

Prepared in cooperation with the Metro Wastewater Reclamation District

Water Quality at a Biosolids-Application Area near Deer Trail, Colorado, 1993–1999



Scientific Investigations Report 2013–5074

Cover. U.S. Geological Survey monitoring well D30 and surface-water grab-sample location S4 on October 3, 1996.

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By Tracy J.B. Yager

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U.S. Department of the Interior
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Contents

Abstract.....	1
Introduction.....	1
Purpose and Scope	6
Description of Study Area	6
Approach.....	11
Site Selection.....	15
Data-Collection Methods	16
Field Methods Used to Collect Data for Physical Properties and Inorganic Chemical Constituents.....	16
Field Methods Used to Sample for Bacteriological Constituents.....	18
Field Methods Used to Sample for Other Constituents	18
Analytical Methods.....	18
Quality-Assurance Methods	19
Water Quality.....	22
Baseline Water Quality	43
Variability in Water Quality.....	43
Spatial Variability	45
Temporal Variability.....	49
Comparison with Regulatory Standards	52
Effects on Water Quality.....	57
Geological Effects.....	57
Meteorological Effects	66
Microbiological Effects.....	67
Flow-Path Effects.....	69
Biosolids Effects.....	71
Comparison with Baseline Data	71
Comparison with Data from a Control Site	74
Comparison of Temporal Patterns.....	75
Other Indicators	79
Summary.....	80
Acknowledgments	83
References Cited.....	83
Appendix 1. Information for U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1993 through 1998.....	88
Appendix 2. Chemical symbols and abbreviations used in reporting chemical data in the appendixes.....	90
Appendix 3. Physical properties and major-ion data for replicate water-quality samples collected near Deer Trail, Colorado, 1993 through 1998	91
Appendix 4. Nutrient data for replicate water-quality samples collected near Deer Trail, Colorado, 1993 through 1998	93
Appendix 5. Trace-element data for replicate water-quality samples collected near Deer Trail, Colorado, 1993 through 1998	95
Appendix 6. Codes used in reporting information and chemical data (appendix 7) for blank water-quality samples collected near Deer Trail, Colorado, 1993 through 1999.....	97

Appendix 7. Information and chemical data for blank water-quality samples collected near Deer Trail, Colorado, 1993 through 1999	99
Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).....	103
Appendix 9. Geochemical modeling results for well D6 using NETPATH for groundwater samples collected near Deer Trail, Colorado, 1993 to 1999.....	122

Figures

1. Map showing location of the study area near Deer Trail, Colorado	2
2. Map showing study area and U.S. Geological Survey sampling sites on original (1993–1995) Metro Wastewater Reclamation District property near Deer Trail, Colorado, 1993 through 1999	3
3. Map showing location of U.S. Geological Survey Expanded Monitoring Program sites near Deer Trail, Colorado, 1999.....	5
4. Photograph showing biosolids after application to a field near Deer Trail, Colorado	6
5. Map showing Metro Wastewater Reclamation District biosolids-application areas near Deer Trail, Colorado	7
6. Map showing drainage basins in the study area	10
7. Schematic diagram showing summary of the U.S. Geological Survey sampling method used to collect groundwater-quality samples near Deer Trail, Colorado, late 1995 through 1999.....	17
8. Map showing baseline water quality for selected constituents in groundwater and surface-water samples collected in 1993 at the Metro Wastewater Reclamation District property.....	44
9. Trilinear diagrams showing water type for (A) drainage basin, (B) site type, (C) well depth, and (D) water-composition groupings near Deer Trail, Colorado, based on median data for 1993–1998	46
10. Map showing groundwater major-ion water-composition groups (figure 9D) overlaying the geologic map presented by Sharps (1980)	48
11. Graphs showing water-quality data for selected dissolved constituents compared with sample depth and (for groundwater samples) depth to groundwater near Deer Trail, Colorado, 1993–1998.....	50
12. Graphs showing groundwater concentrations of nitrite plus nitrate as nitrogen over time at monitoring wells near Deer Trail, Colorado, 1993 through 1998.....	51
13. Graphs showing distribution of groundwater-concentration data for samples collected near Deer Trail, Colorado, compared to regulatory standards for selected constituents, 1993 through 1999.....	54
14. Graphs showing ion plots showing milliequivalent ratios for (A) gypsum, (B) calcite, (C) dolomite, (D) halite, and (E) epsomite (or another magnesium-sulfate mineral) from samples collected from selected monitoring wells near Deer Trail, Colorado, 1993 through 1998.....	62
15. Graphs showing comparison of baseline, post-biosolids, and control-site groundwater-quality data for selected constituents in samples from all monitoring wells near Deer Trail, Colorado, 1993 through 1998.....	72
16. Graphs showing comparison of selected water-quality constituents with biosolids-application data for selected sites near Deer Trail, Colorado, 1993 through 1998.....	76

Tables

1. Biosolids applications to the study area near Deer Trail, Colorado, 1993 through 1999.....	8
2. U.S. Geological Survey sampling sites near Deer Trail, Colorado, 1993 through 1999.....	12
3. Laboratory methods used by the Metro Wastewater Reclamation District Laboratory for analyses of water samples	19
4. Laboratory methods used by the U.S. Geological Survey National Water Quality Laboratory, 1994 through 1999.....	20
5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998	24
6. Bacteria data for water-quality samples collected near Deer Trail, Colorado, 1993 through 1998.....	40
7. Water-quality data for redox-indicator sampling near Deer Trail, Colorado, July 1999.....	42
8. Summary of groundwater-quality data collected for this study near Deer Trail, Colorado, during 1993–1999, and groundwater regulatory limits	53
9. Chemical data for core samples collected from D31 and D33 boreholes during drilling near Deer Trail, Colorado, May 1995	58
10. Concentrations of redox-sensitive constituents and terminal electron-acceptor processes for groundwater from selected wells near Deer Trail, Colorado, July 1999.....	60
11. Groundwater information indicated by dissolved-gas sampling at selected wells near Deer Trail, Colorado, 1998.....	67
12. Groundwater information indicated by chlorofluorocarbon sampling at selected wells near Deer Trail, Colorado, 1998.....	68

Conversion Factors, Abbreviations, and Datums

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
inch	2.54	centimeter (cm)
kilometer (km)	0.6214	mile (mi)
micrometer (micron)	0.00003937	inch (in.)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.004047	square kilometer (km ²)
section (640 acres or 1 square mile)	259.0	square hectometer (hm ²)
square mile (mi ²)	2.590	square kilometer (km ²)
	Volume	
gallon (gal)	3.785	liter (L)
liter (L)	0.2642	gallon (gal)
milliliter (mL)	0.002113	pint (pt)
	Mass	
milligram (mg)	35.27	ounce, avoirdupois (oz)
pound, avoirdupois (lb)	0.4536	kilogram (kg)
ton, short (2,000 lb)	0.9072	megagram (Mg)
ton, long (2,240 lb)	1.016	megagram (Mg)
	Application	
pound per acre (lb/acre)	1.121	kilogram per hectare

Temperature in degrees Celsius ($^{\circ}\text{C}$) may be converted to degrees Fahrenheit ($^{\circ}\text{F}$) as follows:

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

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29) or North American Vertical Datum of 1988 (NAVD 88), as noted.

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

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

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius ($\mu\text{S}/\text{cm}$).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L), micrograms per liter ($\mu\text{g}/\text{L}$), or milliequivalents per liter (meq/L); parts per million (PPM) is equivalent to milligrams per liter, and parts per billion (PPB) is equivalent to micrograms per liter.

Concentrations of chemical constituents in gas are given either in milligrams per liter (mg/L), or nanomoles per liter (nmol/L).

Concentrations of chemical constituents in solids are given in parts per million (PPM), which is equivalent to milligrams per kilogram (mg/kg) or micrograms per gram ($\mu\text{g}/\text{g}$), or in percent composition by mass (%).

Additional Abbreviations

Metro District	Metro Wastewater Reclamation District
NWQL	National Water Quality Laboratory
USGS	U.S. Geological Survey
CFC	Chlorofluorocarbons
MRL	Minimum reporting level
TEAP	Terminal electron-acceptor process

Water Quality at a Biosolids-Application Area near Deer Trail, Colorado, 1993–1999

By Tracy J.B. Yager

Abstract

The Metro Wastewater Reclamation District (Metro District) in Denver, Colo., applied biosolids resulting from municipal sewage treatment to farmland in eastern Colorado beginning in December 1993. In mid-1993, the U.S. Geological Survey in cooperation with the Metro District began monitoring water quality at the biosolids-application area about 10 miles east of Deer Trail, Colo., to evaluate baseline water quality and the combined effects of natural processes, land uses, and biosolids applications on water quality of the biosolids-application area. Water quality was characterized by baseline and post-biosolids-application sampling for selected inorganic and bacteriological constituents during 1993 through 1998, with some additional specialized sampling in 1999. The study included limited sampling of surface water and the unsaturated zone, but primarily focused on groundwater.

The baseline data indicate that major-ion, nutrient, trace-element, and bacteria sources other than biosolids were present in the study area and that water in the study area was of variable quality before biosolids ever were applied. Large concentrations of chloride, sulfate, nitrate, iron, and manganese were detected in some baseline samples. Concentrations of other major ions, phosphorus, cadmium, chromium, nickel, and fecal streptococcus bacteria also were detected above the minimum reporting level in baseline samples.

Variability in water quality of the study area was evident from the baseline data as well as from the data collected after biosolids applications began. The hydrology of the study area likely accounts for some of the variability in water quality; groundwater recharged preferentially from ponds and through desiccation cracks and coarse-grained deposits and outcrops, not uniformly through the unsaturated zone beneath all fields. Spatial variability was largest for concentrations of sulfate, nitrate, iron, and manganese. Soil pore-water data indicated that chloride, nitrate, and copper reservoirs in the upper 3 feet of the unsaturated zone could eventually migrate to the saturated zone. Temporal variability was largest for concentrations of nitrate, iron, and manganese and fecal streptococcus bacteria counts. Of the limited analytes considered for this study, nitrate increased in concentration the most consistently over time.

Groundwater samples from the study area exceeded various Colorado regulatory standards, both in baseline samples and in post-biosolids-treatment samples. Concentrations of constituents in the groundwater exceeded Colorado standards for nitrate, chromium, iron, manganese, and nickel concentrations. Baseline groundwater concentrations of chloride, sulfate, nitrate, iron, and manganese in samples from some sites exceeded Colorado regulatory standards before biosolids applications to the study area began, sometimes by a large margin.

In general, biosolids applications may have affected water quality in parts of the study area during 1993–1998 through increases in nitrate and possibly a few other constituents, particularly where groundwater was oxic. However, increased nitrate concentrations were not widespread throughout the study area during the 1–5 years after biosolids applications began. Microbial processes in oxygen-depleted shallow groundwater have kept nitrate concentrations small and could reduce additional nitrogen inputs to the groundwater. For most water-quality constituents, any effects from biosolids on water quality of the study area during 1993–1998 were obscured by high variation in concentrations, and the effects of biosolids applications on water quality of the study area during 1993–1999 were less than natural geological or microbiological effects.

Introduction

Municipal sewage from the Denver area was treated at the Metro Wastewater Reclamation District (Metro District) in Denver, Colo. (fig. 1). Biosolids are solid organic matter recovered from a sewage-treatment process that met State and Federal regulatory criteria for a beneficial use such as soil amendment or fertilizer (Colorado Department of Public Health and Environment, 1998). In 1993, the Metro District acquired farmland and rangeland (about 15 square miles, mi²; fig. 2) on the eastern plains of Colorado in Arapahoe and Elbert Counties about 10 miles (mi) east of Deer Trail, Colo. (fig. 1). During December 1993 through 1999 (1993–1999), the Metro District applied biosolids as a fertilizer and soil amendment to their farmland property near Deer Trail. The biosolids were trucked about 75 mi east from Denver to the Metro District property (fig. 1) and were applied to

