--	--	--

Table 13. Absolute difference for replicate ground-water samples collected near Deer Trail, Colorado, 1999–2003.—Continued

[Absolute difference is defined as (sample value – replicate value)]; for this analysis, all values that were less than the reporting limit were set equal to the reporting limit and estimated values were included; calculations done on unrounded data; --, no data; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; pCi/L , picocuries per liter]

Parameter	DTX3 10/21/02	D6 01/03/03	DTX6 01/07/03	D6 04/04/03	DTX6 04/03/03	D6 07/10/03	DTX4 07/08/03	DTX8A 10/06/03	Median absolute difference	Number of replicate samples
Specific conductance, laboratory ($\mu\text{S}/\text{cm}$)	10	0	0	400	29	140	10	0	10	39
pH, whole water, laboratory (standard units)	0.1	0.09	0.1	0	0	0	0.1	0	0	39
Calcium, dissolved (mg/L as Ca)	4	0	0	10	0	9	18	1	5	39
Magnesium, dissolved (mg/L as Mg)	1	0	0	100	0	240	3.1	0.6	6.33	39
Sodium, dissolved (mg/L as Na)	2	100	0	0	0	20	5	2	5	39
Potassium, dissolved (mg/L as K)	0.04	0	0	0.2	0.2	2	0.4	0.2	0.34	39
Acid neutralizing capacity, titration to 4.5, laboratory (mg/L as CaCO_3)	39	1	1	2	1	0	0	1	1	39
Sulfate, dissolved (mg/L as SO_4)	2	100	0	600	0	500	0	5	5.4	39
Chloride, dissolved (mg/L as Cl)	0.2	3	0	2	1.1	1	0.21	0.4	1.09	39
Fluoride, dissolved (mg/L as F)	0	0	0.018	0.008	0	0.02	0.01	0.01	0.002	39
Bromide, dissolved (mg/L as Br)	0	0.01	0	0	0.005	0.19	0.001	0.002	0.01	39
Silica, dissolved (mg/L as SiO_2)	0.2	1	0	0	0	0	0.1	0.2	0.26	39
Solids, residue on evaporation at 180 degrees Celsius, dissolved (mg/L)	0	200	10	1,100	0	100	30	0	40	39
Nitrite plus nitrate (mg/L as N)	0.02	0.1	0.008	0.1	0.003	0	0.007	0	0.04	38
Nitrogen ammonia, dissolved (mg/L as N)	0.02	0.01	0.01	0.01	0	0.005	0	0.03	0.008	38
Nitrogen ammonia plus organic, total (mg/L as N)	0	0.7	0.03	0	0	0.7	0	0.1	0.015	39
Nitrogen ammonia plus organic, dissolved (mg/L as N)	0.02	0	0.013	0.1	0.04	0.11	0.01	0	0.025	38
Phosphorus, total (mg/L as P)	0	0.015	0	0.004	0.007	0	0	0	0.003	39
Phosphorus, dissolved (mg/L as P)	0	0.01	0	0	0	0.001	0	0	0.000	38
Aluminum, dissolved ($\mu\text{g}/\text{L}$ as Al)	0	0	0	0	0	0.2	0	0.1	0	39
Antimony, dissolved ($\mu\text{g}/\text{L}$ as Sb)	0	0.56	0	0	0	0.1	0	0	0	39
Arsenic, dissolved ($\mu\text{g}/\text{L}$ as As)	0	0.5	0	0	0	0	0	0.1	0	39
Barium, dissolved ($\mu\text{g}/\text{L}$ as Ba)	0	0.27	0	0.3	0.04	0.57	0	0.1	0	39
Beryllium, dissolved ($\mu\text{g}/\text{L}$ as Be)	0	0	0	0	0	0	0	0	0	39
Boron, dissolved ($\mu\text{g}/\text{L}$ as B)	10	56	14	49	19	113	5	1	20	39
Cadmium, dissolved ($\mu\text{g}/\text{L}$ as Cd)	0	0	0	0	0	0.02	0.004	0	0	39
Chromium, dissolved ($\mu\text{g}/\text{L}$ as Cr)	0	0	0	0	0	0.4	0	0	0	39
Cobalt, dissolved ($\mu\text{g}/\text{L}$ as Co)	0.03	0.09	0.13	0.04	0	0.12	0.008	0.002	0.07	39
Copper, dissolved ($\mu\text{g}/\text{L}$ as Cu)	0.4	1.4	1.17	0.8	0.3	2.7	0.16	0.1	1	39
Iron, dissolved ($\mu\text{g}/\text{L}$ as Fe)	0	0	0	0	20	120	0	12	0	39
Lead, dissolved ($\mu\text{g}/\text{L}$ as Pb)	0	0	0.03	0	0	0	0	0	0	39
Manganese, dissolved ($\mu\text{g}/\text{L}$ as Mn)	0	100	0.17	0	0	50	0.03	11	30	39
Mercury, dissolved ($\mu\text{g}/\text{L}$ as Hg)	0	0	0	0	0	0	0	0	0	39
Molybdenum, dissolved ($\mu\text{g}/\text{L}$ as Mo)	0.1	0.28	0.04	0.19	0.01	0.13	0.01	0	0.1	39
Nickel, dissolved ($\mu\text{g}/\text{L}$ as Ni)	0.84	0.9	2.3	0.4	0.2	0.9	0.11	0.21	0.9	39
Selenium, dissolved ($\mu\text{g}/\text{L}$ as Se)	2	0.5	0.9	0.4	1.2	0.9	0.5	0.1	0.7	39
Silver, dissolved ($\mu\text{g}/\text{L}$ as Ag)	0	0	0	0	0	0	0	0	0	39
Strontium, dissolved ($\mu\text{g}/\text{L}$ as Sr)	10	0	0	0	100	700	140	30	70	39
Zinc, dissolved ($\mu\text{g}/\text{L}$ as Zn)	0	1.6	0.1	0.1	0.4	1.7	0.2	0	1	39
Uranium, natural ($\mu\text{g}/\text{L}$ as U)	0.3	2	0.5	0	0.3	1	0.1	0.01	1	39
Gross alpha, dissolved (pCi/L)	--	--	--	--	--	--	--	--	3.95	2
Gross beta, dissolved (pCi/L)	--	--	--	--	--	--	--	--	2.5	2
Plutonium-238, whole water (pCi/L as Pu)	--	--	0	--	--	--	--	--	0.002	9
Plutonium-239+240, whole water (pCi/L as Pu)	--	--	0.016	--	--	--	--	--	0.004	9

Table 14. Percent difference for replicate ground-water samples collected near Deer Trail, Colorado, 1999–2003.

[Percent difference is defined as $(\text{sample value} - \text{replicate value}) / ((\text{sample value} + \text{replicate value}) / 2) \times 100$; for this analysis, all values that were less than the reporting limit were set equal to the reporting limit and estimated values were included; calculations done on unrounded data; --, no data; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; pCi/L , picocuries per liter]