2 Water Quality at a Biosolids-Application Area near Deer Trail, Colorado, 1993–1999

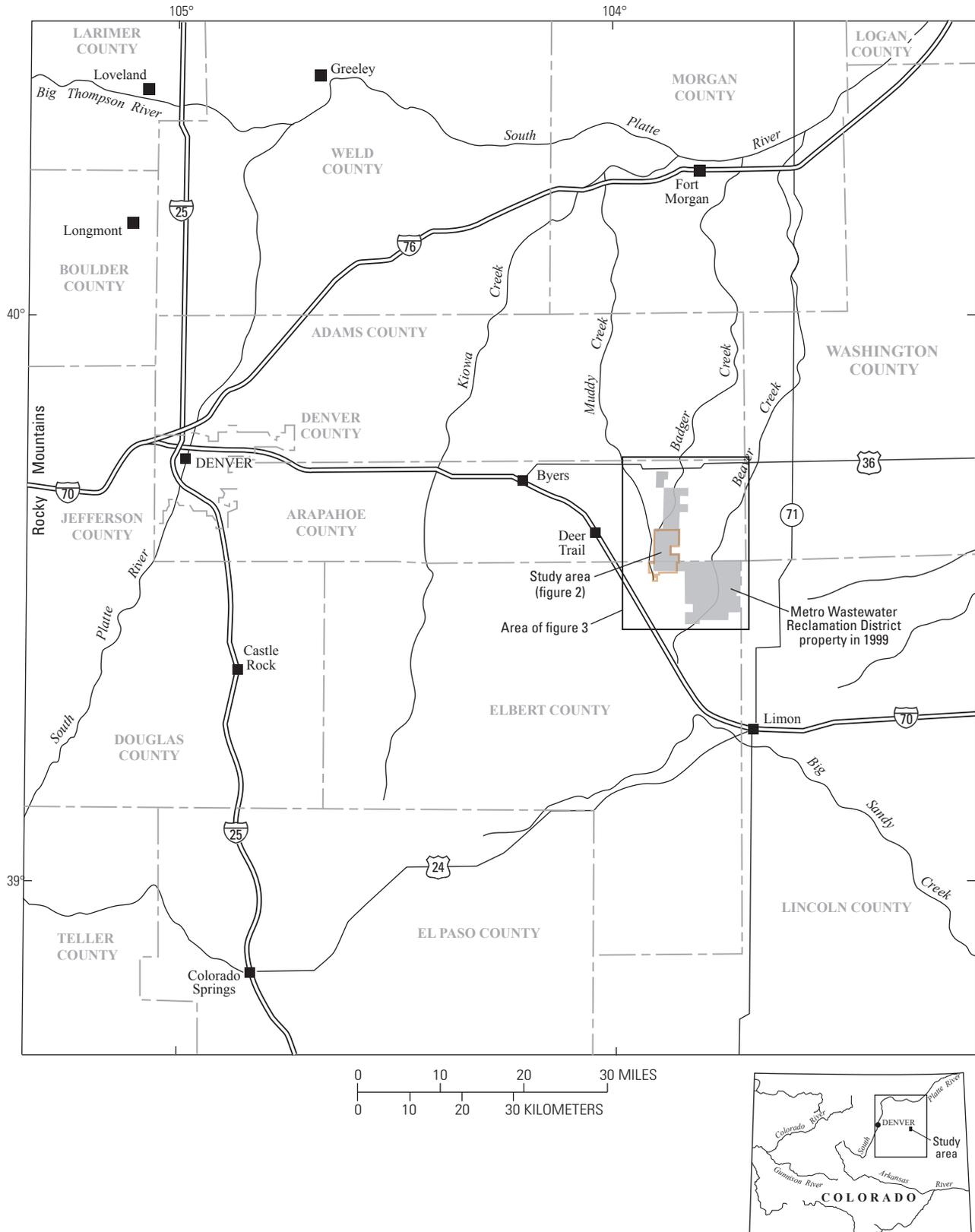


Figure 1. Location of the study area near Deer Trail, Colorado.

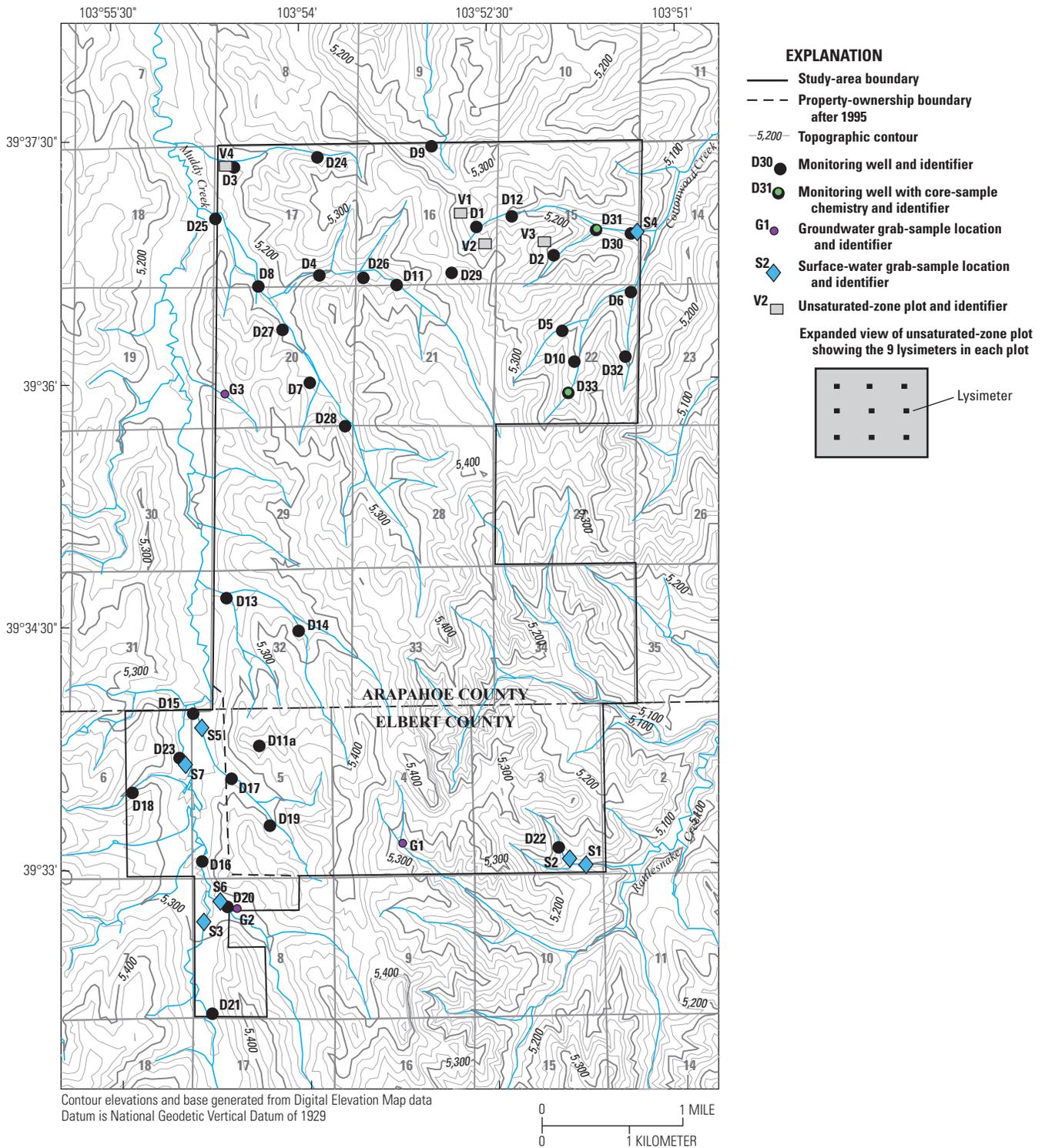


Figure 2. Study area and U.S. Geological Survey sampling sites on original (1993–1995) Metro Wastewater Reclamation District property near Deer Trail, Colorado (now part of the Central property), 1993 through 1999.

4 Water Quality at a Biosolids-Application Area near Deer Trail, Colorado, 1993–1999

nonirrigated farmland. In 1995, the Metro District traded some of the first property and acquired additional property in the same area. The revised boundaries of the original property became known as the Metro District Central property (fig. 3). The additional properties consisted of about 14.5 mi² known as the North property and about 50 mi² known as the South property (fig. 3). In 1999, the three Metro District properties together (North, South, and Central), known as the METROGRO Farm, encompassed almost 70 mi² of farmland in Arapahoe and Elbert Counties (fig. 3). The Metro District properties continued to be farmed after the applications of biosolids began.

Animal waste related to grazing wildlife and domestic livestock, as well as farming applications of pesticides and fertilizers (including biosolids), can affect the quality of water in the unsaturated zone, ponds or streams, and alluvial and bedrock aquifers (Freeze and Cherry, 1979). 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 shallow groundwater 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.

Past studies indicated that various land-disposal methods for human sewage products can increase concentrations of inorganic and organic constituents in water at the disposal site (Berti and Jacobs, 1996 and 1998; Eljarrat and others, 1997; Moolenaar and Beltrami, 1998; Sloan and others, 1998; Steenhuis and others, 1999). Robson (1977), Gaggiani (1991), Johncox and Gaggiani (1991), Tindall and others (1994), and Lull and Gaggiani (1996) all reported increased concentrations of selected inorganic constituents in groundwater or surface water at sewage-disposal sites in Colorado. However, biosolids applications differ from pit disposal of other sewage products because biosolids must meet additional regulatory criteria and application rates based on growing vegetation that is planned to assimilate nitrogen, phosphorus, and trace elements as plant nutrients.

Biosolids applications to the study area began in late 1993 and continue in all but the southwest part of the study area through the present (October 1, 2012). Metro District staff transported and applied the biosolids, and only biosolids from the Metro District treatment plant were applied to the study area. Biosolids were applied according to agronomic loading rates through a process permitted by the State of Colorado. The agronomic loading rates resulted in biosolids lightly broadcast on the fields, not thickly laid (fig. 4). Metro District biosolids-application areas in the vicinity of the study area are shown in figure 5. Detailed information about each biosolids application to these areas during 1993–1999 is listed in table 1. Land-applied biosolids had to meet regulations (Colorado Department of Public Health and Environment, 1998; U.S. Environmental Protection Agency, 1993); otherwise, agronomic loading rates might be exceeded and the area could become overloaded with

nitrogen and 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 other constituents.

Water quality at a biosolids-application site may not represent effects from biosolids just because biosolids were present at that site. Many of the chemical constituents used as indicators of biosolids contamination (such as trace elements) also could be contributed by geologic materials (Drever, 1988). Other water-quality constituents (such as nutrients and organic compounds) attributed to biosolids also could be contributed by other farming practices (Freeze and Cherry, 1979) or by livestock grazed on the property. Water quality is not just the result of chemicals added to the land surface but also is affected by dissolution, precipitation, reaction, and transport of natural and anthropogenic chemical constituents along the surface and in the subsurface, depending on the flow path of the water. Water quality can be affected by the hydrology, weather, and geology of a site. The chemical constituents of the geologic materials interact in the presence of water through a variety of natural processes. The chemistry of water in the unsaturated zone, ponds, streams, and aquifers at a biosolids-application site will be determined by complicated geochemical reactions affected by geology, hydrology, microbiology, land use, and anthropogenic applications. Thus, an interpretation of the contribution of biosolids to water quality requires an understanding of the geology, hydrology, land-use activities, and baseline water quality of the site.

In mid-1993, the U.S. Geological Survey (USGS) in cooperation with the Metro District began monitoring hydrology and water quality on the Metro District property near Deer Trail. This study was done to evaluate baseline water quality and the combined effects of natural processes, land uses, and biosolids applications on water quality of the biosolids-application area. The study area consisted of the 1993 Metro District property (fig. 2). Hydrology was monitored from 1993 through 1998 (1993–1998) by measuring groundwater levels and precipitation. Water quality was monitored from 1993–1998 by sampling for selected inorganic and bacteriological constituents, with some additional specialized sampling in 1999. The study included limited sampling of surface water and the unsaturated zone, but primarily focused on the sampling of groundwater, which was more abundant. In 1999, the USGS also began the Expanded Monitoring Program at the same location (conducted during 1999–2004), in cooperation with the Metro District and the North Kiowa Bijou Groundwater Management District, that built on the earlier USGS monitoring program but included all three Metro District properties (fig. 3) and expanded monitoring components. As part of the Expanded Monitoring Program, water-quality data were collected, the geology of the area was evaluated to identify aquifer materials, and hydrogeologic structure maps were prepared. The results of monitoring hydrology in the study area during 1993–1998 were reported by Yager and Arnold (2003), along with geologic information and hydrogeologic structure maps for the Expanded Monitoring Program (the area shown in fig. 3).