Parameter	DTX6 03/18/99	D6 03/19/99	D30 04/12/99	DTX5 04/13/99	DTX1 07/07/99	DTX3 07/09/99	DTX1 11/08/99	D6 11/12/99	D29 01/07/00	DTX3 01/10/00
Specific conductance, laboratory ($\mu\text{S}/\text{cm}$)	0.25	0.00	0.40	0.64	0.00	1.65	0.24	8.47	0.25	0.00
pH, whole water, laboratory (standard units)	0.00	0.00	0.00	0.00	0.00	1.32	0.00	0.00	1.11	0.36
Calcium, dissolved (mg/L as Ca)	0.00	6.59	2.25	1.46	2.06	0.00	2.11	0.00	1.70	7.21
Magnesium, dissolved (mg/L as Mg)	3.92	4.44	0.00	2.08	4.65	2.11	0.00	0.00	5.60	9.49
Sodium, dissolved (mg/L as Na)	0.00	0.00	2.60	1.11	2.74	0.00	2.90	0.00	1.99	7.53
Potassium, dissolved (mg/L as K)	8.00	22.22	4.88	1.94	8.70	1.87	2.90	8.00	3.97	2.95
Acid neutralizing capacity, titration to 4.5, laboratory (mg/L as CaCO_3)	0.00	0.16	1.03	0.00	0.32	0.00	0.33	0.16	0.41	0.12
Sulfate, dissolved (mg/L as SO_4)	0.00	0.00	3.17	0.00	0.00	0.00	0.00	0.00	0.74	0.17
Chloride, dissolved (mg/L as Cl)	4.88	0.00	8.00	0.00	1.94	9.52	2.02	2.41	0.69	0.76
Fluoride, dissolved (mg/L as F)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	13	11
Bromide, dissolved (mg/L as Br)	0.00	4.88	1.53	0.00	1.53	11	1.32	0.00	5.41	0.00
Silica, dissolved (mg/L as SiO_2)	0.00	13	4.65	0.00	2.99	0.00	2.99	0.00	1.25	1.93
Solids, residue on evaporation at 180 degrees Celsius, dissolved (mg/L)	0.49	0.50	0.39	0.63	0.72	0.46	1.21	0.97	0.28	0.00
Nitrite plus nitrate (mg/L as N)	4.26	0.00	0.00	0.00	--	0.00	5.41	0.00	4.65	0.00
Nitrogen ammonia, dissolved (mg/L as N)	29	0.00	13	13	--	0.00	0.00	40	0.00	70
Nitrogen ammonia plus organic, total (mg/L as N)	0.00	0.00	0.00	0.00	0.00	0.00	67	7.41	2.38	9.84
Nitrogen ammonia plus organic, dissolved (mg/L as N)	0.00	0.00	0.00	22	--	13	5.13	57	6.45	32
Phosphorus, total (mg/L as P)	0.00	29	22	0.00	0.00	0.00	15	22	2.53	0.00
Phosphorus, dissolved (mg/L as P)	0.00	29	44	0.00	--	0.00	22	0.00	11	0.00
Aluminum, dissolved ($\mu\text{g}/\text{L}$ as Al)	40	0.00	67	80	29	0.00	0.00	50	18	67
Antimony, dissolved ($\mu\text{g}/\text{L}$ as Sb)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50	0.00	0.00
Arsenic, dissolved ($\mu\text{g}/\text{L}$ as As)	0.00	0.00	0.00	0.00	40	0.00	0.00	67	0.00	0.00
Barium, dissolved ($\mu\text{g}/\text{L}$ as Ba)	0.00	0.00	9.52	5.41	0.00	0.00	0.00	50	0.00	0.00
Beryllium, dissolved ($\mu\text{g}/\text{L}$ as Be)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50	0.00	0.00
Boron, dissolved ($\mu\text{g}/\text{L}$ as B)	2.42	3.38	7.50	0.00	7.24	1.04	3.18	20	2.71	1.89
Cadmium, dissolved ($\mu\text{g}/\text{L}$ as Cd)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50	0.00	0.00
Chromium, dissolved ($\mu\text{g}/\text{L}$ as Cr)	8.00	111	0.00	0.00	0.00	0.00	22	0.00	0.00	29
Cobalt, dissolved ($\mu\text{g}/\text{L}$ as Co)	15	0.00	40	0.00	0.00	0.00	0.00	50	0.00	0.00
Copper, dissolved ($\mu\text{g}/\text{L}$ as Cu)	13	3.39	0.00	12	13	0.00	0.00	7.14	15	40
Iron, dissolved ($\mu\text{g}/\text{L}$ as Fe)	0.00	0.00	50	0.00	40	0.00	0.00	0.00	1.40	0.00
Lead, dissolved ($\mu\text{g}/\text{L}$ as Pb)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50	0.00	0.00
Manganese, dissolved ($\mu\text{g}/\text{L}$ as Mn)	8.70	0.28	3.14	4.18	3.92	0.00	2.30	2.38	0.12	0.00
Mercury, dissolved ($\mu\text{g}/\text{L}$ as Hg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molybdenum, dissolved ($\mu\text{g}/\text{L}$ as Mo)	0.00	0.00	40	0.00	0.00	0.00	0.00	50	0.00	0.00
Nickel, dissolved ($\mu\text{g}/\text{L}$ as Ni)	44	4.44	7.41	14	147	0.00	6.45	10	0.00	0.00
Selenium, dissolved ($\mu\text{g}/\text{L}$ as Se)	0.00	13	0.00	0.00	22	0.00	0.00	18	18	0.00
Silver, dissolved ($\mu\text{g}/\text{L}$ as Ag)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	50	0.00	0.00
Strontium, dissolved ($\mu\text{g}/\text{L}$ as Sr)	3.57	0.00	1.63	1.71	1.74	13	1.77	0.00	1.21	2.94
Zinc, dissolved ($\mu\text{g}/\text{L}$ as Zn)	67	18	18	18	18	0.00	18	13	0.00	0.00
Uranium, natural ($\mu\text{g}/\text{L}$ as U)	0.00	1.27	2.53	2.35	1.94	0.00	0.00	1.29	0.00	0.00
Gross alpha, dissolved (pCi/L)	--	--	--	--	10	28	--	--	--	--
Gross beta, dissolved (pCi/L)	--	--	--	--	10	0.00	--	--	--	--
Plutonium-238, whole water (pCi/L as Pu)	--	--	--	--	-200	-200	--	--	-200	200
Plutonium-239+240, whole water (pCi/L as Pu)	--	--	--	--	29	400	--	--	200	200

Table 14. Percent difference for replicate ground-water samples collected near Deer Trail, Colorado, 1999–2003.—Continued

[Percent difference is defined as $(\text{sample value} - \text{replicate value}) / ((\text{sample value} + \text{replicate value}) / 2) \times 100$; for this analysis, all values that were less than the reporting limit were set equal to the reporting limit and estimated values were included; calculations done on unrounded data; --, no data; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; pCi/L , picocuries per liter]

Parameter	DTX3	D6	D25	D6	D25	D6	D25	D6	D6	D25
	04/11/00	04/13/00	07/06/00	07/11/00	10/10/00	10/12/00	01/03/01	01/08/01	04/04/01	04/10/01
Specific conductance, laboratory ($\mu\text{S}/\text{cm}$)	0.00	0.00	0.44	0.00	0.20	0.62	0.61	0.61	0.60	0.41
pH, whole water, laboratory (standard units)	0.01	0.38	0.00	0.00	0.00	0.39	0.00	1.40	2.82	0.00
Calcium, dissolved (mg/L as Ca)	3.25	3.38	2.22	0.70	0.38	0.42	0.15	6.15	1.15	0.43
Magnesium, dissolved (mg/L as Mg)	3.40	3.96	3.96	0.46	0.46	0.46	0.39	1.42	0.47	2.12
Sodium, dissolved (mg/L as Na)	0.62	4.88	5.39	0.00	0.00	0.48	1.74	1.98	1.00	4.13
Potassium, dissolved (mg/L as K)	4.34	2.75	20	4.88	1.21	3.72	4.30	7.29	6.35	14
Acid neutralizing capacity, titration to 4.5, laboratory (mg/L as CaCO_3)	0.00	0.16	2.04	0.11	21	0.00	2.83	0.00	0.15	1.43
Sulfate, dissolved (mg/L as SO_4)	1.03	1.54	0.40	0.76	0.35	1.53	0.35	0.77	0.00	0.74
Chloride, dissolved (mg/L as Cl)	3.52	1.05	0.20	0.25	2.99	0.24	1.89	2.99	2.05	2.05
Fluoride, dissolved (mg/L as F)	0.00	6.85	3.36	8.88	9.52	0.00	9.52	0.00	0.00	11
Bromide, dissolved (mg/L as Br)	0.00	2.74	18	0.25	0.72	0.24	2.06	0.24	0.67	0.00
Silica, dissolved (mg/L as SiO_2)	3.81	0.47	2.85	1.45	0.69	1.02	8.81	1.37	0.94	2.26
Solids, residue on evaporation at 180 degrees Celsius, dissolved (mg/L)	1.30	2.43	1.07	0.47	1.92	2.83	0.38	1.42	0.48	0.82
Nitrite plus nitrate (mg/L as N)	0.08	5.49	0.33	7.36	1.82	0.00	1.23	0.65	3.70	3.58
Nitrogen ammonia, dissolved (mg/L as N)	0.00	27	6.99	0.00	0.00	3.01	8.70	3.51	19	16
Nitrogen ammonia plus organic, total (mg/L as N)	6.69	15	2.56	0.00	19	0.00	3.35	0.00	8.51	14
Nitrogen ammonia plus organic, dissolved (mg/L as N)	0.00	0.00	5.56	0.00	153	12	1.13	0.00	16	8.45
Phosphorus, total (mg/L as P)	0.00	17	2.72	7.23	5.31	0.00	5.03	67	0.00	12
Phosphorus, dissolved (mg/L as P)	0.00	35	0.66	47	0.89	0.00	15	2.99	38	13
Aluminum, dissolved ($\mu\text{g}/\text{L}$ as Al)	143	8.00	0.00	0.00	0.00	0.00	0.00	0.00	67	0.00
Antimony, dissolved ($\mu\text{g}/\text{L}$ as Sb)	0.00	0.00	0.00	0.00	0.00	0.00	6.45	18	13	0.00
Arsenic, dissolved ($\mu\text{g}/\text{L}$ as As)	0.00	25	26	40	0.00	3.17	0.00	0.00	0.00	10
Barium, dissolved ($\mu\text{g}/\text{L}$ as Ba)	0.00	0.00	0.00	0.00	0.00	0.00	0.51	1.77	5.61	1.11
Beryllium, dissolved ($\mu\text{g}/\text{L}$ as Be)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Boron, dissolved ($\mu\text{g}/\text{L}$ as B)	0.46	0.00	7.06	2.22	5.66	0.00	2.91	8.03	7.51	16
Cadmium, dissolved ($\mu\text{g}/\text{L}$ as Cd)	0.00	0.00	0.00	0.00	0.00	0.00	4.08	18	18	0.00
Chromium, dissolved ($\mu\text{g}/\text{L}$ as Cr)	22	22	29	0.00	4.44	0.00	0.00	90	0.00	0.00
Cobalt, dissolved ($\mu\text{g}/\text{L}$ as Co)	0.00	0.00	0.00	0.00	0.00	15	3.48	3.67	1.90	3.66
Copper, dissolved ($\mu\text{g}/\text{L}$ as Cu)	0.00	3.23	11	22	0.00	5.88	1.79	3.64	1.04	0.90
Iron, dissolved ($\mu\text{g}/\text{L}$ as Fe)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Lead, dissolved ($\mu\text{g}/\text{L}$ as Pb)	0.00	0.00	0.00	0.00	0.00	184.62	15.38	8.33	10.31	13.33
Manganese, dissolved ($\mu\text{g}/\text{L}$ as Mn)	0.00	2.42	13.29	14.02	2.09	0.80	0.92	4.13	3.15	18.58
Mercury, dissolved ($\mu\text{g}/\text{L}$ as Hg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molybdenum, dissolved ($\mu\text{g}/\text{L}$ as Mo)	0.00	0.00	0.00	0.00	7.41	28.57	3.89	0.00	5.26	1.01
Nickel, dissolved ($\mu\text{g}/\text{L}$ as Ni)	0.00	0.00	80.85	4.88	15.38	31.58	11.23	14.98	8.30	190.32
Selenium, dissolved ($\mu\text{g}/\text{L}$ as Se)	5.09	109.09	18.18	8.28	0.00	6.90	29.89	15.25	3.32	15.38
Silver, dissolved ($\mu\text{g}/\text{L}$ as Ag)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium, dissolved ($\mu\text{g}/\text{L}$ as Sr)	1.08	3.49	4.24	0.60	0.00	0.00	0.00	0.00	0.00	1.47
Zinc, dissolved ($\mu\text{g}/\text{L}$ as Zn)	100.00	4.65	18.18	15.38	0.00	8.70	0.00	2.90	2.35	0.00
Uranium, natural ($\mu\text{g}/\text{L}$ as U)	0.00	0.00	0.00	3.37	3.39	1.18	1.87	1.58	0.57	6.54
Gross alpha, dissolved (pCi/L)	--	--	--	--	--	--	--	--	--	--
Gross beta, dissolved (pCi/L)	--	--	--	--	--	--	--	--	--	--
Plutonium-238, whole water (pCi/L as Pu)	--	--	--	--	200.00	0.00	--	--	--	--
Plutonium-239+240, whole water (pCi/L as Pu)	--	--	--	--	1,000	-600	--	--	--	--

Table 14. Percent difference for replicate ground-water samples collected near Deer Trail, Colorado, 1999–2003.—Continued

[Percent difference is defined as $(\text{sample value} - \text{replicate value}) / ((\text{sample value} + \text{replicate value}) / 2) \times 100$; for this analysis, all values that were less than the reporting limit were set equal to the reporting limit and estimated values were included; calculations done on unrounded data; --, no data; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; pCi/L , picocuries per liter]

Parameter	D25 07/09/01	D6 07/10/01	D6 10/10/01	D25 10/15/01	D6 01/14/02	D25 01/07/02	DTX3 04/09/02	D6R 04/04/02	D6 07/09/02	DTX2 07/10/02	D6 10/17/02
Specific conductance, laboratory ($\mu\text{S}/\text{cm}$)	1.71	1.82	0.00	0.43	0.00	0.00	0.00	0.63	0.64	0.00	0.00
pH, whole water, laboratory (standard units)	0.00	0.00	0.00	0.00	0.07	0.41	0.14	0.12	1.40	0.00	0.00
Calcium, dissolved (mg/L as Ca)	1.10	1.17	1.90	8.85	2.00	0.24	1.70	4.77	1.18	0.61	0.91
Magnesium, dissolved (mg/L as Mg)	0.40	0.43	3.69	3.00	1.64	2.00	4.15	1.84	0.44	1.53	1.33
Sodium, dissolved (mg/L as Na)	0.64	0.48	3.09	2.21	0.70	0.31	3.96	6.18	1.48	0.96	1.41
Potassium, dissolved (mg/L as K)	2.04	3.57	3.23	25	2.11	4.63	9.50	0.40	7.53	4.90	0.90
Acid neutralizing capacity, titration to 4.5, laboratory (mg/L as CaCO_3)	1.52	0.31	0.16	1.14	0.39	0.38	0.02	0.49	0.00	0.00	0.31
Sulfate, dissolved (mg/L as SO_4)	0.76	0.00	0.00	1.47	0.87	0.02	0.58	0.28	0.00	0.04	0.74
Chloride, dissolved (mg/L as Cl)	1.72	2.53	2.63	1.36	0.28	1.33	5.86	1.44	1.48	0.23	0.26
Fluoride, dissolved (mg/L as F)	0.00	13	12	0.00	2.48	2.08	5.21	0.23	0.00	0.00	11
Bromide, dissolved (mg/L as Br)	6.81	2.80	1.29	1.17	2.11	0.56	2.28	1.49	0.95	1.65	1.38
Silica, dissolved (mg/L as SiO_2)	1.07	2.82	7.67	6.06	0.51	0.82	2.85	5.65	0.93	1.20	1.34
Solids, residue on evaporation at 180 degrees Celsius, dissolved (mg/L)	5.76	5.06	0.00	0.62	0.93	0.85	1.13	2.51	0.47	0.05	0.00
Nitrite plus nitrate (mg/L as N)	2.44	1.24	0.63	3.17	0.85	1.67	0.81	2.01	2.93	0.00	1.72
Nitrogen ammonia, dissolved (mg/L as N)	17	14	3.92	37	14	13	0.00	60	0.00	2.21	0.00
Nitrogen ammonia plus organic, total (mg/L as N)	3.13	3.64	6.45	4.38	21	1.37	13	5.79	0.00	1.02	6.90
Nitrogen ammonia plus organic, dissolved (mg/L as N)	7.84	5.71	48	1.44	15	5.86	3.54	14	0.00	1.03	27
Phosphorus, total (mg/L as P)	2.08	0.00	55	4.38	0.00	12	0.00	47	0.00	0.00	29
Phosphorus, dissolved (mg/L as P)	0.00	0.00	0.00	1.56	0.00	3.54	0.00	0.00	29	0.00	0.00
Aluminum, dissolved ($\mu\text{g}/\text{L}$ as Al)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	14	0.00	0.00	0.00
Antimony, dissolved ($\mu\text{g}/\text{L}$ as Sb)	5.41	0.00	0.00	0.00	0.00	4.88	81	13	20	0.00	0.00
Arsenic, dissolved ($\mu\text{g}/\text{L}$ as As)	7.14	19	27	3.77	18	8.10	0.00	20	22	67	40
Barium, dissolved ($\mu\text{g}/\text{L}$ as Ba)	0.00	0.00	0.00	0.00	0.00	0.37	5.58	5.46	0.00	3.20	0.00
Beryllium, dissolved ($\mu\text{g}/\text{L}$ as Be)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Boron, dissolved ($\mu\text{g}/\text{L}$ as B)	7.09	0.00	8.98	7.69	2.99	9.16	14	14	2.38	0.31	2.17
Cadmium, dissolved ($\mu\text{g}/\text{L}$ as Cd)	62	4.44	17	4.44	0.00	0.00	29	9.52	26	0.00	67
Chromium, dissolved ($\mu\text{g}/\text{L}$ as Cr)	6.45	17	0.00	3.77	0.17	0.00	0.00	0.00	67	0.00	0.00
Cobalt, dissolved ($\mu\text{g}/\text{L}$ as Co)	2.60	1.27	3.12	12	11	2.05	9.91	7.58	1.76	0.57	8.34
Copper, dissolved ($\mu\text{g}/\text{L}$ as Cu)	26	3.02	8.37	17	4.79	4.45	7.88	1.09	8.98	2.21	16
Iron, dissolved ($\mu\text{g}/\text{L}$ as Fe)	0.00	0.00	0.00	0.00	0.00	100	0.00	0.00	0.00	0.79	0.00
Lead, dissolved ($\mu\text{g}/\text{L}$ as Pb)	0.00	7.75	42	0.00	70	0.00	0.00	0.00	0.00	0.00	0.00
Manganese, dissolved ($\mu\text{g}/\text{L}$ as Mn)	3.28	2.18	1.66	6.71	8.65	2.94	50	4.30	1.01	0.37	2.69
Mercury, dissolved ($\mu\text{g}/\text{L}$ as Hg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Molybdenum, dissolved ($\mu\text{g}/\text{L}$ as Mo)	3.11	6.25	0.00	0.97	8.29	2.88	0.18	5.67	6.25	6.06	8.70
Nickel, dissolved ($\mu\text{g}/\text{L}$ as Ni)	194	23	50	11	0.14	151	130	3.30	5.59	0.62	17
Selenium, dissolved ($\mu\text{g}/\text{L}$ as Se)	5.41	4.75	28	3.77	6.73	0.00	12	6.92	11	0.00	10
Silver, dissolved ($\mu\text{g}/\text{L}$ as Ag)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Strontium, dissolved ($\mu\text{g}/\text{L}$ as Sr)	0.00	0.59	3.12	1.90	1.40	0.77	1.45	5.95	1.89	0.93	1.17
Zinc, dissolved ($\mu\text{g}/\text{L}$ as Zn)	44	2.30	4.76	7.41	1.10	9.27	14	2.49	4.55	0.00	0.00
Uranium, natural ($\mu\text{g}/\text{L}$ as U)	6.26	0.00	1.77	1.21	4.85	3.29	1.28	2.23	1.18	0.29	13
Gross alpha, dissolved (pCi/L)	--	--	--	--	--	--	--	--	--	--	--
Gross beta, dissolved (pCi/L)	--	--	--	--	--	--	--	--	--	--	--
Plutonium-238, whole water (pCi/L as Pu)	--	--	--	--	105	72	--	--	--	--	--
Plutonium-239+240, whole water (pCi/L as Pu)	--	--	--	--	200	-200	--	--	--	--	--

Table 14. Percent difference for replicate ground-water samples collected near Deer Trail, Colorado, 1999–2003.—Continued

[Percent difference is defined as $(\text{sample value} - \text{replicate value}) / ((\text{sample value} + \text{replicate value}) / 2) \times 100$; for this analysis, all values that were less than the reporting limit were set equal to the reporting limit and estimated values were included; calculations done on unrounded data; --, no data; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L , milligrams per liter; $\mu\text{g}/\text{L}$, micrograms per liter; pCi/L , picocuries per liter]