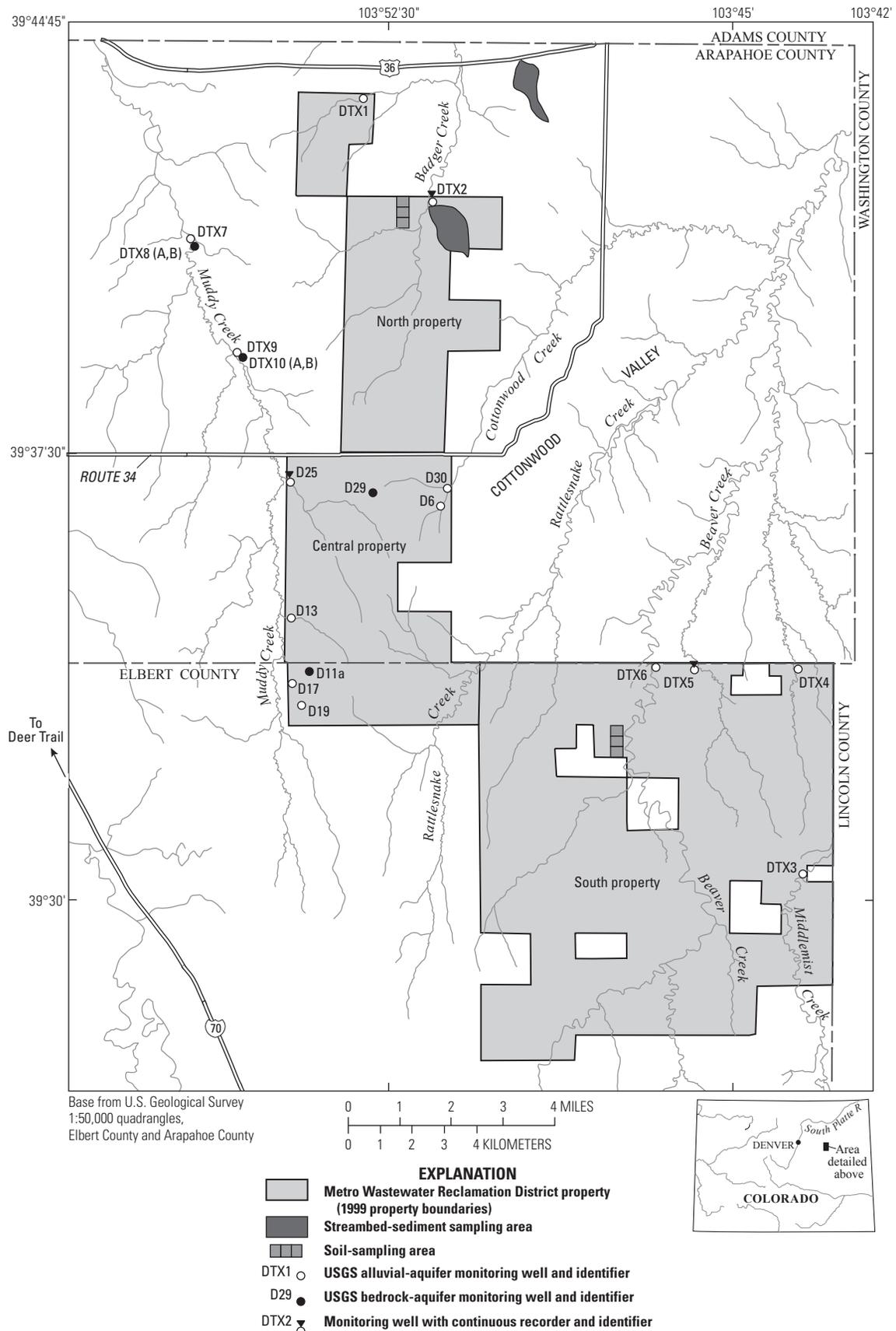


Figure 3. Location of U.S. Geological Survey Expanded Monitoring Program sites near Deer Trail, Colorado, 1999. [Base from U.S. Geological Survey, 1976; U.S. Geological Survey, 1980a]



Figure 4. Biosolids (dark clumps) after application to a field near Deer Trail, Colorado. Photograph by U.S. Geological Survey.

Purpose and Scope

The purpose of this report is to present the results of water-quality monitoring done by the USGS near Deer Trail, Colo., during 1993–1999 as part of the first USGS study related to biosolids applications in that area. The report includes water-quality data for alluvial and bedrock groundwater in addition to limited data for surface water and the unsaturated zone. Chemical data for core samples from two boreholes in the study area also are included. The focus of the report is an interpretive discussion of water quality for the study area. The report does not include the data and interpretations for 1999 from the Expanded Monitoring Program; these results were reported by Stevens and others (2003) and Yager and others (2004b).

The report includes additional, related information in various appendixes. Detailed monitoring-well information such as well-completion data are listed in appendix 1. Chemical symbols and abbreviations used in reporting quality-control data are listed in appendix 2. Quality-control data for the water-quality samples collected during 1993–1999 are listed in appendixes 3 through 8. The results of geochemical modeling done for groundwater quality at one well are included as appendix 9.

Description of Study Area

The study area (described in more detail in Yager and Arnold, 2003; Yager and others, 2004b) was located on the eastern plains of Colorado about 10 mi east of Deer Trail (fig. 1). The study area was on the eastern margin of the Denver Basin, a bowl-shaped sequence of sedimentary rocks that was formed in an ocean or near-ocean environment. The surficial 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 primary water-supply aquifer in the study area during 1993–1999 was the Laramie-Fox Hills aquifer, which is a bedrock aquifer that ranged from 0 to about 200 feet (ft) in thickness in the study area and is the bottom aquifer in the Denver Basin aquifer sequence (Robson, 1981; Robson and Banta, 1995; Yager and Arnold, 2003). Multiple alluvial aquifers were present in the study area during 1993–1999. Depth to groundwater below land surface at sampling locations ranged from a few feet to about 100 ft. The alluvial aquifers were associated with the surficial drainage network and contained water of variable quality, were of limited extent, and generally yielded little water (Stevens and others, 2003; Yager and Arnold, 2003). Parts of four drainage basins comprise the study area: Badger Creek, Cottonwood Creek, Rattlesnake Creek, and Muddy Creek (fig. 6); the Cottonwood Creek and Rattlesnake Creek drainage basins are part of the Beaver Creek drainage basin (Seaber and others, 1987). The entire study area is within the South Platte River drainage basin; all streams in this area drain northward to the South Platte River (fig. 1; Yager and Arnold, 2003). Short segments of some of the streams were intermittent, but in general, the streams during 1993–1999 were ephemeral and flowed only after storms. No surface water flowed off the Metro District properties except after storms. Surface water predominantly was in the form of ponds. Most ponds in the area were created by water-detention structures. The climate was semi-arid; less than 20 inches of precipitation usually was received each year (Yager and Arnold, 2003). Most of the precipitation occurred as rainfall in spring and in late summer. Soils in the area generally were 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).

Land use in the study area historically was rangeland or cropland and pasture (U.S. Geological Survey, 1980b). Some petroleum exploration was done in the area (Drew and others, 1979), but no oil or gas production took place on the Metro District properties during 1993–1999 (N. Crews, Metro Wastewater Reclamation District, written commun., April 13, 2011). Land in the study area was used as rangeland or cropland during 1993–1999. Cattle and sheep were the primary domesticated animals grazing the area, although no concentrated animal-feeding operations were located on the Metro District properties during 1993–1999. Winter wheat was the primary crop during 1993–1999; farmland was not irrigated. Herbicides and other chemicals were applied to the study area for farming and weed-control purposes (B. Patterson, Metro Wastewater Reclamation District, written commun., December 6, 1999). Pesticides and other fertilizers also may have been applied to the Metro District properties historically, but little information was available about these historical applications. Biosolids were applied as the only fertilizer and soil amendment on the Metro District properties during the study.

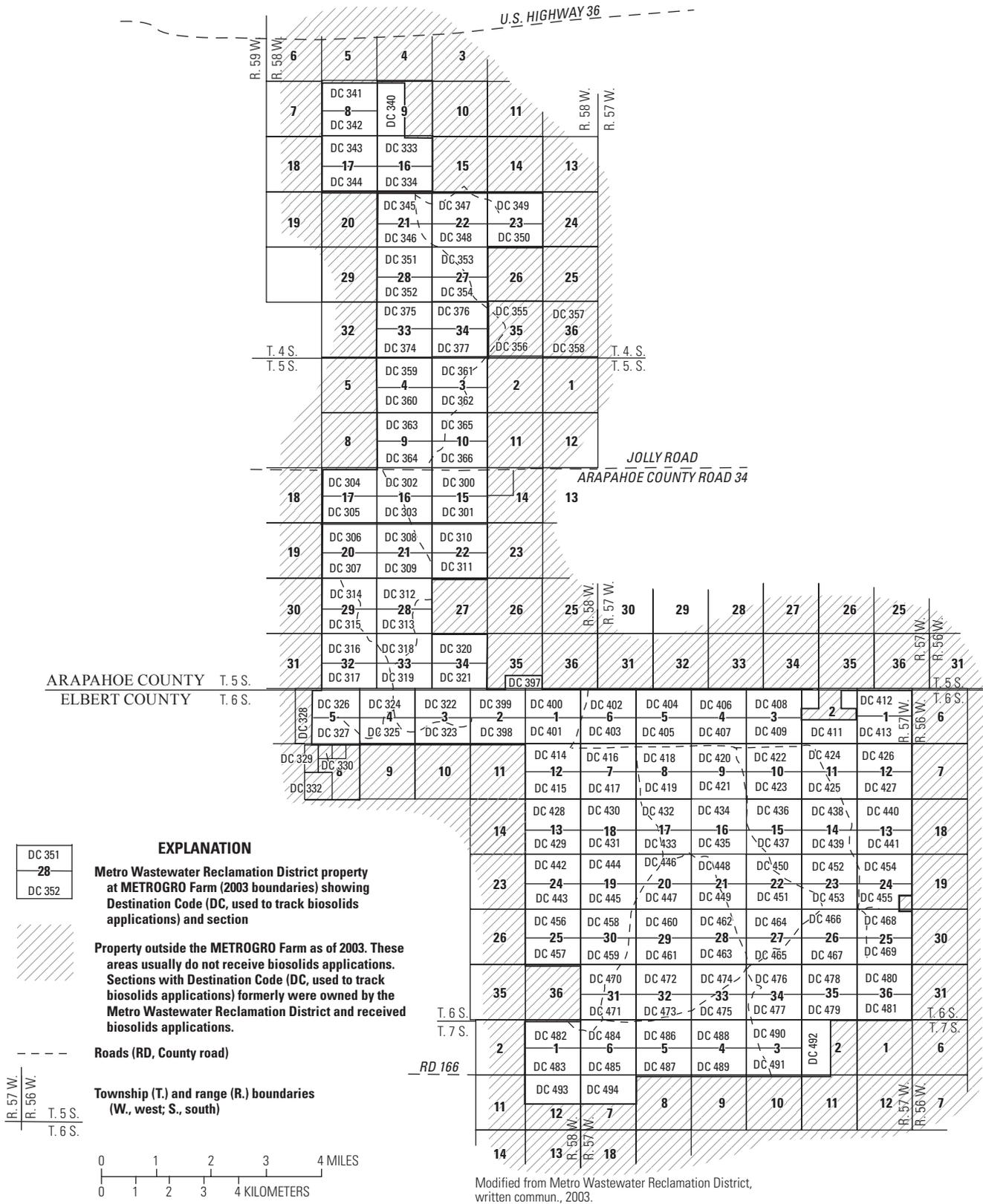


Figure 5. Metro Wastewater Reclamation District biosolids-application areas near Deer Trail, Colorado.

Table 1. Biosolids applications to the study area near Deer Trail, Colorado, 1993 through 1999.

[All information provided by the Metro Wastewater Reclamation District; DC, destination code; wT, wet tons; dT, dry tons; Cake, Table 3 Class B biosolids; --, no information available; lb, pound; MAC, biosolids amended with wood fiber; incorporated, biosolids are pushed down into the soil 4 to 8 inches after application by the tines of a rotating implement pulled by a tractor]

DC (fig. 5)	Application start date	Application stop date	Area applied, acre	Product applied	Application method	Number of loads applied	Total biosolids applied, wT	Total biosolids applied, dT	Biosolids loading rate, dT/acre	Nitrogen loading rate, lb/acre	Crop	Reclamation project ¹
301	12/8/1993	6/8/1994	286.2	Cake	--	208	4,586	787	2.75	74	Wheat	--
302	12/8/1993	7/18/1994	301.6	Cake	--	242	5,329	886	2.94	75	Wheat	--
303	12/8/1993	8/2/1994	301.6	Cake	--	207	4,615	796	2.64	70	Wheat	--
309	3/4/1994	3/14/1994	320.0	Cake	--	202	4,503	782	2.44	66	Wheat	--
311	3/15/1994	4/19/1994	320.0	Cake	--	170	3,783	651	2.03	48	Wheat	--
310	4/20/1994	5/7/1994	299.1	Cake	--	221	4,880	854	2.86	69	Wheat	--
308	5/7/1994	5/27/1994	314.0	Cake	--	240	5,438	953	3.04	73	Wheat	--
300	6/12/1994	6/24/1994	286.2	Cake	--	206	4,708	827	2.89	75	Wheat	--
304	7/3/1994	7/18/1994	267.4	Cake	--	172	3,814	650	2.43	64	Wheat	--
305	7/19/1994	7/27/1994	225.7	Cake	--	168	3,746	627	2.78	62	Wheat	--
306	8/6/1994	8/13/1994	180.0	Cake	--	114	2,527	423	2.35	53	Wheat	--
306	8/6/1994	5/10/1995	232.0	Cake	--	153	3,390	572	2.47	57	Wheat	--
307	8/12/1994	8/13/1994	60.0	Cake	--	32	707	122	2.03	46	Wheat	--
307	8/12/1994	5/31/1995	250.0	Cake	--	134	3,041	527	2.11	53	Wheat	--
312	8/14/1994	4/8/1995	305.0	Cake	--	180	3,995	650	2.13	55	Wheat	--
323	10/4/1994	10/9/1994	140.0	Cake	--	110	2,444	404	2.89	72	Wheat	--
322	10/10/1994	10/22/1994	245.0	Cake	--	159	3,565	594	2.42	58	Wheat	--
313	11/4/1994	4/6/1995	280.0	Cake	--	232	5,113	807	2.88	77	Wheat	--
318	4/8/1995	6/29/1995	300.0	Cake	--	246	5,478	887	2.96	82	Wheat	--
319	4/14/1995	4/30/1995	180.0	Cake	--	135	3,044	495	2.75	79	Wheat	--
324	5/1/1995	5/6/1995	135.0	Cake	--	108	2,459	393	2.91	76	Wheat	--
325	5/6/1995	5/20/1995	180.0	Cake	--	132	3,026	526	2.92	84	Wheat	--
315	5/23/1995	5/26/1995	95.0	Cake	--	75	1,504	261	2.75	64	Wheat	--
314	5/27/1995	5/30/1995	95.0	Cake	--	69	1,583	265	2.79	72	Wheat	--
316	5/31/1995	6/5/1995	135.0	Cake	--	100	2,308	391	2.90	72	Wheat	--
327	6/7/1995	7/3/1995	195.0	Cake	--	134	3,039	547	2.81	69	Wheat	--
317	6/8/1995	6/12/1995	70.0	Cake	--	50	1,149	203	2.90	68	Wheat	--
326	6/10/1995	6/27/1995	235.0	Cake	--	168	3,773	671	2.86	71	Wheat	--
330	6/28/1995	7/3/1995	25.0	Cake	--	33	735	134	5.36	130	Wheat	--
329	7/2/1995	7/13/1995	50.0	Cake	--	58	1,330	241	4.82	110	Wheat	--
332	7/3/1995	7/19/1995	160.0	Cake	--	229	5,184	940	5.88	137	Wheat	--