Parameter	DTX3 10/21/02	D6 01/03/03	DTX6 01/07/03	D6 04/04/03	DTX6 04/03/03	D6 07/10/03	DTX4 07/08/03	DTX8A 10/06/03	Median percent difference	Number of replicate samples
Specific conductance, laboratory ($\mu\text{S}/\text{cm}$)	0.48	0.00	3.40	2.53	0.68	0.86	0.49	0.00	0.41	39
pH, whole water, laboratory (standard units)	1.36	1.24	1.40	0.00	0.00	0.00	1.42	0.00	0	39
Calcium, dissolved (mg/L as Ca)	1.48	0.00	0.00	2.41	0.00	2.01	4.72	0.66	1.46	39
Magnesium, dissolved (mg/L as Mg)	0.99	0.00	0.00	4.44	0.00	11	5.15	1.85	1.84	39
Sodium, dissolved (mg/L as Na)	1.64	4.88	0.00	0.00	0.00	0.91	4.78	0.83	1.11	39
Potassium, dissolved (mg/L as K)	0.55	0.00	0.00	2.04	1.41	14	4.88	3.08	3.97	39
Acid neutralizing capacity, titration to 4.5, laboratory (mg/L as CaCO_3)	15	0.16	0.39	0.31	0.39	0.00	0.00	0.47	0.31	39
Sulfate, dissolved (mg/L as SO_4)	0.20	0.77	0.00	4.35	0.00	3.77	0.00	0.67	0.35	39
Chloride, dissolved (mg/L as Cl)	0.97	0.82	0.00	0.55	6.03	0.25	2.86	1.43	1.44	39
Fluoride, dissolved (mg/L as F)	0.00	0.00	3.52	0.84	0.00	1.80	3.64	2.99	0.23	39
Bromide, dissolved (mg/L as Br)	0.00	0.24	0.00	0.00	2.70	4.45	2.01	0.64	1.29	39
Silica, dissolved (mg/L as SiO_2)	1.10	4.65	0.00	0.00	0.00	0.00	0.96	1.43	1.25	39
Solids, residue on evaporation at 180 degrees Celsius, dissolved (mg/L)	0.00	0.96	0.23	5.13	0.00	0.47	1.62	0.00	0.63	39
Nitrite plus nitrate (mg/L as N)	0.40	0.54	4.15	0.52	1.76	0.00	4.78	0.00	1.04	38
Nitrogen ammonia, dissolved (mg/L as N)	56	13	29	29	0.00	6.21	0.00	2.06	7.84	38
Nitrogen ammonia plus organic, total (mg/L as N)	9.09	93	35	0.00	0.00	61	0.00	6.90	3.64	39
Nitrogen ammonia plus organic, dissolved (mg/L as N)	0.00	0.00	13	6.06	50	14	7.41	0.00	5.96	38
Phosphorus, total (mg/L as P)	0.00	46	0.00	18	25	0.00	0.00	0.00	2.53	39
Phosphorus, dissolved (mg/L as P)	0.00	22	0.00	0.00	0.00	3.08	0.00	0.00	0	38
Aluminum, dissolved ($\mu\text{g}/\text{L}$ as Al)	0.00	0.00	0.00	0.00	0.00	1.80	0.00	6.45	0	39
Antimony, dissolved ($\mu\text{g}/\text{L}$ as Sb)	0.00	31	0.00	0.00	0.00	4.88	0.00	0.00	0	39
Arsenic, dissolved ($\mu\text{g}/\text{L}$ as As)	0.00	11	0.00	0.00	0.00	0.00	0.00	40	0	39
Barium, dissolved ($\mu\text{g}/\text{L}$ as Ba)	0.00	4.28	0.00	5.89	0.50	12	0.00	0.78	0	39
Beryllium, dissolved ($\mu\text{g}/\text{L}$ as Be)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	39
Boron, dissolved ($\mu\text{g}/\text{L}$ as B)	3.77	5.65	3.66	5.70	5.03	16	2.32	0.40	3.66	39
Cadmium, dissolved ($\mu\text{g}/\text{L}$ as Cd)	0.00	0.00	0.00	0.00	0.00	8.70	12	0.00	0	39
Chromium, dissolved ($\mu\text{g}/\text{L}$ as Cr)	0.00	0.00	0.00	0.00	0.00	22	0.00	0.00	0	39
Cobalt, dissolved ($\mu\text{g}/\text{L}$ as Co)	5.94	1.05	17	0.58	0.00	1.62	1.32	0.32	1.62	39
Copper, dissolved ($\mu\text{g}/\text{L}$ as Cu)	7.55	4.28	13	2.05	2.64	7.60	4.32	5.13	4.79	39
Iron, dissolved ($\mu\text{g}/\text{L}$ as Fe)	0.00	0.00	0.00	0.00	100	86	0.00	1.98	0	39
Lead, dissolved ($\mu\text{g}/\text{L}$ as Pb)	0.00	0.00	22	0.00	0.00	0.00	0.00	0.00	0	39
Manganese, dissolved ($\mu\text{g}/\text{L}$ as Mn)	0.00	2.39	62	0.00	0.00	1.14	18	9.13	2.42	39
Mercury, dissolved ($\mu\text{g}/\text{L}$ as Hg)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	39
Molybdenum, dissolved ($\mu\text{g}/\text{L}$ as Mo)	18	8.14	4.30	5.91	1.38	3.80	1.46	0.00	1.46	39
Nickel, dissolved ($\mu\text{g}/\text{L}$ as Ni)	11	3.19	15	2.38	3.72	4.30	1.20	12	10	39
Selenium, dissolved ($\mu\text{g}/\text{L}$ as Se)	12	2.99	42	4.65	60	8.96	9.01	22	8.28	39
Silver, dissolved ($\mu\text{g}/\text{L}$ as Ag)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	39
Strontium, dissolved ($\mu\text{g}/\text{L}$ as Sr)	0.32	0.00	0.00	0.00	1.71	3.99	4.56	1.14	1.21	39
Zinc, dissolved ($\mu\text{g}/\text{L}$ as Zn)	0.00	5.37	2.06	0.44	7.69	5.85	7.41	0.00	4.76	39
Uranium, natural ($\mu\text{g}/\text{L}$ as U)	1.28	1.02	1.38	0.00	0.81	0.62	0.53	5.13	1.27	39
Gross alpha, dissolved (pCi/L)	--	--	--	--	--	--	--	--	19	2
Gross beta, dissolved (pCi/L)	--	--	--	--	--	--	--	--	5.15	2
Plutonium-238, whole water (pCi/L as Pu)	--	--	0.00	--	--	--	--	--	0	9
Plutonium-239+240, whole water (pCi/L as Pu)	--	--	200	--	--	--	--	--	200	9

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Table 15. Statistical comparison of concentrations for selected constituents in ground-water samples collected near Deer Trail, Colorado, 1999–2003, and lowest applicable water-quality standard.

[Units for concentration data are milligrams per liter for nitrate and micrograms per liter for arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc; --, not applicable; <, less than; >, greater than; standard is from Colorado Department of Public Health and Environment (1997a); H, health-based standard; A, agricultural standard; Y, yes; N, no]

Well	Number of samples for statistical comparison	Minimum ground-water value used for statistical comparison ¹	Maximum ground-water value used for statistical comparison ¹	Median ground-water value used for statistical comparison ¹	Colorado standard	Type of regulatory standard	p-value ²	Are concentrations significantly (alpha = 0.05) higher than the lowest regulatory standard?
Nitrate ³								
D6	20	10.7	21.6	15.2	10	H	0.000	Y
D13	18	0.04	0.05	0.05	10	H	>0.40	N
D17	19	0.60	5.70	1.20	10	H	>0.30	N
D25	19	0.58	7.40	2.50	10	H	>0.30	N
D29	20	0.05	0.05	0.05	10	H	>0.30	N
D30	18	0.04	0.06	<0.05	10	H	>0.40	N
DTX1	18	1.13	2.80	1.31	10	H	>0.40	N
DTX10A	20	<0.05	0.06	<0.05	10	H	>0.30	N
DTX2	20	0.05	0.05	<0.05	10	H	>0.30	N
DTX3	20	0.04	16.0	4.20	10	H	>0.25	N
DTX4	13	0.09	6.50	0.33	10	H	>0.50	N
DTX5	19	<0.05	0.75	<0.05	10	H	>0.30	N
DTX6	20	0.17	0.52	0.26	10	H	>0.30	N
DTX8A	20	0.04	0.11	<0.05	10	H	>0.30	N
Arsenic								
D6	20	2.0	9.0	4.0	10	H	>0.30	N
D13	19	1.0	<2.0	<2.0	10	H	>0.30	N
D17	19	<2.0	2.0	<2.0	10	H	>0.30	N
D25	20	1.0	6.0	3.0	10	H	>0.30	N
D29	20	1.0	2.0	<2.0	10	H	>0.30	N
D30	19	1.0	3.0	<2.0	10	H	>0.30	N
DTX1	19	1.0	4.0	<2.0	10	H	>0.30	N
DTX10A	20	1.0	<2.0	<2.0	10	H	>0.30	N
DTX2	20	1.0	2.0	<2.0	10	H	>0.30	N
DTX3	20	<1.3	<2.0	<2.0	10	H	>0.30	N
DTX4	13	1.0	<2.0	<2.0	10	H	>0.50	N
DTX5	19	1.0	2.0	<2.0	10	H	>0.30	N
DTX6	20	0.60	2.0	<2.0	10	H	>0.30	N
DTX8A	20	0.30	<2.0	<2.0	10	H	>0.30	N
Cadmium								
D6	20	0.10	<7.0	0.26	5	H	>0.40	N
D13	19	0.07	<1.0	<1.0	5	H	>0.30	N
D17	19	0.04	<1.0	<1.0	5	H	>0.30	N
D25	20	0.17	<3.0	0.24	5	H	>0.30	N
D29	20	0.04	<2.0	<2.0	5	H	>0.30	N
D30	19	0.04	<2.0	<2.0	5	H	>0.30	N
DTX1	19	0.10	<2.0	0.19	5	H	>0.30	N
DTX10A	20	<2.0	<2.0	<2.0	5	H	>0.30	N
DTX2	20	0.13	<2.0	<2.0	5	H	>0.30	N
DTX3	20	<1.0	1.0	<1.0	5	H	>0.30	N
DTX4	13	0.04	<2.0	<2.0	5	H	>0.50	N
DTX5	19	0.08	<2.0	<2.0	5	H	>0.30	N
DTX6	20	<2.0	<2.0	<2.0	5	H	>0.30	N
DTX8A	20	<1.0	<1.0	<1.0	5	H	>0.30	N

Table 15. Statistical comparison of concentrations for selected constituents in ground-water samples collected near Deer Trail, Colorado, 1999–2003, and lowest applicable water-quality standard.—Continued

[Units for concentration data are milligrams per liter for nitrate and micrograms per liter for arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc; --, not applicable; <, less than; >, greater than; standard is from Colorado Department of Public Health and Environment (1997a); H, health-based standard; A, agricultural standard; Y, yes; N, no]