Table 1. Biosolids applications to the study area near Deer Trail, Colorado, 1993 through 1999.—Continued

[All information provided by the Metro Wastewater Reclamation District; DC, destination code; wT, wet tons; dT, dry tons; Cake, Table 3 Class B biosolids; --, no information available; lb, pound; MAC, biosolids amended with wood fiber; incorporated, biosolids are pushed down into the soil 4 to 8 inches after application by the tines of a rotating implement pulled by a tractor]

DC (fig. 5)	Application start date	Application stop date	Area applied, acre	Product applied	Application method	Number of loads applied	Total biosolids applied, wT	Total biosolids applied, dT	Biosolids loading rate, dT/acre	Nitrogen loading rate, lb/acre	Crop	Reclamation project ¹
328	7/20/1995	8/13/1995	309.1	Cake	--	455	10,010	1,762	5.70	140	Wheat	--
306	4/24/1997	7/31/1997	232.0	Cake	--	153	3,501	612	2.64	58	Wheat	--
307	6/10/1997	7/30/1997	250.0	Cake	--	135	3,127	533	2.13	48	Wheat	--
314	6/17/1997	7/1/1997	92.0	Cake	--	67	1,532	263	2.86	63	Wheat	--
312	7/1/1997	7/17/1997	185.3	Cake	--	134	3,061	524	2.83	69	Wheat	--
313	7/7/1997	7/17/1997	179.0	Cake	--	128	2,878	482	2.69	61	Wheat	--
316	7/11/1997	7/13/1997	95.0	Cake	--	66	1,513	241	2.54	52	Wheat	--
317	7/13/1997	7/22/1997	155.0	Cake	--	113	2,616	433	2.79	67	Wheat	--
315	7/18/1997	7/18/1997	19.0	Cake	--	7	159	28	1.47	30	Wheat	--
319	7/22/1997	7/23/1997	66.0	Cake	--	41	917	154	2.33	64	Wheat	--
318	7/24/1997	7/27/1997	124.0	Cake	--	67	1,432	242	1.95	49	Wheat	--
309	8/9/1997	1/29/1998	320.0	Cake	--	123	2,779	476	1.49	38	Wheat	--
308	8/24/1997	9/7/1997	314.0	Cake	--	212	4,817	827	2.63	70	Wheat	--
310	9/7/1997	10/5/1997	299.1	Cake	--	177	4,039	681	2.28	68	Wheat	--
311	9/13/1997	10/1/1997	320.0	Cake	--	157	3,600	599	1.87	50	Wheat	--
303	9/17/1997	9/20/1997	301.6	Cake	--	78	1,752	298	0.99	25	Wheat	--
305	10/5/1997	2/14/1998	270.0	Cake	--	105	2,283	370	1.37	39	Wheat	--
304	10/6/1997	10/11/1997	267.4	Cake	--	112	2,447	405	1.51	41	Wheat	--
302	10/13/1997	1/29/1998	301.6	Cake	--	116	2,550	416	1.38	34	Wheat	--
301	1/29/1998	2/4/1998	286.2	Cake	--	111	2,501	410	1.43	39	Wheat	--
300	2/4/1998	2/9/1998	286.2	Cake	--	108	2,432	386	1.35	38	Wheat	--
318	4/16/1999	6/30/1999	44.3	Cake/MAC	Incorporated	98	2,148	370	7.18	209	Oats, grass	Yes
316	4/27/1999	6/9/1999	153.0	Cake/MAC	Incorporated	207	4,573	799	5.22	133	Oats, grass	Yes
317	6/9/1999	3/4/2000	159.6	Cake/MAC	Incorporated	722	16,122	2,674	16.30	415	Oats, grass	Yes
326	6/29/1999	11/27/1999	145.1	Cake/MAC	Incorporated	600	12,393	2,211	14.63	375	Oats, grass	Yes
319	7/9/1999	12/16/1999	94.3	Cake/MAC	Incorporated	115	2,600	441	4.37	106	Oats, grass	Yes
319	7/9/1999	2/28/2000	94.3	Cake/MAC	Incorporated	137	3,094	519	5.20	130	Oats, grass	Yes
327	7/30/1999	10/26/1999	125.5	Cake/MAC	Incorporated	496	11,073	1,773	14.00	371	Oats, grass	Yes
325	10/31/1999	12/9/1999	74.0	Cake/MAC	Incorporated	284	6,266	959	12.53	355	Oats, grass	Yes
324	11/7/1999	12/25/1999	77.3	Cake/MAC	Incorporated	311	6,962	1,069	13.45	364	Oats, grass	Yes

¹As described by Colorado Department of Public Health and Environment (1998).

10 Water Quality at a Biosolids-Application Area near Deer Trail, Colorado, 1993–1999

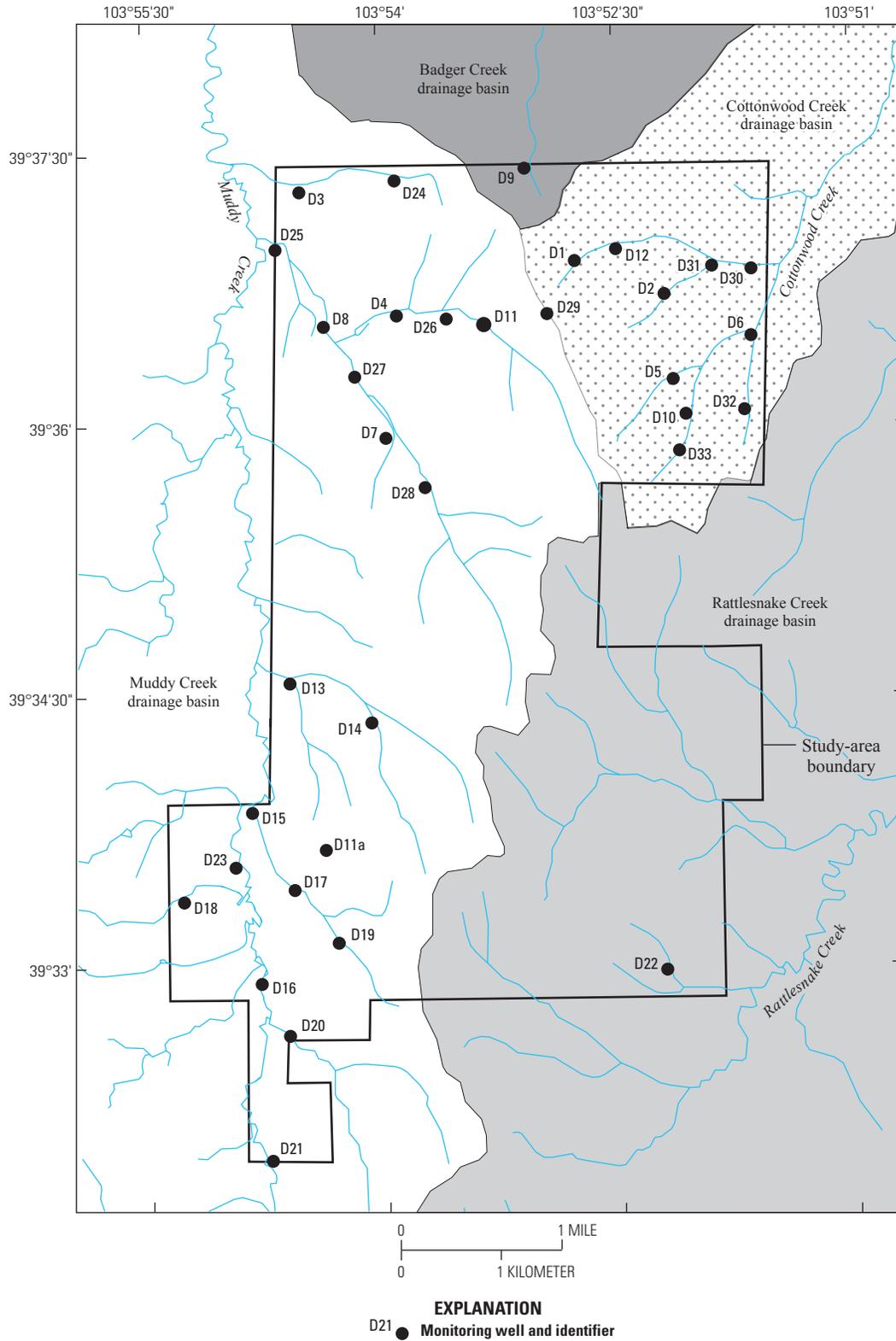


Figure 6. Drainage basins in the study area.

Approach

To evaluate the water quality of the study area, the USGS used multiple approaches. Water-quality samples were collected through baseline sampling, reconnaissance sampling, routine sampling, and specialty sampling. Additional water-quality data were collected through other specialty monitoring, such as the use of in-situ instruments to continuously record water-quality data. Core samples also were collected and analyzed. The resulting data were compared to evaluate temporal and spatial (geographic) differences. Water-quality data also were compared to regulatory standards to evaluate the magnitude of concentrations. Limited geochemical modeling was done to evaluate flow paths and the evolution of groundwater in a selected part of the study area.

Baseline sampling was done in 1993 to provide information about water quality in the study area before biosolids applications began. To qualify as a baseline-sampling site, the site needed to be identified and sampled at least twice before biosolids were applied, and the site needed to be accessible and consistently have sufficient water for sampling throughout the 1993–1998 study period. Unfortunately, not all parts of the study area were accessible because of farming and there was insufficient time to install all the planned monitoring wells before biosolids applications started in the study area, so only some of the planned monitoring wells could be used as baseline-sampling sites. The USGS installed 11 new wells in the study area (wells D1 through D11) in 1993, however, no baseline samples could be collected from two of these wells (D1 and D11) because they never contained enough water to sample even though they were located in drainage valleys that seemed likely to contain alluvial aquifers (table 2). The USGS and the Metro District removed pump equipment from an old livestock-watering well (D12) in 1993 and included that well in the baseline sampling. All baseline samples were collected by the USGS before any biosolids were applied to the study area. Baseline samples were analyzed by the Metro District laboratory for selected major ions, nutrients, and trace elements in filtered samples and bacteria (fecal coliform and fecal streptococcus bacteria) in unfiltered samples. Baseline sampling at each site usually was completed within 1 month.

Reconnaissance sampling was done during 1993 through 1995 to establish the spatial variability in water quality of the study area. The reconnaissance-sampling data also provided information that was used to determine the most suitable sampling methods and the number and location of routine water-quality sampling sites. In addition to the water-quality samples collected from the 10 monitoring wells installed in 1993 (wells D2 through D10 and D12), water-quality grab samples were collected from windmill-pumped livestock wells in the study area in 1993. The resulting chemical data indicated that water samples from the windmill-pumped livestock wells were affected by the extraction mechanisms and not representative of natural groundwater so sampling at the windmill-pumped livestock wells was discontinued. Additional shallow monitoring wells (wells D13 through D28 and wells D30 through D33) were installed and sampled during 1994 and 1995, and

groundwater from wells D2 through D10 and D12 was sampled again for comparison. During reconnaissance sampling in 1994 and 1995, each monitoring well was sampled at least annually. Water-quality grab samples also were collected from streams and ponds in drainage valleys in the study area, but the transient nature of these surface-water features made them challenging for baseline or routine sampling because subsequent samples could not be collected or were not comparable. Reconnaissance samples were analyzed by the Metro District laboratory for selected major ions, nutrients, and trace elements in filtered samples, and bacteria in unfiltered samples. Based on previous studies of the effect of sewage disposal on groundwater quality in Colorado (Robson, 1977; Gaggiani, 1991; Johncox and Gaggiani, 1991; Tindall and others, 1994; and Lull and Gaggiani, 1996), biosolids effects were expected to be apparent from inorganic and bacteriological water-quality data that were compared to baseline or control-site data.

Routine sampling was done during 1995 through 1998 to establish the temporal variation in water quality after biosolids applications began. The data resulting from baseline and reconnaissance sampling indicated spatial and temporal variability in water quality, so a better understanding of groundwater quality of the study area required sampling a variety of well locations throughout the study area and repetitive sampling of the same sites at different times of the year. Therefore, inorganic water-quality samples were collected quarterly from the monitoring wells. Routine sampling focused on groundwater sites rather than surface-water sites because of the ephemeral nature of the streams and the flashy, unpredictable, powerful flows through the stream valleys in that area. Crest-stage gages installed in the study area by the USGS in 1994 were washed away during the first summer of operation so autosamplers were not deployed to sample surface water. Inorganic samples from routine sampling were analyzed for selected physical properties, major ions, nutrients, and trace elements in filtered samples at the Metro District laboratory. Bacteria samples from routine sampling were collected twice each year from the monitoring wells and occasionally from nearby ponds. The bacteria samples were analyzed for fecal coliform and fecal streptococcus bacteria at the Metro District laboratory.

Specialty sampling for unsaturated-zone pore water was initiated by the USGS in 1994 to determine if pore-water chemistry under biosolids-applied farmland differed from pore-water chemistry under farmland that was not applied with biosolids. Four unsaturated-zone plots were prepared in the study area (fig. 2), including a control plot (V4) where biosolids were not applied. Each plot was instrumented with nine suction lysimeters (Tindall and Kunkel, 1999) (fig. 2) to extract the pore water. Only some of the 36 lysimeters yielded pore-water samples in April 1994; no lysimeters in the control plot yielded pore water. No lysimeters in any of the unsaturated-zone plots yielded pore-water samples in May 1995 despite the wet spring weather that preceded the sampling attempts. Therefore, the pore-water sampling at the unsaturated-zone plots was discontinued in 1996. Pore-water samples were analyzed for selected major ions, nutrients, and trace elements in filtered samples at the Metro District laboratory.

Table 2. U.S. Geological Survey sampling sites near Deer Trail, Colorado, 1993 through 1999.

[Details of monitoring-well location and completion are listed in appendix 1; B, baseline water-quality compared with post-application water quality; F, water-quality flow path information; V, aquifer spatial variability; U, USGS-installed monitoring well; Metro District, Metro Wastewater Reclamation District; d, Continuous-recorder instrumentation; P, water quality at property boundary; s, interactions between surface water and groundwater; A, shallow-deep aquifer interactions; e, old livestock well with windmill or other pump; K, owned by Metro Wastewater Reclamation District until 1995 then transferred to a private owner; C, control site with no biosolids applied; c, core-sample chemistry; r, reconnaissance sampling only; t, water trough; n, none; Z, unsaturated-zone pore-water chemistry; L, suction lysimeters at depths of 1.5, 3, and 5 feet]

Site (fig. 2)	Sample type	Sampling purpose	Target sampling frequency	Site type	Site installation	Topographic setting	Drainage basin (fig. 6)	Property owner	County	Location ³
D1	Groundwater	B, F, V	Dry well, no samples available	Shallow well	U	Upland draw	Cottonwood Creek	Metro District	Arapahoe	T5S R58W S16 NE,SE
D2	Groundwater	B, F, V	Quarterly, if access	Shallow well	U, d	Flood plain	Cottonwood Creek	Metro District	Arapahoe	T5S R58W S15 SE,SW
D3	Groundwater	B, F, P, V	Quarterly, if access	Shallow well ¹	U	Flood plain	Muddy Creek	Metro District	Arapahoe	T5S R58W S17 NW,NW
D4	Groundwater	B, F, V	Quarterly, if access	Shallow well ¹	U	Flood plain	Muddy Creek	Metro District	Arapahoe	T5S R58W S17 SE,SE
D5	Groundwater	B, F, s, V	Quarterly, if access	Shallow well	U	Flood plain	Cottonwood Creek	Metro District	Arapahoe	T5S R58W S22 SE,NW
D6	Groundwater	B, F, P, V	Quarterly, if access	Alluvial-aquifer well	U, d	Flood plain	Cottonwood Creek	Metro District	Arapahoe	T5S R58W S22 NE,NE
D7	Groundwater	B, F, V	Quarterly, if access	Shallow well ²	U	Flood plain	Muddy Creek	Metro District	Arapahoe	T5S R58W S20 NW,SE
D8	Groundwater	B, F, V	Quarterly, if access	Shallow well ²	U	Flood plain	Muddy Creek	Metro District	Arapahoe	T5S R58W S17 SE,SW
D9	Groundwater	B, F, P, V	Quarterly, if access	Bedrock-aquifer well	U	Upland draw	Badger Creek	Metro District	Arapahoe	T5S R58W S16 NW,NE
D10	Groundwater	B, F, V	Quarterly, if access	Shallow well	U	Stream channel	Cottonwood Creek	Metro District	Arapahoe	T5S R58W S22 NW,SE
D11	Groundwater	B, F, V	Dry well, no samples available	Shallow well	U	Flood plain	Muddy Creek	Metro District	Arapahoe	T5S R58W S16 SE,SW
D11a	Groundwater	A, F, V	Quarterly, if access	Bedrock-aquifer well	U	Hilltop	Muddy Creek	Metro District	Arapahoe	T6S R58W S5 NE,NW
D12	Groundwater	B, F, V	Quarterly, if access	Shallow well ¹	e	Flood plain	Cottonwood Creek	Metro District	Arapahoe	T5S R58W S15 SE,NW
D13	Groundwater	F, P, V	Quarterly, if access	Shallow well	U	Flood plain	Muddy Creek	Metro District	Arapahoe	T5S R58W S32 NW,NW
D14	Groundwater	F, V	Quarterly, if access	Shallow well	U	Flood plain	Muddy Creek	Metro District	Arapahoe	T5S R58W S32 SW,NE
D15	Groundwater	F, P, s, V	Quarterly, if access	Shallow well ²	U	Flood plain	Muddy Creek	K	Elbert	T6S R58W S5 NW,NW
D16	Groundwater	F, s, V	Quarterly, if access	Shallow well	U	Flood plain	Muddy Creek	K	Elbert	T6S R58W S6 SE,SE
D17	Groundwater	F, V	Quarterly, if access	Alluvial-aquifer well	U	Flood plain	Muddy Creek	Metro District	Elbert	T6S R58W S5 SE,NW
D18	Groundwater	F, P, V	Dry well, no samples available	Shallow well	U	Stream channel	Muddy Creek	K	Elbert	T6S R58W S6 SW,NE
D19	Groundwater	F, V	Quarterly, if access	Shallow well ¹	U	Upland draw	Muddy Creek	Metro District	Elbert	T6S R58W S5 NW,SE
D20	Groundwater	F, V	Quarterly, if access	Shallow well	U	Flood plain	Muddy Creek	K	Elbert	T6S R58W S8 NW,NW
D21	Groundwater	C, F, P, V	Quarterly, if access	Shallow well	U	Flood plain	Muddy Creek	K	Elbert	T6S R58W S8 SW,SW
D22	Groundwater	F, P, V	Quarterly, if access	Shallow well ¹	U	Flood plain	Rattlesnake Creek	Metro District	Elbert	T6S R58W S3 SW,SE
D23	Groundwater	F, s, V	Quarterly, if access	Shallow well ²	U, d	Flood plain	Muddy Creek	K	Elbert	T6S R58W S6 NE,NE
D24	Groundwater	A, F, s, V	Quarterly, if access	Shallow well ¹	U	Stream channel	Muddy Creek	Metro District	Arapahoe	T5S R58W S17 NW,NE

Table 2. U.S. Geological Survey sampling sites near Deer Trail, Colorado, 1993 through 1999.—Continued

[Details of monitoring-well location and completion are listed in appendix 1; B, baseline water-quality compared with post-application water quality; F, water-quality flow path information; V, aquifer spatial variability; U, USGS-installed monitoring well; Metro District, Metro Wastewater Reclamation District; d, Continuous-recorder instrumentation; P, water quality at property boundary; s, interactions between surface water and groundwater; A, shallow-deep aquifer interactions; e, old livestock well with windmill or other pump; K, owned by Metro Wastewater Reclamation District until 1995 then transferred to a private owner; C, control site with no biosolids applied; c, core-sample chemistry; r, reconnaissance sampling only; t, water trough; n, none; Z, unsaturated-zone pore-water chemistry; L, suction lysimeters at depths of 1.5, 3, and 5 feet]

Site (fig. 2)	Sample type	Sampling purpose	Target sampling frequency	Site type	Site installation	Topographic setting	Drainage basin (fig. 6)	Property owner	County	Location ³
D25	Groundwater	F, P, s, V	Quarterly, if access	Alluvial-aquifer well	U	Flood plain	Muddy Creek	Metro District	Arapahoe	T5S R58W S17 SW,NW
D26	Groundwater	F, V	Quarterly, if access	Shallow well ¹	U	Flood plain	Muddy Creek	Metro District	Arapahoe	T5S R58W S16 SW,SW
D27	Groundwater	F, V	Quarterly, if access	Shallow well ²	U	Flood plain	Muddy Creek	Metro District	Arapahoe	T5S R58W S20 SW,NE
D28	Groundwater	F, V	Quarterly, if access	Shallow well ²	U	Stream channel	Muddy Creek	Metro District	Arapahoe	T5S R58W S20 SE,SE
D29	Groundwater	A, F, V	Quarterly, if access	Bedrock-aquifer well	U	Hilltop	Cottonwood Creek	Metro District	Arapahoe	T5S R58W S16 SW,SW
D30	Groundwater	F, P, s, V	Quarterly, if access	Shallow well ²	U	Stream channel	Cottonwood Creek	Metro District	Arapahoe	T5S R58W S15 NE,SE
D31	Groundwater	F, V, c	Quarterly, if access	Alluvial-aquifer well	U	Flood plain	Cottonwood Creek	Metro District	Arapahoe	T5S R58W S15 NW,SE
D32	Groundwater	F, V	Quarterly, if access	Shallow well ¹	U	Stream channel	Cottonwood Creek	Metro District	Arapahoe	T5S R58W S15 SE,NE
D33	Groundwater	F, V, c	Quarterly, if access	Alluvial-aquifer well	U	Flood plain	Cottonwood Creek	Metro District	Arapahoe	T5S R58W S22 NW,SE
G1	Groundwater	r	Occasionally	Trough of livestock well	e, t	Flood plain	Rattlesnake Creek	Metro District	Elbert	T6S R58W S4 SW1/4 SE1/4
G2	Groundwater	r	Occasionally	Trough of livestock well	e, t	Flood plain	Muddy Creek	K	Elbert	T6S R58W S8 NW1/4 SE1/4
G3	Groundwater	r	Occasionally	Trough of livestock well	e, t	Flood plain	Muddy Creek	Metro District	Arapahoe	T5S R58W S20 SW1/4 SW1/4
S1	Surface water	r, s	Occasionally	Stream	n	Stream channel	Rattlesnake Creek	Metro District	Elbert	T6S R58W S3 SE1/4 SE1/4
S2	Surface water	r, s	Occasionally	Near shore	n	Lake or swamp	Rattlesnake Creek	Metro District	Elbert	T6S R58W S3 SE1/4 SE1/4
S3	Surface water	r, s	Occasionally	Near east shore	n	Ponded stream channel	Muddy Creek	K	Elbert	T6S R58W S8 NW1/4 SW1/4
S4	Surface water	r, s	Occasionally	Near shore by well D30	n	Ponded stream channel	Cottonwood Creek	Metro District	Arapahoe	T5S R58W S15 NE,SE
S5	Surface water	r, s	Occasionally	Small swamp near well D15	n	Lake or swamp	Muddy Creek	K	Elbert	T6S R58W S5 NW,NW
S6	Surface water	r, s	Occasionally	East shore near well D15	n	Ponded stream channel	Muddy Creek	K	Elbert	T6S R58W S8 NW,NW
S7	Surface water	r, s	Occasionally	East shore near well D20	n	Ponded stream channel	Muddy Creek	K	Elbert	T6S R58W S6 NE,NE
				near well D23		stream channel				

Table 2. U.S. Geological Survey sampling sites near Deer Trail, Colorado, 1993 through 1999.—Continued

[Details of monitoring-well location and completion are listed in appendix 1; B, baseline water-quality compared with post-application water quality; F, water-quality flow path information; V, aquifer spatial variability; U, USGS-installed monitoring well; Metro District, Metro Wastewater Reclamation District; d, Continuous-recorder instrumentation; P, water quality at property boundary; s, interactions between surface water and groundwater; A, shallow-deep aquifer interactions; e, old livestock well with windmill or other pump; K, owned by Metro Wastewater Reclamation District until 1995 then transferred to a private owner; C, control site with no biosolids applied; c, core-sample chemistry; r, reconnaissance sampling only; t, water trough; n, none; Z, unsaturated-zone pore-water chemistry; L, suction lysimeters at depths of 1.5, 3, and 5 feet]

Site (fig. 2)	Sample type	Sampling purpose	Target sampling frequency	Site type	Site installation	Topographic setting	Drainage basin (fig. 6)	Property owner	County	Location ³
V1 ⁴	Unsaturated-zone pore water	F, Z	Attempted annually (1994 and 1995)	Farmed plot with 9 lysimeters	L	Hillside	Cottonwood Creek	Metro District	Arapahoe	T5S R58W S16 NE,SE
V2 ⁵	Unsaturated-zone pore water	F, Z	Attempted annually (1994 and 1995)	Farmed plot with 9 lysimeters	L	Hillside	Cottonwood Creek	Metro District	Arapahoe	T5S R58W S16 NE,SE
V3 ⁶	Unsaturated-zone pore water	F, Z	Attempted annually (1994 and 1995)	Farmed plot with 9 lysimeters	L	Hillside	Cottonwood Creek	Metro District	Arapahoe	T5S R58W S15 SE,SW
V4	Unsaturated-zone pore water	C, F, Z	Attempted annually (1994 and 1995) Dry lysimeters, no samples available	Farmed plot with 9 lysimeters	L	Flood plain	Muddy Creek	Metro District	Arapahoe	T5S R58W S17 NW,NW

¹Probably bedrock-aquifer well.