Well	Number of samples for statistical comparison	Minimum ground-water value used for statistical comparison ¹	Maximum ground-water value used for statistical comparison ¹	Median ground-water value used for statistical comparison ¹	Colorado standard	Type of regulatory standard	p-value ²	Are concentrations significantly (alpha = 0.05) higher than the lowest regulatory standard?
Chromium								
D6	20	2.0	<4.0	<4.0	100	H, A	>0.30	N
D13	19	0.90	2.0	<1.0	100	H, A	>0.30	N
D17	19	<1.0	<1.0	<1.0	100	H, A	>0.30	N
D25	20	<2.4	27.0	<2.4	100	H, A	>0.30	N
D29	20	0.80	18.0	<1.6	100	H, A	>0.30	N
D30	19	0.90	9.50	<4.0	100	H, A	>0.30	N
DTX1	19	1.4	14.5	<1.6	100	H, A	>0.30	N
DTX10A	20	1.0	5.7	<3.2	100	H, A	>0.30	N
DTX2	20	2.1	11.3	<2.4	100	H, A	>0.30	N
DTX3	20	<1.0	1.7	<1.0	100	H, A	>0.30	N
DTX4	13	0.90	11.3	<1.0	100	H, A	>0.50	N
DTX5	19	0.90	8.2	<2.0	100	H, A	>0.30	N
DTX6	20	0.80	10.6	<3.2	100	H, A	>0.30	N
DTX8A	20	<1.0	<1.0	<1.0	100	H, A	>0.30	N
Copper								
D6	20	5.5	103.0	35.9	200	A	>0.30	N
D13	19	1.8	5.7	2.6	200	A	>0.30	N
D17	19	0.40	1.2	0.80	200	A	>0.30	N
D25	20	7.1	28.5	10.6	200	A	>0.30	N
D29	20	6.0	23.0	8.8	200	A	>0.30	N
D30	19	5.0	33.3	11.4	200	A	>0.30	N
DTX1	19	6.0	21.7	8.8	200	A	>0.30	N
DTX10A	20	2.9	19.1	5.95	200	A	>0.30	N
DTX2	20	4.4	23.5	7.9	200	A	>0.30	N
DTX3	20	1.7	6.6	3.6	200	A	>0.30	N
DTX4	13	3.8	12.5	6.3	200	A	>0.50	N
DTX5	19	2.7	16.6	6.6	200	A	>0.30	N
DTX6	20	6.3	27.5	9.4	200	A	>0.30	N
DTX8A	20	1.9	7.2	2.4	200	A	>0.30	N
Lead ⁵								
D6	20	0.25	<7.0	<7.0	50	H	>0.30	N
D13	19	0.13	<1.0	<1.0	50	H	>0.30	N
D17	19	<1.0	<1.0	<1.0	50	H	>0.30	N
D25	20	<3.0	<3.0	<3.0	50	H	>0.30	N
D29	20	0.18	<2.0	<2.0	50	H	>0.30	N
D30	19	<2.0	<2.0	<2.0	50	H	>0.30	N
DTX1	19	<2.0	<2.0	<2.0	50	H	>0.30	N
DTX10A	20	<2.0	<2.0	<2.0	50	H	>0.30	N
DTX2	20	<2.0	<2.0	<2.0	50	H	>0.30	N
DTX3	20	<1.0	<1.0	<1.0	50	H	>0.30	N
DTX4	13	0.13	<2.0	<2.0	50	H	>0.50	N
DTX5	19	0.08	<2.0	<2.0	50	H	>0.30	N
DTX6	20	<2.0	<2.0	<2.0	50	H	>0.30	N
DTX8A	20	0.09	<1.0	<1.0	50	H	>0.30	N

Table 15. Statistical comparison of concentrations for selected constituents in ground-water samples collected near Deer Trail, Colorado, 1999–2003, and lowest applicable water-quality standard.—Continued

[Units for concentration data are milligrams per liter for nitrate and micrograms per liter for arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc; --, not applicable; <, less than; >, greater than; standard is from Colorado Department of Public Health and Environment (1997a); H, health-based standard; A, agricultural standard; Y, yes; N, no]

Well	Number of samples for statistical comparison	Minimum ground-water value used for statistical comparison ¹	Maximum ground-water value used for statistical comparison ¹	Median ground-water value used for statistical comparison ¹	Colorado standard	Type of regulatory standard	p-value ²	Are concentrations significantly (alpha = 0.05) higher than the lowest regulatory standard?
Mercury ⁵								
D6	20	<0.20	<0.20	<0.20	2	H	>0.30	N
D13	19	<0.20	<0.20	<0.20	2	H	>0.30	N
D17	19	<0.20	<0.20	<0.20	2	H	>0.30	N
D25	20	<0.20	<0.20	<0.20	2	H	>0.30	N
D29	20	0.10	<0.20	<0.20	2	H	>0.30	N
D30	19	<0.20	<0.20	<0.20	2	H	>0.30	N
DTX1	19	<0.20	<0.20	<0.20	2	H	>0.30	N
DTX10A	20	<0.20	<0.20	<0.20	2	H	>0.30	N
DTX2	20	<0.20	<0.20	<0.20	2	H	>0.30	N
DTX3	20	<0.20	<0.20	<0.20	2	H	>0.30	N
DTX4	13	<0.20	<0.20	<0.20	2	H	>0.50	N
DTX5	19	<0.20	<0.20	<0.20	2	H	>0.30	N
DTX6	20	<0.20	<0.20	<0.20	2	H	>0.30	N
DTX8A	20	<0.20	<0.20	<0.20	2	H	>0.30	N
Molybdenum ⁶								
D6	20	0.50	6.0	3.5	-- ⁶	--	--	--
D13	19	0.50	1.4	1.0	-- ⁶	--	--	--
D17	19	5.4	6.6	5.9	-- ⁶	--	--	--
D25	20	7.6	14.0	9.8	-- ⁶	--	--	--
D29	20	0.40	3.95	1.0	-- ⁶	--	--	--
D30	19	1.0	3.7	2.8	-- ⁶	--	--	--
DTX1	19	5.0	7.0	5.9	-- ⁶	--	--	--
DTX10A	20	0.50	3.0	1.38	-- ⁶	--	--	--
DTX2	20	1.0	2.75	1.56	-- ⁶	--	--	--
DTX3	20	0.50	0.81	0.55	-- ⁶	--	--	--
DTX4	13	0.50	4.8	1.0	-- ⁶	--	--	--
DTX5	19	0.50	1.2	1.0	-- ⁶	--	--	--
DTX6	20	0.50	1.0	0.73	-- ⁶	--	--	--
DTX8A	20	0.50	2.3	0.56	-- ⁶	--	--	--
Nickel								
D6	20	1.13	30.6	14.9	100	H	>0.30	N
D13	19	<0.60	10.0	3.1	100	H	>0.30	N
D17	19	0.25	2.8	1.1	100	H	>0.30	N
D25	20	<0.60	38.4	15.25	100	H	>0.30	N
D29	20	0.50	25.6	7.9	100	H	>0.30	N
D30	19	<0.20	21.0	10.4	100	H	>0.30	N
DTX1	19	1.67	31.0	15.6	100	H	>0.30	N
DTX10A	20	<0.60	21.5	4.34	100	H	>0.30	N
DTX2	20	<0.60	26.0	13.0	100	H	>0.30	N
DTX3	20	<0.60	9.49	2.6	100	H	>0.30	N
DTX4	13	<1.0	20.4	9.2	100	H	>0.50	N
DTX5	19	<0.60	46.2	8.7	100	H	>0.30	N
DTX6	20	<1.0	40.0	5.5	100	H	>0.30	N
DTX8A	20	<1.0	5.6	2.4	100	H	>0.30	N

Table 15. Statistical comparison of concentrations for selected constituents in ground-water samples collected near Deer Trail, Colorado, 1999–2003, and lowest applicable water-quality standard.—Continued

[Units for concentration data are milligrams per liter for nitrate and micrograms per liter for arsenic, cadmium, chromium, copper, lead, mercury, molybdenum, nickel, selenium, and zinc; --, not applicable; <, less than; >, greater than; standard is from Colorado Department of Public Health and Environment (1997a); H, health-based standard; A, agricultural standard; Y, yes; N, no]

Well	Number of samples for statistical comparison	Minimum ground-water value used for statistical comparison ¹	Maximum ground-water value used for statistical comparison ¹	Median ground-water value used for statistical comparison ¹	Colorado standard	Type of regulatory standard	<i>p</i> -value ²	Are concentrations significantly (alpha = 0.05) higher than the lowest regulatory standard?
Selenium								
D6	20	6.0	42.9	12.5	20	A	>0.25	N
D13	19	<3.0	3.0	<3.0	20	A	>0.30	N
D17	19	5.0	9.0	8.0	20	A	>0.30	N
D25	20	2.0	6.0	<3.0	20	A	>0.30	N
D29	20	1.3	3.0	<3.0	20	A	>0.30	N
D30	19	3.0	5.0	<3.0	20	A	>0.30	N
DTX1	19	2.0	6.0	<3.0	20	A	>0.30	N
DTX10A	20	0.90	3.0	<3.0	20	A	>0.30	N
DTX2	20	1.0	4.0	<3.0	20	A	>0.30	N
DTX3	20	4.0	18.0	14.0	20	A	>0.30	N
DTX4	13	1.0	12.0	2.0	20	A	>0.50	N
DTX5	19	1.0	<3.0	3.0	20	A	>0.30	N
DTX6	20	<3.0	6.0	<3.0	20	A	>0.30	N
DTX8A	20	0.50	4.0	<3.0	20	A	>0.30	N
Zinc								
D6	20	5.0	82.0	32.0	2,000	A	>0.30	N
D13	19	1.0	3.0	2.0	2,000	A	>0.30	N
D17	19	<1.0	2.0	<1.0	2,000	A	>0.30	N
D25	20	5.0	25.0	7.5	2,000	A	>0.30	N
D29	20	6.0	28.0	10.0	2,000	A	>0.30	N
D30	19	4.0	19.0	9.0	2,000	A	>0.30	N
DTX1	19	4.0	<14.0	6.0	2,000	A	>0.30	N
DTX10A	20	<2.0	12.0	5.0	2,000	A	>0.30	N
DTX2	20	4.0	14.0	6.0	2,000	A	>0.30	N
DTX3	20	1.0	5.0	2.0	2,000	A	>0.30	N
DTX4	13	3.0	<11.0	5.0	2,000	A	>0.50	N
DTX5	19	2.0	<14.0	5.0	2,000	A	>0.30	N
DTX6	20	5.0	15.0	6.0	2,000	A	>0.30	N
DTX8A	20	1.0	5.0	2.0	2,000	A	>0.30	N

¹Many of the values used in the statistical comparison were derived from concentrations that are less than the minimum reporting limit and therefore were set equal to the highest minimum reporting limit.