²Probably alluvial-aquifer well.

³Location indicated by township, range, section, quarter-section, and quarter of quarter section. The letters after the section number represent successive subdivisions of the section assigned directionally by quadrant (NW, northwest; NE, northeast; SE, southeast; SW, southwest).

⁴Samples obtained from L1 and L2, both of which were lysimeters that sampled pore water at 1.5 feet below land surface.

⁵Samples obtained from L3, L4, and L8, all of which were lysimeters that sampled pore water at 1.5 feet below land surface; sample also obtained from L7, a lysimeter that sampled pore water at 3 feet below land surface.

⁶Samples obtained from L3 and L8, both of which were lysimeters that sampled pore water at 1.5 feet below land surface.

Specialty sampling for dissolved gases and chlorofluorocarbons (CFCs) was done at selected monitoring wells in 1998 to infer information about water quality, flow paths, and groundwater recharge. Dissolved gases that were analyzed in the groundwater samples included argon, carbon dioxide, methane, nitrogen, and oxygen. Chlorofluorocarbons are anthropogenic organic compounds in production since the 1930's and are present in young groundwater (recharged after about 1940). Dissolved-gas and chlorofluorocarbon (DG-CFC) samples were collected one time (November 1998) at 10 monitoring wells in the study area. The DG-CFC samples were analyzed at the USGS Reston Chlorofluorocarbon Laboratory. Sampling and analytical methods for DG-CFC are described by Busenberg and Plummer (1992), Busenberg and others (1999), Plummer and Friedman (1999), Stute and others (1992), and Wilson and McNeill (1997). The resulting data were reported by Yager and Arnold (2003, tables II.5 and II.6).

Specialty sampling for oxidation-reduction (redox) information was done in 1999 to determine redox states in the groundwater. Eight monitoring wells were sampled for redox information. Redox-indicator sampling included analyses for dissolved oxygen, hydrogen gas, hydrogen sulfide, and methane in the field by the USGS. The redox-indicator samples also were analyzed for full inorganic chemistry at the USGS National Water Quality Laboratory (NWQL).

Other specialty monitoring included the use of automated data recorders during 1997 and 1998 to provide detailed information about selected water-quality characteristics. Routine water-quality sampling data provide large-scale (periodic) information about temporal and spatial water-quality variability, but continuous-recorder data provide small-scale (detailed) information about the temporal variability at a site. The large values of specific conductance indicated from baseline and reconnaissance sampling at well D6 were, therefore, examined in detail through automated data recorders. Both specific conductance and groundwater temperature were continuously recorded during 1997 and 1998. The complete data-collection methods and resulting data were reported by Yager and Arnold (2003).

Core-chemistry data from well borings in the study area also were obtained for comparison with the water-quality data. These core samples were analyzed for selected properties (pH, specific conductance, percent organic matter, percent volatile solids, percent total solids), nutrients, and trace elements at the Metro District laboratory.

Site Selection

USGS personnel collected data from numerous sources and locations in the study area (figs. 2 and 3). Sites were selected to monitor shallow alluvial-aquifer and bedrock-aquifer groundwater, deeper bedrock-aquifer groundwater, surface water, and pore water in the unsaturated zone. Sites also were selected for continuous monitoring of groundwater-quality properties and for sampling core materials. All sites where

data were collected are listed in table 2 and shown in figure 2. Additional information about site selection, such as well completion, is described by Yager and Arnold (2003). Access to the monitoring sites in the study area was challenging due to a lack of roads and the rough terrain. Farming activities, muddy conditions, large sand dunes, and large desiccation cracks in the ground occasionally prevented access to monitoring sites. These access restrictions resulted in decreased data collection during the study and created temporal gaps in the data sets.

Shallow alluvial-aquifer and bedrock-aquifer groundwater was monitored throughout the study area. Three windmill-pumped livestock wells were sampled twice in 1993 to provide approximate water-quality information for the study before wells could be installed and to help select monitoring locations. The USGS and the Metro District removed pump equipment from another livestock-watering well (D12) in 1993 and included that well in the monitoring program. Long-term monitoring wells were installed at 31 locations to monitor shallow groundwater. Shallow wells were located in the drainage valleys because the alluvial aquifers were not continuous throughout the study area but existed only in the drainage valleys or in paleochannels of flood plains. Wells were located near property boundaries to evaluate the quality of groundwater leaving the study area. Wells were located further upgradient from property boundaries to evaluate chemical and hydrologic variability within each alluvial aquifer. The first three monitoring wells (D1, D2, and D3) were located topographically downgradient from the four unsaturated-zone plots (fig. 2). The alluvial aquifers generally were located in flood plains; Yager and Arnold (2003) determined that shallow groundwater was not present at the drainage divides (the basin boundaries shown in fig. 6) where in some places biosolids were not applied. The topography (fig. 2) indicated that the biosolids-application areas in the study area were headwaters for most of the streams in the study area, so few locations were available to monitor groundwater upgradient from the biosolids-application areas. Sites that are chemically and hydrologically representative of other sampled locations in the study area but not affected by biosolids applications through infiltration, surface-water runoff, groundwater transport, or wind transport could be control sites for groundwater. Only one control site (D21) could be established for this study, although the data from well D21 samples indicated that water quality at this site was not representative of water quality at other locations in the study area.

Two deeper bedrock-aquifer wells (D11a, D29) were installed in 1997 by the USGS. These wells were located in sandstone ridges where alluvial aquifers were not present to evaluate water quality in the deeper part of the bedrock aquifer where it was not mixing with alluvial aquifers.

DG-CFC samples were collected at monitoring wells in the study area that had chemical concentrations of concern or anomalous water quality compared to other nearby wells. Ten wells were sampled for DG-CFCs: wells D3, D5, D6, D9, D10, D13, D14, D17, D24, and D25.

Only monitoring wells where the dissolved oxygen in the groundwater was less than 1 mg/L were candidates for redox-indicator sampling. Therefore, redox information was obtained from wells D15, D16, D21, D22, D23, and D30 in the study area (fig. 2) and from wells DTX2 and DTX10 (zone A) in the USGS Expanded Monitoring Program (fig. 3) in July 1999.

Streams in the study area were ephemeral and flashy, so surface-water sampling sites consisted of the four largest ponds in the study area. These ponds all were located in drainage valleys near monitoring wells. Water-quality samples were collected occasionally from these surface-water sites to determine if the surface-water quality resembled the groundwater quality in the study area. All the surface-water sampling sites were either ephemeral or were visited by livestock so were not routinely sampled.

Four unsaturated-zone plots were selected and prepared before biosolids-applications began. The unsaturated-zone plots were located in upland areas, which were where biosolids were to be applied at the site, not drainage valleys where no biosolids could be applied (fig. 2). These unsaturated-zone plots included one control plot where biosolids were not applied (V4 near well D3), as well as three plots where biosolids were applied (V1, north of well D1; V2, south of well D1; and V3, north of well D2) (fig. 2). Each unsaturated-zone plot was about 150 ft by 150 ft and contained nine porous-cup suction lysimeters (also called “solution samplers” by Tindall and Kunkel, 1999, p. 569). The unsaturated-zone plots were surveyed in the fall of 1993, and biosolids were applied to three of the plots (V1, V2, and V3) in December 1993. In February 1994, suction lysimeters were installed in the four unsaturated-zone plots using a portable two-person-operated auger. Each unsaturated-zone plot was instrumented with nine suction lysimeters (Tindall and Kunkel, 1999): three suction lysimeters installed at a depth of 1.5 ft, three suction lysimeters installed at a depth of 3 ft, and three suction lysimeters installed at a depth of 5 ft. The installation depth of each lysimeter was determined through a random-number table based on the method described by Lüscher (1994). The USGS attempted to sample all the suction lysimeters in each plot each pore-water-sampling trip. The unsaturated-zone plots were dismantled in 1996.

Core-sampling sites were not originally planned to be part of the study, but the initial groundwater-quality data from reconnaissance sampling indicated a likely geochemical signature in the groundwater so core sampling was added. Two of the last alluvial-aquifer boreholes drilled in 1995 (completed as wells D31 and D33) were selected as core-sampling sites. Core samples were collected from throughout the unsaturated zone of the two boreholes.

Data-Collection Methods

Data collection consisted of measuring selected water-quality properties and related parameters in the field at the time of sampling, collecting samples that were analyzed by a laboratory, and continuously recording water-quality properties in the field at selected sites. Core samples from selected

sites also were collected in the field and analyzed by a laboratory. Various methods were used to collect samples and other water-quality data from the study area during 1993–1999.

Field Methods Used to Collect Data for Physical Properties and Inorganic Chemical Constituents

During baseline and reconnaissance sampling, samples were collected from the monitoring wells for inorganic analyses. Wells were purged 1–2 days in advance of sampling by hand-bailing or by using a submersible pump during 1993 through mid-1994. During mid-1994 through 1995, wells were purged at the time of sampling. Monitoring wells were sampled according to standard USGS methods (Sylvester and others, 1990) by using a submersible pump (most of the time) or by using a clean plastic tube with a peristaltic pump. Wells were occasionally hand bailed during 1993–1995 in cases of equipment failure. All sampling equipment was cleaned in the field between sampling sites. Standard USGS methods (Sylvester and others, 1990) were used for sample processing. The baseline and reconnaissance samples were submitted on the day of sample collection to the Metro District laboratory for analysis.

During reconnaissance sampling, grab samples were collected at an assortment of windmill-pumped livestock wells and at surface-water features in the study area for inorganic analyses. Groundwater grab samples were collected either from the discharge line of the windmill pump or, if the windmill was not pumping, from the top, center part of the water trough that was filled by the windmill-pumped well. Each groundwater grab sample was collected in a large, clean, plastic bottle then processed by filtration and sample preservation. Surface-water grab samples were collected by dipping a large, clean, plastic bottle directly into the surface-water feature and filling the bottle from along the shore near the surface. The surface-water grab samples were then processed by filtration and sample preservation. Standard USGS methods (Sylvester and others, 1990) were used for sample processing. The grab samples were submitted on the day of sample collection to the Metro District laboratory for analysis.

During routine sampling, samples were again collected from the monitoring wells for inorganic analyses. Depth to groundwater was measured before sampling procedures were started. Wells were purged until field properties stabilized (measured through a flow-through chamber) at the time of sampling using a pump. Wells that were screened deeper than 30 ft below land surface were sampled by using a stainless-steel submersible pump that was cleaned in the field between sites. Wells that were screened at less than 30 ft below land surface were sampled by using a peristaltic pump with dedicated silicone and polyethylene tubing inside the well to the depth of the screened area. Samples were collected and processed during most of 1995 according to the standard USGS methods described by Sylvester and others (1990). In 1994, a national USGS research effort documented a new sampling protocol for trace-element water-quality sampling (Horowitz and others, 1994). After reviewing the data obtained through

October 1995, the USGS decided stricter sampling and processing protocols were needed to ensure groundwater-data quality for this study because many water-quality constituents were present in such small concentrations that uncertainty contributed by field and laboratory factors made these constituents difficult to accurately quantify. Therefore, in late 1995, sampling preparations, field methods, and documentation procedures for this study were revised to follow those of Horowitz and others (1994), Koterba and others (1995), and U.S. Geological Survey (variously dated). The new sampling protocol that was used for the collection and processing of inorganic groundwater samples in the study area during late 1995 through 1999 was more appropriate for low-concentration constituents and is summarized in figure 7. All routine water-quality samples collected during 1995 through 1998 were submitted on the day of sample collection to the Metro District laboratory for analysis.

During specialty sampling for pore water, each lysimeter in all four unsaturated-zone plots was pressurized then sampled by using methods described by Tindall and Vencill (1995). Not all lysimeters yielded enough pore water for analysis; most lysimeters only yielded a little mist. The lysimeter samples that had at least 0.5 mL of pore water were processed at the USGS in Denver according to methods described by Tindall and Vencill (1995), which included dilution to 0.1 L with deionized water. The diluted pore-water samples were delivered to the Metro District laboratory for analysis.