²The *p*-value results from a one-tailed Sign Test (Helsel and Hirsch, 2002), which is used to indicate the level of statistical evidence that selected constituent concentrations are significantly greater than the regulatory standards. A value close to 1.0 indicates less evidence that the median concentration exceeded the standard, whereas a value close to zero indicates much evidence that the median concentration exceeded the standard. The percent confidence of the test can be determined by subtracting the *p*-value from 1 and multiplying by 100.

³Data compared to standard are for nitrite plus nitrate. Results indicate nitrite is a minor component.

⁴Minimum reporting limits for well D6 in three instances were greater than the water-quality standard, so the remaining data were not recensored to the highest minimum reporting limit for the cadmium comparison.

⁵Nearly all data at all sites were less than laboratory minimum reporting limit. Laboratory minimum reporting limit is less than the water-quality standard.

⁶No regulatory standard for molybdenum. The Food and Agricultural Organization of the United Nations recommends a maximum molybdenum concentration of 10 micrograms per liter in irrigation water (Pais and Jones, 1997, p. 31). All molybdenum concentrations in ground water from all wells were less than 10 micrograms per liter except well D25.

Table 16. Statistical evaluation of time-series trend using the Kendall's tau correlation coefficient for selected constituents in ground-water samples collected near Deer Trail, Colorado, 1999–2003.

[Kendall's tau statistic (Helsel and Hirsch, 2002) is used as an indicator of monotonic correlation between concentration and time. Kendall's tau is a number between -1 and +1 where values closer to zero indicate lesser strength of the correlation. These results supersede those reported by Stevens and others (2003) and Yager and others (2004a, 2004b). Estimated and variably censored data were recensored to the highest minimum reporting limit for this evaluation. N, number of samples; NA, not applicable because all data were tied so the test statistic was zero]

Well	N	tau	p-value	Significant trend at alpha = 0.05	Significant trend at alpha = 0.10	Trend direction
Nitrite plus nitrate						
D13	18	-0.020	0.847	No	No	Downward
D17	19	-0.304	0.074	No	Yes	Downward
D25	19	-0.439	0.010	Yes	Yes	Downward
D29	20	0.000	NA	No	No	None (flat)
D30	18	-0.124	0.207	No	No	Downward
D6	20	0.842	0.000	Yes	Yes	Upward
DTX1	18	0.144	0.426	No	No	Upward
DTX10A	20	0.011	0.931	No	No	Upward
DTX2	20	0.000	NA	No	No	None (flat)
DTX3	20	0.063	0.721	No	No	Upward
DTX4	13	0.179	0.426	No	No	Upward
DTX5	19	0.105	0.439	No	No	Upward
DTX6	20	0.011	0.974	No	No	Upward
DTX8A	20	-0.111	0.349	No	No	Downward
Arsenic						
D13	19	0.082	0.235	No	No	Upward
D17	18	0.000	NA	No	No	None (flat)
D25	20	-0.179	0.252	No	No	Downward
D29	20	0.100	0.169	No	No	Upward
D30	19	0.053	0.596	No	No	Upward
D6	20	0.284	0.068	No	No ³	Upward
DTX1	19	0.135	0.315	No	No	Upward
DTX10A	20	0.089	0.165	No	No	Upward
DTX2	20	-0.005	NA	No	No	None (flat)
DTX3	20	-0.100	0.119	No	No	Downward
DTX4	13	0.154	0.142	No	No	Upward
DTX5	19	0.082	0.235	No	No	Upward
DTX6	20	-0.026	0.801	No	No	Downward
DTX8A	20	-0.100	0.559	No	No	Downward
Cadmium						
D13	19	-0.047	0.523	No	No	Downward
D17	19	-0.088	0.354	No	No	Downward
D25	20	-0.495	0.002	No ¹	No ¹	Downward
D29	20	0.032	0.753	No	No	Upward
D30	19	-0.099	0.428	No	No	Downward
D6	20	0.026	0.851	No	No	Upward
DTX1	19	-0.456	0.003	No ¹	No ¹	Downward
DTX10A	20	0.000	NA	No	No	None (flat)
DTX2	20	-0.058	0.386	No	No	Downward
DTX3	20	0.000	NA	No	No	None (flat)
DTX4	13	-0.115	0.432	No	No	Downward
DTX5	19	-0.240	0.048	No ¹	No ¹	Downward
DTX6	20	0.000	NA	No	No	None (flat)
DTX8A	20	0.000	NA	No	No	None (flat)
Chromium						
D13	19	-0.023	0.867	No	No	Downward
D17	19	0.000	NA	No	No	None (flat)
D25	20	-0.279	0.036	Yes ²	Yes ²	Downward
D29	20	-0.195	0.167	No	No	Downward
D30	19	0.000	NA	No	No	None (flat)

Table 16. Statistical evaluation of time-series trend using the Kendall's tau correlation coefficient for selected constituents in ground-water samples collected near Deer Trail, Colorado, 1999–2003.—Continued

[Kendall's tau statistic (Helsel and Hirsch, 2002) is used as an indicator of monotonic correlation between concentration and time. Kendall's tau is a number between -1 and +1 where values closer to zero indicate lesser strength of the correlation. These results supersede those reported by Stevens and others (2003) and Yager and others (2004a, 2004b). Estimated and variably censored data were recensored to the highest minimum reporting limit for this evaluation. N, number of samples; NA, not applicable because all data were tied so the test statistic was zero]

Well	N	tau	p-value	Significant trend at alpha = 0.05	Significant trend at alpha = 0.10	Trend direction
Chromium—Continued						
D6	20	0.100	0.119	No	No	Upward
DTX1	19	-0.105	0.400	No	No	Downward
DTX10A	20	-0.021	0.888	No	No	Downward
DTX2	20	-0.026	0.864	No	No	Downward
DTX3	20	-0.026	0.801	No	No	Downward
DTX4	13	0.000	NA	No	No	None (flat)
DTX5	19	-0.082	0.554	No	No	Downward
DTX6	20	0.137	0.357	No	No	Upward
Copper						
D13	19	0.129	0.460	No	No	Upward
D17	19	-0.386	0.019	No ¹	No ¹	Downward
D25	20	0.337	0.041	Yes	Yes	Upward
D29	20	0.311	0.060	No	Yes	Upward
D30	19	0.251	0.141	No	No	Upward
D6	20	0.211	0.206	No	No	Upward
DTX1	19	0.129	0.462	No	No	Upward
DTX10A	20	0.174	0.299	No	No	Upward
DTX2	20	0.116	0.495	No	No	Upward
DTX3	20	0.247	0.135	No	No	Upward
DTX4	13	0.205	0.360	No	No	Upward
DTX5	19	0.123	0.483	No	No	Upward
DTX6	20	0.095	0.581	No	No	Upward
DTX8A	20	0.011	0.974	No	No	Upward
Lead						
D13	19	-0.070	0.315	No	No	Downward
D17	19	0.000	NA	No	No	None (flat)
D25	20	0.000	NA	No	No	None (flat)
D29	20	-0.047	0.488	No	No	Downward
D30	19	0.000	NA	No	No	None (flat)
D6	20	0.032	0.792	No	No	Upward
DTX1	19	0.000	NA	No	No	None (flat)
DTX10A	20	0.000	NA	No	No	None (flat)
DTX2	20	0.000	NA	No	No	None (flat)
DTX3	20	0.000	NA	No	No	None (flat)
DTX4	13	-0.077	0.504	No	No	Downward
DTX5	19	0.000	NA	No	No	None (flat)
DTX6	20	0.000	NA	No	No	None (flat)
DTX8A	20	-0.079	0.225	No	No	Downward
Mercury						
D13	19	0.000	NA	No	No	None (flat)
D17	19	0.000	NA	No	No	None (flat)
D25	20	0.000	NA	No	No	None (flat)
D29	20	0.089	0.165	No	No	Upward
D30	19	0.000	NA	No	No	None (flat)
D6	20	0.000	NA	No	No	None (flat)
DTX1	19	0.000	NA	No	No	None (flat)
DTX10A	20	0.000	NA	No	No	None (flat)
DTX3	20	0.000	NA	No	No	None (flat)
DTX4	13	0.000	NA	No	No	None (flat)

Table 16. Statistical evaluation of time-series trend using the Kendall's tau correlation coefficient for selected constituents in ground-water samples collected near Deer Trail, Colorado, 1999–2003.—Continued

[Kendall's tau statistic (Helsel and Hirsch, 2002) is used as an indicator of monotonic correlation between concentration and time. Kendall's tau is a number between -1 and +1 where values closer to zero indicate lesser strength of the correlation. These results supersede those reported by Stevens and others (2003) and Yager and others (2004a, 2004b). Estimated and variably censored data were recensored to the highest minimum reporting limit for this evaluation. N, number of samples; NA, not applicable because all data were tied so the test statistic was zero]