During other specialty monitoring for specific conductance and groundwater temperature, automated data recorders were used to provide detailed data. Specific conductance and water temperature were continuously monitored at well D6 by using submersible sensors that were cabled to a data logger and deployed for several years at the same field site. These sensors were inspected during monthly site visits, and

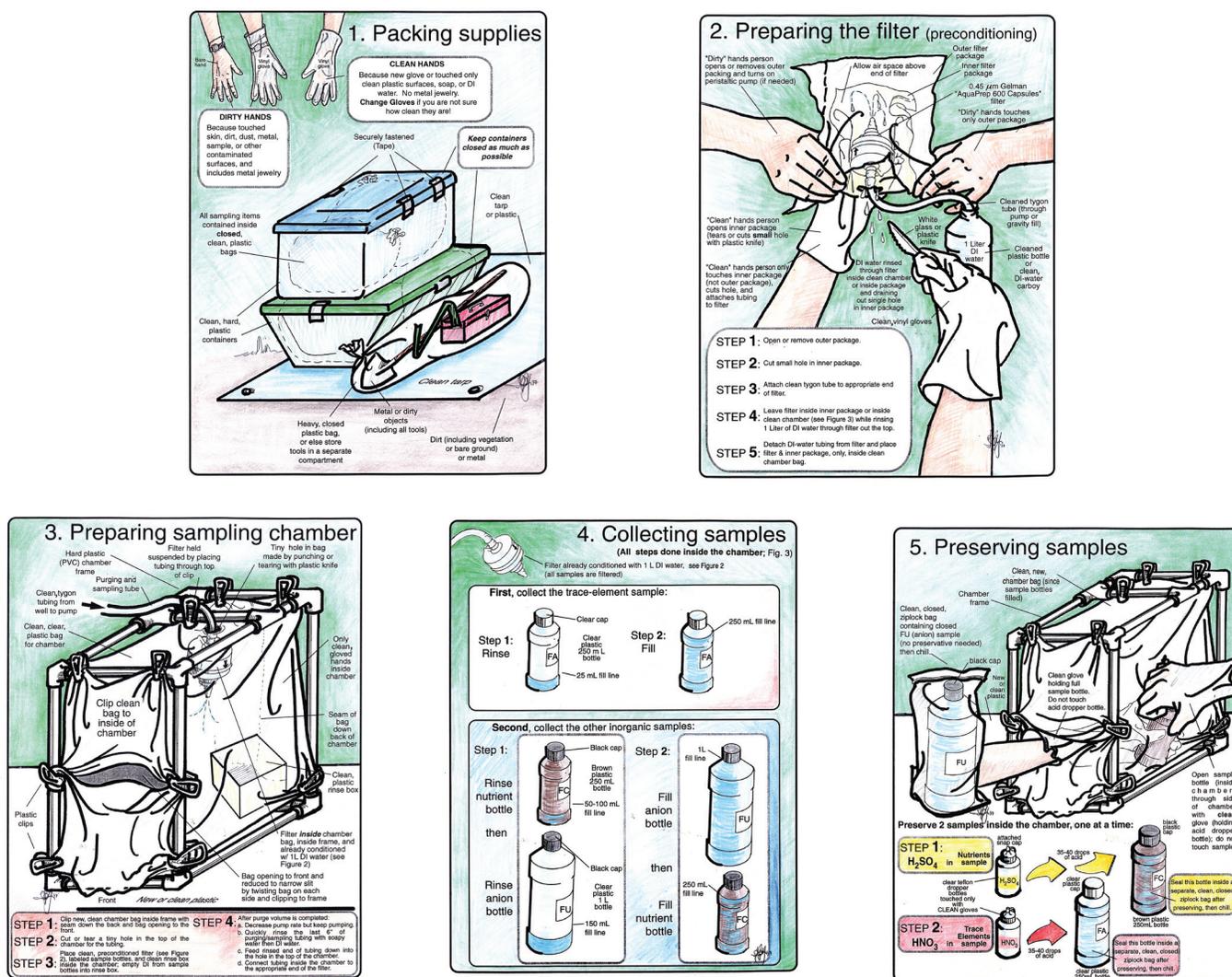


Figure 7. Summary of the U.S. Geological Survey sampling method used to collect groundwater-quality samples near Deer Trail, Colorado, late 1995 through 1999. [DI, deionized water; FA, filtered and acidified sample; FC, filtered and chilled sample; FU, filtered and unpreserved sample; L, liter; PVC, polyvinyl chloride (plastic); mL, milliliter; H₂SO₄, sulfuric acid; HNO₃, nitric acid]

Figure 7 includes five panels. Click on the thumbnails to view the enlarged version of each panel

data were downloaded approximately monthly from the data logger. The resulting data are reported by Yager and Arnold (2003, figure II.6). Large periods of missing record in these data were the result of flooding in the nearby drainage valley that also flooded the continuous-recorder instrumentation. Because the periods of missing record were during critical recharge periods, the monitoring period was extended to last about 2 years.

Core of shallow subsurface geologic materials was sampled when drilling was done to install two monitoring wells (D31 and D33). Core was collected from the borehole by using split-spoon core barrels in hollow-stem augers. Samples were collected from measured sections of core by using a clean plastic spoon to scrape away any part of the core that had been in contact with the core barrel and to transfer the scraped core sample to a clean sample jar that was provided by the Metro District laboratory. The core samples were delivered to the Metro District laboratory on the same day collected.

Field Methods Used to Sample for Bacteriological Constituents

Groundwater and surface-water sites in the study area were sampled for selected bacteria. All bacteria samples collected during 1993–1998 were chilled and delivered within about 4 to 6 hours of collection to the Metro District laboratory where the samples were cultured and analyzed.

From 1993 through 1996, bacteria samples were collected from unpumped wells on a different day from the inorganic water-quality sampling because of the short time period after sample collection that the samples had to be delivered to the Metro District laboratory for culturing. The sampling method utilized a single brass bailer as described by Gaggiani (1991, p. 22). The brass bailer was tied to cotton/polyester rope. Some erratic and questionable results were obtained with this method (for example, a D2 sample on 10/3/96). Therefore, sampling methods were revised in 1996 to improve the quality of bacteria data by ensuring that any contamination was not from field sampling or processing.

From 1997 through 1998, bacteria samples were collected from purged wells immediately after the inorganic groundwater samples (on the same day) using single-use autoclaved polyethylene bailers attached to bleach-washed, plastic-coated cable. The groundwater sample that was collected in the bailer was poured immediately into a clean autoclaved sample bottle that was provided by the Metro District laboratory. The revised sampling methods were described by Myers and Sylvester (1997, sections 7.1.1 and 7.1.2) and U.S. Geological Survey (variously dated).

Ponds in the study area were sampled occasionally for bacteria during 1995 through 1998. Pond samples were collected by dipping an autoclaved sample bottle that was provided by the Metro District laboratory directly into the pond for a grab sample. These surface-water grab samples were collected near the surface and bank of the pond.

Field Methods Used to Sample for Other Constituents

Specialty sampling for DG-CFCs used equipment and methods that are described by Busenberg and others (1999), Plummer and Friedman (1999), Stute and others (1992), and Wilson and McNeill (1997). A description of sampling equipment and methods, as well as the USGS applications of the resulting data, also are provided on the Internet (<http://water.usgs.gov/lab/cfc> and <http://water.usgs.gov/lab/dissolved-gas>, accessed October 3, 2012). The DG-CFC samples were chilled and shipped immediately to Reston, Va., for analysis. Samples for inorganic constituents were not collected at this time.

Specialty sampling for redox-sensitive constituents involved a variety of field methods. Methods for sampling and processing the redox-sensitive constituents are described by Chapelle and others (1995) and Lovley and others (1994). The redox-indicator samples were delivered to a mobile field laboratory or to a USGS research laboratory in Denver for analysis. The monitoring wells that were sampled for redox-indicator constituents also were sampled for field properties, major ions, nutrients, and trace elements at the same time. The samples for these inorganic constituents were collected and processed using the same methods that were used for routine sampling during 1996 through 1998 (Horowitz and others, 1994; Koterba and others, 1995; U.S. Geological Survey, variously dated) but were delivered to the NWQL in Denver for analysis.

Analytical Methods

Various laboratories provided chemical data for samples from the study area. Both USGS laboratories and the Metro District laboratory analyzed samples during 1993–1999.

The Metro District laboratory in Denver provided all inorganic analyses of environmental samples during 1993–1998, including the analyses of groundwater, surface-water, pore-water, and core samples. The water-quality samples of groundwater, surface water, and pore water were analyzed for selected physical properties, major ions, nutrients, and trace elements according to the methods listed in table 3. Groundwater and surface-water samples also were cultured and analyzed for fecal coliform and fecal streptococcus bacteria according to the methods listed in table 3. The core samples were dried, sieved, and split for analysis at the Metro District laboratory and were analyzed for inorganic constituents using analytical methods similar to those listed in table 3 (M.L. Castlebury, Metro District laboratory, oral commun., October 1995). After the first 2 years of sampling, it was determined that the Metro District laboratory did not have sufficiently low reporting limits for characterizing most of the trace elements of interest at most of the monitoring wells, so selected groundwater samples collected during 1995–1998 also were analyzed at the NWQL.

Table 3. Laboratory methods used by the Metro Wastewater Reclamation District Laboratory for analyses of water samples.

[All information provided by the Metro Wastewater Reclamation District (M.L. Castlebury, Metro Wastewater Reclamation District, written commun., June 1998); additional information about the analytical methods used is available from the Metro Wastewater Reclamation District; MRL, minimum reporting level, although dilutions for samples having high specific conductance resulted in higher MRL's for some samples; CaCO₃, calcium carbonate; mg/L, milligrams per liter; --, no information; ICP, inductively coupled plasma; °C, degrees Celsius; N, nitrogen; ASF, automated segmented-flow spectrophotometry; P, phosphorus; µg/L, micrograms per liter; GFAA, graphite-furnace atomic absorption spectrometry; MS, mass spectroscopy; mL, milliliters]

Characteristic or constituent	Units	Analytical method used, Metro Wastewater Reclamation District	Most frequent MRL
Water characteristics and major ions			
Alkalinity, laboratory, as CaCO ₃	mg/L	Electrometric titration	0
Hardness, as CaCO ₃ , dissolved	mg/L	--	10
Dissolved solids, residue at 180°C	mg/L	Gravimetric	10
Calcium, dissolved	mg/L	ICP	1
Chloride, dissolved	mg/L	Colorimetry	1
Potassium, dissolved	mg/L	ICP	0.1
Magnesium, dissolved	mg/L	ICP	1
Sodium, dissolved	mg/L	ICP	10
Sulfate, dissolved	mg/L	Colorimetry	3
Nutrients			
Nitrogen, ammonia plus organic, dissolved as N	mg/L	Colorimetry, ASF, microKjeldahl digestion	0.3
Nitrogen, ammonia, dissolved as N	mg/L	Colorimetry, ASF, salicylate-hypochlorite	0.1
Nitrogen, nitrite, dissolved as N	mg/L	Colorimetry, ASF, diazotization	0.02
Nitrogen, nitrite plus nitrate, dissolved as N	mg/L	Colorimetry, ASF, cadmium reduction, diazotization	0.02
Phosphorus, orthophosphate, dissolved as P	mg/L	Colorimetry	0.02
Trace elements			
Cadmium, dissolved	µg/L	ICP or GFAA	0.2
Chromium, dissolved	µg/L	ICP or GFAA	20
Copper, dissolved	µg/L	ICP or GFAA	20
Iron, dissolved	µg/L	ICP	50
Lead, dissolved	µg/L	ICP or GFAA	10
Manganese, dissolved	µg/L	ICP or GFAA	20
Nickel, dissolved	µg/L	ICP-MS	20
Zinc, dissolved	µg/L	ICP or GFAA	20
Bacteria			
Coliform, fecal	colonies/100 mL	Plate culture	20
Streptococci, fecal	colonies/100 mL	Plate culture	20

The NWQL analyzed selected groundwater-sample replicates and blanks during 1995–1998, as well as all groundwater samples collected during 1999. The analytical methods used by the NWQL are listed in table 4. The analyses at the NWQL (table 4) included some lower minimum reporting levels (MRLs) and additional analytes (physical properties, major ions, nutrients, and trace elements) relative to the analyses at the Metro District laboratory (table 3).

The DG-CFC samples were analyzed by the USGS Chlorofluorocarbon Laboratory in Reston, Va., using analytical methods described by Busenberg and others (1999), Plummer and Friedman (1999), Stute and others (1992), and Wilson and McNeill (1997). The analytical methods also are described on the Internet at <http://water.usgs.gov/lab/cfc>, and <http://water.usgs.gov/lab/dissolved-gas> (accessed October 3, 2012).

The redox-indicator samples were analyzed in the field or analyzed by a USGS research laboratory in Denver. Methods for analyzing the redox-indicator samples are described by Chappelle and others (1995) and Lovley and others (1994).

Quality-Assurance Methods

Quality-assurance methods routinely were used by the USGS in the collection of data from the study area. These methods included replicate field measurements, checking and calibration of equipment, participation in performance-evaluation programs, USGS project reviews, data verification, preparation and analysis of various quality-control samples (blanks and replicates), and laboratory quality-assurance programs. Water-level equipment, sampling equipment, and water-quality meters were checked regularly and calibrated in the field or office. All equipment used to measure field properties also was checked for accuracy through the USGS National Field Quality Assurance (NFQA) Program (Stanley and others, 1998) during 1996 through 1999.