Well	N	tau	p-value	Significant trend at alpha = 0.05	Significant trend at alpha = 0.10	Trend direction
Mercury—Continued						
DTX5	19	0.000	NA	No	No	None (flat)
DTX6	20	0.000	NA	No	No	None (flat)
DTX8A	20	0.000	NA	No	No	None (flat)
Molybdenum						
D13	19	0.146	0.346	No	No	Upward
D17	19	-0.292	0.083	No	Yes	Downward
D25	20	-0.300	0.069	No	Yes	Downward
D29	20	-0.158	0.334	No	No	Downward
D30	19	-0.152	0.372	No	No	Downward
D6	20	-0.421	0.009	No ¹	No ¹	Downward
DTX1	19	0.673	0.000	Yes	Yes	Upward
DTX10A	20	-0.411	0.009	Yes	Yes	Downward
DTX2	20	-0.195	0.224	No	No	Downward
DTX3	20	-0.368	0.018	No ¹	No ¹	Downward
DTX4	13	-0.346	0.081	No	No ¹	Downward
DTX5	19	-0.427	0.008	No ¹	No ¹	Downward
DTX6	20	-0.268	0.079	No	No ¹	Downward
DTX8A	20	-0.547	0.001	Yes	Yes	Downward
Nickel						
D13	19	0.006	NA	No	No	None (flat)
D17	19	-0.058	0.753	No	No	Downward
D25	20	-0.084	0.626	No	No	Downward
D29	20	-0.011	0.974	No	No	Downward
D30	19	0.123	0.484	No	No	Upward
D6	20	0.211	0.206	No	No	Upward
DTX1	19	0.099	0.576	No	No	Upward
DTX10A	20	-0.053	0.768	No	No	Downward
DTX2	20	0.111	0.516	No	No	Upward
DTX3	20	0.047	0.795	No	No	Upward
DTX4	13	-0.487	0.024	Yes	Yes	Downward
DTX5	19	-0.117	0.505	No	No	Downward
DTX6	20	0.047	0.792	No	No	Upward
DTX8A	20	0.047	0.792	No	No	Upward
Selenium						
D13	19	0.000	NA	No	No	None (flat)
D17	19	-0.304	0.056	No	Yes	Downward
D25	20	-0.053	0.729	No	No	Downward
D29	20	-0.100	0.119	No	No	Downward
D30	19	0.053	0.596	No	No	Upward
D6	20	0.416	0.011	Yes	Yes	Upward
DTX1	19	-0.029	0.824	No	No	Downward
DTX10A	20	0.084	0.430	No	No	Upward
DTX2	20	0.111	0.349	No	No	Upward
DTX3	20	0.132	0.394	No	No	Upward
DTX4	13	0.474	0.020	Yes	Yes	Upward
DTX5	19	0.246	0.023	No ³	No ³	Upward
DTX6	20	-0.100	0.465	No	No	Downward
DTX8A	20	-0.068	0.451	No	No	Downward

Table 16. Statistical evaluation of time-series trend using the Kendall's tau correlation coefficient for selected constituents in ground-water samples collected near Deer Trail, Colorado, 1999–2003.—Continued

[Kendall's tau statistic (Helsel and Hirsch, 2002) is used as an indicator of monotonic correlation between concentration and time. Kendall's tau is a number between –1 and +1 where values closer to zero indicate lesser strength of the correlation. These results supersede those reported by Stevens and others (2003) and Yager and others (2004a, 2004b). Estimated and variably censored data were recensored to the highest minimum reporting limit for this evaluation. N, number of samples; NA, not applicable because all data were tied so the test statistic was zero]

Well	N	tau	p-value	Significant trend at alpha = 0.05	Significant trend at alpha = 0.10	Trend direction
Zinc						
D13	19	–0.029	0.879	No	No	Downward
D17	19	0.047	0.523	No	No	Upward
D25	20	–0.016	0.948	No	No	Downward
D29	20	–0.147	0.378	No	No	Downward
D30	19	–0.053	0.777	No	No	Downward
D6	20	0.026	0.897	No	No	Upward
DTX1	19	–0.076	0.667	No	No	Downward
DTX10A	20	–0.126	0.449	No	No	Downward
DTX2	20	–0.163	0.320	No	No	Downward
DTX3	20	–0.058	0.731	No	No	Downward
DTX4	13	0.179	0.417	No	No	Upward
DTX5	19	–0.006	NA	No	No	Downward
DTX6	20	–0.084	0.617	No	No	Downward
DTX8A	20	–0.042	0.788	No	No	Downward

¹An apparent trend is caused by the block of less-than values at the beginning of the data set followed by lower values that were greater than the minimum reporting limit. When all the data (both less than and greater than the reporting limit) were recensored to the highest minimum reporting limit, the apparent trend disappears and is no longer significant.

²Trend likely is the result of increased laboratory precision and sensitivity, not changes in ground water.

³An apparent trend is caused by the block of less-than values at the end of the data set preceded by lower values that were greater than the minimum reporting limit. When all the data (both less than and greater than the reporting limit) were recensored to the highest minimum reporting limit, the apparent trend disappears or is no longer significant.

Table 17. Evaluation of variability in chemical data for streambed-sediment samples based on replicate samples collected near Deer Trail, Colorado, 2000–2003.

[Shaded values indicate the measure and value of variability selected to represent that constituent (shown graphically in fig. 19); values less than the reporting level were set equal to the reporting level for this evaluation; calculations done on unrounded data; <, less than; mm, millimeters; μm , micrometers; mg/kg, milligrams per kilogram; g/kg, grams per kilogram; $\mu\text{g/g}$, micrograms per gram; pCi/g, picocuries per gram; --, no replicate sample]

Measure of variability ¹	Information for each sample-replicate pair							Median	Mean
	07/17/2000	07/27/2001	08/17/2001	07/07/2002	08/05/2002	06/01/2003	08/08/2003		
Ammonia plus organic nitrogen in sediment <2 mm, mg/kg as N									
Relative standard deviation	10	6	13	5	70	1	0	6	15
Absolute difference	106	90	144	110	860	10	0	106	189
Percent difference	14	8	19	8	99	2	0	8	21
Phosphorus in sediment <2 mm, mg/kg									
Relative standard deviation	8	13	2	4	124	36	127	13	45
Absolute difference	62	118	14	33	364	2	189	62	112
Percent difference	11	18	2	5	175	51	179	18	63
Organic carbon in sediment <2 mm, g/kg									
Relative standard deviation	9	1	15	1	2	14	15	9	8
Absolute difference	1	0	1	0	0	1	2	1.01	0.82
Percent difference	13	2	21	2	2	20	22	13	12
Arsenic in sediment <63 μm , $\mu\text{g/g}$									
Relative standard deviation	47	1	1	1	0	26	2	1.32	11
Absolute difference	0.5	0.03	0.01	0.12	0	4	0.2	0.12	0.71
Percent difference	67	2	1	2	0	37	3	2	16
Cadmium in sediment <63 μm , $\mu\text{g/g}$									
Relative standard deviation	14	3	31	4	6	27	3	6	12
Absolute difference	0.03	0.01	0.06	0.01	0.01	0.12	0.01	0.01	0.03
Percent difference	19	4	44	5	8	38	5	8	18
Chromium in sediment <63 μm , $\mu\text{g/g}$									
Relative standard deviation	4	1	46	7	0	26	0	4	12
Absolute difference	0.57	0.22	6.79	2.30	0.00	14	0.00	0.57	3.41
Percent difference	5	2	65	10	0	37	0	5	17
Copper in sediment <63 μm , $\mu\text{g/g}$									
Relative standard deviation	14	11	3	4	1	22	5	5	9
Absolute difference	2.31	3.07	0.83	1.00	0.10	6	1.00	1.00	2.04
Percent difference	20	16	5	6	1	32	6	6	12
Lead in sediment <63 μm , $\mu\text{g/g}$									
Relative standard deviation	8	3	0	5	5	28	0	5	7
Absolute difference	1.64	0.80	0.00	1.10	1.00	9	0.00	1.00	1.93
Percent difference	11	4	0	7	7	40	0	7	10
Mercury in sediment <63 μm , $\mu\text{g/g}$									
Relative standard deviation	4	33	15	51	52	67	41	41	38
Absolute difference	0.00	0.01	0.00	0.01	0.01	0.08	0.01	0.01	0.02
Percent difference	6	47	21	72	74	95	58	58	53
Molybdenum in sediment <63 μm , $\mu\text{g/g}$									
Relative standard deviation	3	5	44	19	18	34	16	18	20
Absolute difference	0.01	0.01	0.18	0.08	0.07	0.27	0.09	0.08	0.10
Percent difference	5	7	62	27	25	48	22	25	28
Nickel in sediment <63 μm , $\mu\text{g/g}$									
Relative standard deviation	1	0.39	21	4	0	24	4	4	8
Absolute difference	0.09	0.10	2.92	1.00	0.00	8	1.00	1.00	1.87
Percent difference	1	1	30	6	0	33	6	6	11

Table 17. Evaluation of variability in chemical data for streambed-sediment samples based on replicate samples collected near Deer Trail, Colorado, 2000–2003.—Continued

[Shaded values indicate the measure and value of variability selected to represent that constituent (shown graphically in fig. 19); values less than the reporting level were set equal to the reporting level for this evaluation; calculations done on unrounded data; <, less than; mm, millimeters; μm , micrometers; mg/kg, milligrams per kilogram; g/kg, grams per kilogram; $\mu\text{g/g}$, micrograms per gram; pCi/g, picocuries per gram; --, no replicate sample]

Measure of variability ¹	Information for each sample-replicate pair							Median	Mean
	07/17/2000	07/27/2001	08/17/2001	07/07/2002	08/05/2002	06/01/2003	08/08/2003		
Selenium in sediment <63 μm , $\mu\text{g/g}$									
Relative standard deviation	47	14	0	3	48	30	16	16	23
Absolute difference	0.50	0.05	0.00	0.05	0.30	0.70	0.18	0.18	0.25
Percent difference	67	20	0	4	68	42	23	23	32
Silver in sediment <63 μm , $\mu\text{g/g}$									
Relative standard deviation	--	--	--	29	0	25	0	12	14
Absolute difference	--	--	--	0.14	0.00	0.09	0.00	0.05	0.06
Percent difference	--	--	--	41	0	35	0	18	19
Uranium in sediment <63 μm , $\mu\text{g/g}$									
Relative standard deviation	--	--	--	9	0	43	0	4	13
Absolute difference	--	--	--	0.19	0.00	2	0.00	0.10	0.55
Percent difference	--	--	--	12	0	61	0	6	18
Zinc in sediment <63 μm , $\mu\text{g/g}$									
Relative standard deviation	5	2	8	1	0	23	2	2	6
Absolute difference	4	1.44	6	1.20	0.00	31	2	2	6
Percent difference	8	2	11	2	0	33	3	3	8
Gross alpha activity in sediment <2mm, pCi/g									
Relative standard deviation	34	6	29	--	--	10	--	19	20
Absolute difference	6.50	0.71	3.59	--	--	2.81	--	3	3
Percent difference	48	9	40	--	--	15	--	28	28
Gross beta activity in sediment <2mm, pCi/g									
Relative standard deviation	0.16	4	6	--	--	30	--	5	10
Absolute difference	0.10	0.44	0.81	--	--	10.58	--	0.63	2.98
Percent difference	0.23	6	8	--	--	42	--	7	14

¹Measures of variability (from Terry Schertz, U.S. Geological Survey., written commun., February 10, 1997) were calculated as follows: relative standard deviation = $100((\text{square root } ((C1-C2)^2/2))/((C1+C2)/2))$; absolute difference = $|C1-C2|$; percent difference = $100(|C1-C2|/((C1+C2)/2))$, which is the same as the absolute value of the relative percent difference calculated in Yager and others, 2004b and 2004c, where C1 is the concentration in the regular sample and C2 is the concentration in the replicate sample. Differences in pairs were not normally distributed, so nonparametric measures (absolute difference and percent difference) are the most appropriate measures. Absolute difference is the best measure when differences between pairs are not larger with larger concentrations. Percent difference is the best measure when differences between pairs are larger with larger concentrations. Mean values were selected to represent central tendency because median values did not represent the broad range of concentration differences.

Table 18. Evaluation of difference in chemical data for paired streambed-sediment samples from the biosolids-applied basin and a control basin near Deer Trail, Colorado, 1999–2003.

[Values less than the reporting level were set equal to the reporting level for this evaluation; calculations done on unrounded data; <, less than; mm, millimeters; μm , micrometers; mg/kg, milligrams per kilogram; g/kg, grams per kilogram; $\mu\text{g/g}$, micrograms per gram; pCi/g, picocuries per gram; --, no sample analyzed]

Measure of difference ¹	Information for each basin pair									Median	Mean
	07/17/2000	07/27/2001	08/17/2001	09/01/2001	06/04/2002	07/07/2002	08/05/2002	06/01/2003	08/08/2003		
Ammonia plus organic nitrogen in sediment <2 mm, mg/kg as N											
Relative standard deviation	1.02	17.82	36.21	26.70	52.51	43.95	88.24	34.69	67.58	36	41
Absolute difference	12.00	320.00	583.00	269.00	834.00	716.00	1,460	390.00	970.00	583	617
Percent difference	1.45	25.20	51.21	37.75	74.27	62.15	124.79	49.06	95.57	51	58
Phosphorus in sediment <2 mm, mg/kg											
Relative standard deviation	4.55	15.35	3.76	33.37	18.67	4.19	40.22	92.89	62.85	19	31
Absolute difference	36.00	141.80	31.87	402.29	206.00	36.00	310.00	11.10	320.00	142	166
Percent difference	6.43	21.71	5.31	47.19	26.41	5.93	56.88	131.36	88.89	26	43
Organic carbon in sediment <2 mm, g/kg											
Relative standard deviation	1.55	35.75	39.28	25.06	45.88	40.92	70.15	41.12	25.71	39	36
Absolute difference	0.16	5.65	4.92	2.46	7.03	5.09	13.05	4.10	2.40	5	5
Percent difference	2.19	50.56	55.55	35.45	64.88	57.87	99.20	58.16	36.36	56	51
Arsenic in sediment <63 μm , $\mu\text{g/g}$											
Relative standard deviation	0.00	0.45	4.13	2.34	8.31	6.74	10.29	26.48	7.97	7	7
Absolute difference	0.00	0.01	0.08	0.04	0.73	0.71	0.80	4.10	0.80	0.71	0.81
Percent difference	0.00	0.63	5.84	3.31	11.75	9.54	14.55	37.44	11.27	10	10
Cadmium in sediment <63 μm , $\mu\text{g/g}$											
Relative standard deviation	7.62	9.87	43.89	26.52	29.58	68.60	39.28	20.87	20.20	27	30
Absolute difference	0.01	0.03	0.09	0.06	0.07	0.13	0.10	0.09	0.05	0.07	0.07
Percent difference	10.78	13.95	62.07	37.50	41.83	97.01	55.56	29.51	28.57	38	42
Chromium in sediment <63 μm , $\mu\text{g/g}$											
Relative standard deviation	17.02	6.62	10.78	40.53	0.00	3.70	13.47	21.31	10.48	11	14
Absolute difference	2.19	1.28	2.28	8.12	0.00	1.30	4.00	11.00	4.00	2	4
Percent difference	24.06	9.36	15.24	57.32	0.00	5.23	19.05	30.14	14.81	15	19
Copper in sediment <63 μm , $\mu\text{g/g}$											
Relative standard deviation	10.86	5.07	14.87	27.68	30.27	9.74	29.65	22.33	10.10	15	18
Absolute difference	1.75	1.23	4.23	4.69	6.10	2.10	5.20	6.00	2.00	4	4
Percent difference	15.35	7.17	21.03	39.15	42.81	13.77	41.94	31.58	14.29	21	25
Lead in sediment <63 μm , $\mu\text{g/g}$											
Relative standard deviation	3.57	2.01	9.80	21.64	11.14	3.97	24.96	33.10	12.86	11	14
Absolute difference	0.68	0.50	2.10	4.30	2.60	0.90	6.00	11.00	3.00	2.6	3.5
Percent difference	5.05	2.85	13.86	30.60	15.76	5.61	35.29	46.81	18.18	16	19
Mercury in sediment <63 μm , $\mu\text{g/g}$											
Relative standard deviation	13.64	13.96	9.79	41.04	69.21	62.60	105.31	34.40	53.43	41	45
Absolute difference	0.00	0.00	0.00	0.01	0.02	0.01	0.04	0.02	0.02	0.01	0.01
Percent difference	19.28	19.75	13.85	58.04	97.87	88.52	148.94	48.65	75.56	58	63
Molybdenum in sediment <63 μm , $\mu\text{g/g}$											
Relative standard deviation	7.78	0.00	12.27	93.13	21.22	63.83	6.53	23.34	28.28	21	28
Absolute difference	0.02	0.00	0.04	0.54	0.14	0.20	0.03	0.17	0.15	0.14	0.14
Percent difference	11.01	0.00	17.35	131.71	30.01	90.27	9.23	33.01	40.00	30	40
Nickel in sediment <63 μm , $\mu\text{g/g}$											
Relative standard deviation	13.62	0.00	18.09	16.85	3.63	3.20	10.10	21.06	4.29	10	10
Absolute difference	2.20	0.00	2.55	3.30	0.80	0.80	2.00	7.00	1.00	2	2
Percent difference	19.26	0.00	25.58	23.83	5.13	4.52	14.29	29.79	6.06	14	14

Table 18. Evaluation of difference in chemical data for paired streambed-sediment samples from the biosolids-applied basin and a control basin near Deer Trail, Colorado, 1999–2003.—Continued

[Values less than the reporting level were set equal to the reporting level for this evaluation; calculations done on unrounded data; <, less than; mm, millimeters; μm , micrometers; mg/kg, milligrams per kilogram; g/kg, grams per kilogram; $\mu\text{g/g}$, micrograms per gram; pCi/g, picocuries per gram; --, no sample analyzed]

Measure of difference ¹	Information for each basin pair								Median	Mean	
	07/17/2000	07/27/2001	08/17/2001	09/01/2001	06/04/2002	07/07/2002	08/05/2002	06/01/2003			08/08/2003
Selenium in sediment <63 μm , $\mu\text{g/g}$											
Relative standard deviation	0.00	30.30	15.15	33.67	22.65	1.25	8.18	22.81	25.98	23	18
Absolute difference	0.00	0.12	0.06	0.10	0.24	0.02	0.04	0.50	0.27	0.10	0.15
Percent difference	0.00	42.86	21.43	47.62	32.04	1.77	11.57	32.26	36.73	32	25
Silver in sediment <63 μm , $\mu\text{g/g}$											
Relative standard deviation	--	--	--	--	99.17	70.21	47.14	33.43	18.86	47	54
Absolute difference	--	--	--	--	0.51	0.28	0.10	0.13	0.04	0.13	0.21
Percent difference	--	--	--	--	140.25	99.29	66.67	47.27	26.67	67	76
Uranium in sediment <63 μm , $\mu\text{g/g}$											
Relative standard deviation	--	--	--	--	18.03	2.15	16.64	31.16	9.43	17	15
Absolute difference	--	--	--	--	0.45	0.05	0.40	1.30	0.20	0.40	0.48
Percent difference	--	--	--	--	25.50	3.04	23.53	44.07	13.33	24	22
Zinc in sediment <63 μm , $\mu\text{g/g}$											
Relative standard deviation	5.93	7.99	16.13	25.90	10.63	1.29	21.28	29.14	11.95	12	14
Absolute difference	3.58	6.94	12.65	19.49	9.20	1.30	17.00	41.00	12.00	12	14
Percent difference	8.39	11.30	22.82	36.62	15.03	1.83	30.09	41.21	16.90	17	20
Gross alpha activity in sediment <2mm, pCi/g											
Relative standard deviation	4.34	14.95	8.11	--	14.01	--	--	17.34	--	14	12
Absolute difference	0.62	1.97	1.16	--	2.20	--	--	4.47	--	1.97	2.08
Percent difference	6.14	21.15	11.46	--	19.82	--	--	24.53	--	20	17
Gross beta activity in sediment <2mm, pCi/g											
Relative standard deviation	0.16	18.06	3.59	--	14.73	--	--	13.86	--	14	10
Absolute difference	0.10	2.17	0.51	--	3.00	--	--	5.40	--	2.17	2.24
Percent difference	0.23	25.54	5.08	--	20.83	--	--	19.61	--	20	14

¹Measures of difference (from Terry Schertz, U.S. Geological Survey., written commun., February 10, 1997) were calculated as follows: relative standard deviation = $100((\text{square root } ((C1-C2)^2/2))/((C1+C2)/2))$; absolute difference = $|C1-C2|$; percent difference = $100(|C1-C2|/((C1+C2)/2))$, which is the same as the absolute value of the relative percent difference calculated in Yager and others, 2004b and 2004c, where C1 is the concentration in the biosolids-applied-basin sample and C2 is the concentration in the control-basin sample. Differences in pairs generally were not normally distributed, so nonparametric measures (absolute difference and percent difference) are the most appropriate measures. Absolute difference is the best measure when differences between pairs are not larger with larger concentrations. Percent difference is the best measure when differences between pairs are larger with larger concentrations.