All equipment used to collect study-area data was kept in locked USGS facilities. Sharing of this equipment with other sites was minimal to decrease the chance of cross-contamination from other sites. All 1993–1999 water-quality samples were kept in locked USGS facilities until the samples

Table 4. Laboratory methods used by the U.S. Geological Survey National Water Quality Laboratory, 1994 through 1999.

[Method references provided in Stevens and others (2003); MRL, minimum reporting level, although dilutions for samples having high specific conductance resulted in higher MRL's for some samples; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; --, not applicable; CaCO_3 , calcium carbonate; mg/L , milligrams per liter; $^\circ\text{C}$, degrees Celsius; ASF, automated segmented-flow spectrophotometry; ICP, inductively coupled plasma; IC, ion chromatography; AA, atomic absorption spectrometry; SiO_2 , silicon dioxide; N, nitrogen; P, phosphorus; $\mu\text{g}/\text{L}$, micrograms per liter; MS, mass spectroscopy; *, various]

Characteristic or constituent	Units	Analytical method	Most frequent MRL
Water characteristics and major ions			
pH, laboratory	Standard units	Electrometric electrode	--
Specific conductance, laboratory	$\mu\text{S}/\text{cm}$	Wheatstone bridge	--
Acid neutralizing capacity as CaCO_3 , laboratory	mg/L	Electrometric titration	--
Dissolved solids, residue at 180°C	mg/L	Gravimetric	10
Bromide, dissolved	mg/L	Colorimetry, ASF, fluorescein	0.01
Calcium, dissolved	mg/L	ICP	0.002
Chloride, dissolved	mg/L	IC	0.1
Fluoride, dissolved	mg/L	Colorimetry, ASF, ion-selective electrode	0.1
Potassium, dissolved	mg/L	AA	0.1
Magnesium, dissolved	mg/L	ICP	0.01
Silica, dissolved, as SiO_2	mg/L	Colorimetry, ASF, molybdate blue	0.020
Sodium, dissolved	mg/L	ICP	0.025
Sulfate, dissolved	mg/L	IC	0.01
Nutrients			
Nitrogen, ammonia plus organic, total, as N	mg/L	Colorimetry, ASF, microKjeldahl digestion	0.1
Nitrogen, ammonia plus organic, dissolved, as N	mg/L	Colorimetry, ASF, microKjeldahl digestion	0.1
Nitrogen, ammonia, dissolved, as N	mg/L	Colorimetry, ASF, salicylate-hypochlorite	0.02
Nitrogen, nitrite, dissolved, as N	mg/L	Colorimetry, ASF	0.001
Nitrogen, nitrite plus nitrate, dissolved, as N	mg/L	Colorimetry, ASF, cadmium reduction, diazotization	0.05
Nitrogen, nitrate, dissolved, as N	mg/L	IC	0.01
Phosphorus, total, as P	mg/L	Colorimetry, ASF, microKjeldahl digestion	0.05
Phosphorus, dissolved, as P	mg/L	Colorimetry, ASF, microKjeldahl digestion	0.05
Phosphorus, orthophosphate, dissolved, as P	mg/L	Colorimetry, ASF, phosphomolybdate	0.002
Trace elements			
Aluminum, dissolved	$\mu\text{g}/\text{L}$	ICP-MS	1
Antimony, dissolved	$\mu\text{g}/\text{L}$	ICP-MS	1
Arsenic, dissolved	$\mu\text{g}/\text{L}$	Hydride generation	1
Barium, dissolved	$\mu\text{g}/\text{L}$	ICP-MS	1
Beryllium, dissolved	$\mu\text{g}/\text{L}$	ICP-MS	1
Boron, dissolved	$\mu\text{g}/\text{L}$	ICP-MS	2
Cadmium, dissolved	$\mu\text{g}/\text{L}$	ICP-MS	1
Chromium, dissolved	$\mu\text{g}/\text{L}$	ICP-MS	1
Cobalt, dissolved	$\mu\text{g}/\text{L}$	ICP-MS	1
Copper, dissolved	$\mu\text{g}/\text{L}$	ICP-MS	1
Iron, dissolved	$\mu\text{g}/\text{L}$	ICP	3
Lead, dissolved	$\mu\text{g}/\text{L}$	ICP-MS	1
Manganese, dissolved	$\mu\text{g}/\text{L}$	ICP	1
Mercury, dissolved	$\mu\text{g}/\text{L}$	Hydride generation	0.10
Molybdenum, dissolved	$\mu\text{g}/\text{L}$	ICP	1
Nickel, dissolved	$\mu\text{g}/\text{L}$	ICP	1
Selenium, dissolved	$\mu\text{g}/\text{L}$	Hydride generation	1
Silver, dissolved	$\mu\text{g}/\text{L}$	ICP	1
Strontium, dissolved	$\mu\text{g}/\text{L}$	ICP	1
Thallium, dissolved	$\mu\text{g}/\text{L}$	ICP	0.10
Uranium, natural dissolved	$\mu\text{g}/\text{L}$	ICP	1
Vanadium, dissolved	$\mu\text{g}/\text{L}$	ICP	*
Zinc, dissolved	$\mu\text{g}/\text{L}$	ICP	1

were delivered personally to the analyzing laboratory, except for DG-CFC samples collected in 1998, which were shipped to a USGS research laboratory in Virginia. Sample handling and custody (including sample delivery at the laboratory) was documented in project files.

All samples were submitted to the Metro District laboratory as double-blind samples. Sample bottles delivered to the laboratory were labeled with arbitrary sample numbers, not well numbers, so the laboratory staff did not know which sample had come from which well. In addition, the quality-control samples (blanks and replicates, including splits) could not be distinguished visually from well samples. The actual sample identification (well number or quality-control sample type) was eventually provided to the Metro District, but only after all water-quality data for that sample were received by the USGS.

Replicate samples were collected in the field by the USGS to quantify variability in the groundwater data contributed by the groundwater, sampling and processing, field conditions, and laboratory conditions and analysis. The USGS usually collected two field replicates each sampling trip. Two types of replicate samples were collected: duplicates and splits. Duplicate samples indicate variability contributed by the environment (groundwater and site conditions), field processing, and laboratory processing and analysis; these samples were prepared by using all the same equipment to concurrently collect an extra sample during collection of the environmental sample. Bottles of a particular type were filled in sequence. For example, after the sample trace-elements bottle was filled, then the duplicate trace-elements bottle was filled, then the sample nutrients bottle was filled, followed by the duplicate nutrients bottle, and so forth. Split samples indicate variability contributed by the laboratory only, and were prepared by compositing sample water for each bottle type, shaking the composite sample to mix, and then apportioning the composite between two bottle sets. The data from analysis of duplicate samples collected during 1993–1995 indicated that variability contributed by either the environment, sampling methods, field processing, or laboratory processing and analysis in the data was substantial, especially in the low-concentration range.

When the groundwater-sampling method was changed in late 1995, the number and types of quality-control samples were expanded to provide more information about the bias and variability in the water-quality data that was contributed by the laboratory and to provide more quantitative information about low-concentration trace elements. From December 1995 through 1998, a special type of replicate sampling was done for at least one well each quarter to provide detailed information about natural groundwater variability (aquifer variation), and variability contributed by sampling, field processing, laboratory processing, and laboratory analysis. This sampling was called a “triplicate-split” sampling; four bottle sets were filled from the same well by making two replicate composites, each of which produced a pair of split samples. The first composite sample produced the environmental sample and a split of the environmental sample (sample sub-type C1), both of which were analyzed by the Metro District laboratory so the differences

in reported values for the first split pair indicated variability contributed only by the processing and analysis at the Metro District laboratory. The sample pair from the second composite sampling (sample sub-type C2) was prepared immediately after the first composite sampling was bottled; the first of this split pair was analyzed by the Metro District laboratory, and the second sample of this split pair was analyzed by the NWQL. Thus, the differences in reported values for the second split pair represented only bias or variability between the two laboratories. Further performance-evaluation data are needed to determine which laboratory value was most accurate (least biased). The difference in reported values between composite 1 (the first split pair) and composite 2 (the second split pair) indicated variability contributed by the environment (groundwater and site conditions), field processing, and laboratory processing and analysis, just like other types of duplicate samples. This sampling was called a “triplicate-split” because three of the four bottle sets were sent to the Metro District laboratory for analysis, and a split of one of the bottle sets was sent to the NWQL for analysis. The data from the triplicate-split sampling indicated that variability in the groundwater data contributed by the laboratory processing and analysis at the Metro District generally was greater than the variability contributed by the environment or field processing (appendixes 3–5).

Blank samples were collected by the USGS and analyzed to quantify contamination, a type of high bias, contributed by specific field conditions, sampling equipment, and laboratory analysis. Note that not all the blank-sample data represent contamination that would affect the water-quality data; some data represent unusual field conditions or equipment combinations that affected few or none of the water-quality samples but provided helpful method information. The USGS usually collected one to three field-blank samples each quarter. Field blanks usually were prepared by passing deionized water (1993 through October 1995) or certified inorganic blank water (December 1995 through 1999) through all the sampling equipment, then processing and preserving like was done for a regular sample at a well site. In addition, equipment blanks occasionally were prepared at the USGS preparatory laboratory in Denver using selected equipment and analyzed as regular samples. Equipment blanks do not indicate bias in the sample data contributed by field conditions near Deer Trail because these samples were prepared at a USGS laboratory near Denver. Blank samples either were submitted to the Metro District laboratory or to the NWQL and usually were analyzed with the same analytical equipment as regular samples. However, a special low-level trace-element sample was analyzed by the NWQL on “blanks only” analytical equipment at least once a year from December 1995 through 1999 to quantify even very low levels of bias. The data from analysis of blank samples indicated that high bias in the low-concentration range generally was less than environmental concentrations (appendix 7).

The continuous-recorder sensors for specific conductance and groundwater temperature that were installed at well D6 during 1997 and 1998 were quality assured. The conductance sensor was calibrated annually and checked periodically for accuracy with standard solutions. The temperature sensor was

checked at least annually for accuracy by comparing the output from the sensor with that from a certified thermometer in various water baths.

Little information was provided to the USGS about the analytical quality-assurance practices and procedures of the Metro District laboratory during 1993–1998. Ion balances were checked by the Metro District and used as rerun criteria before any data were released to the USGS (M.L. Castlebury, Metro District laboratory, oral commun., October 1995). The USGS was not provided the opportunity to request verification of analytical values or reanalysis of samples when data were anomalous, so the chemical data in this report may contain some laboratory errors, particularly for anomalously small or large concentration values. The Metro District laboratory participated in a laboratory review conducted by the USGS in late 1991; this laboratory was found to be “performing at an adequate level of operation” at that time (D.W. Erdmann, USGS, written commun., March 10, 1992).

The analytical quality-assurance practices and procedures for the NWQL during 1993–1999 are documented by various reports. The analytical quality-assurance practices and procedures of the NWQL are described by Friedman and Erdmann (1982). Analytical bias contributed by the NWQL also was evaluated for non-blank concentrations through USGS Blind Sample programs and performance-evaluation studies (Pirkey and Glodt, 1998). Variability in the water-quality data contributed by the NWQL also was evaluated through NWQL method-performance programs (Pirkey and Glodt, 1998). Quality assurance of the NWQL was done at many levels. Field quality-control samples (blanks and replicates analyzed by the NWQL) indicate bias and variability of the NWQL, as well as of field methods. The NWQL also had a three-tier quality-control process consisting of (1) method-performance evaluations (laboratory blanks, laboratory spikes, laboratory replicates, calibration standards, and calibration-check samples or standard reference materials), (2) data review and blind-sample programs, and (3) internal and external performance-evaluation studies (Pirkey and Glodt, 1998).

Both the Metro District laboratory and the NWQL participated in the USGS Standard Reference performance evaluation program during 1993–1999. This program was described by Farrar and Long (1996), and a similar report was published by the USGS for each set of performance-evaluation samples that were distributed. For this program, spiked natural-water solutions were distributed about twice each year to the participating laboratories for analysis, then the results were statistically analyzed and used to calculate the most probable value for the spiked solution. These performance-evaluation data (appendix 8) can indicate possible laboratory bias for constituents analyzed in the samples collected near Deer Trail during 1993–1999. However, laboratory methods and quality-assurance practices used for the performance-evaluation samples may have differed from those used for the samples collected near Deer Trail because these performance-evaluation samples were not submitted to the laboratories as Deer Trail project samples.

Water Quality

Water quality is determined by many processes. Chemical constituents can be added to the hydrologic system from transport in recharging water, dissolution of gases or rock minerals in the water, and chemical reactions that change one constituent into another. Chemical constituents can be subtracted from the hydrologic system by transport in discharging water, precipitation of constituents into solids, degassing of constituents into vapors, and chemical reactions. The occurrences and rates of these processes vary spatially and temporally. The result of all constituent additions and subtractions at a particular place for a particular time is described as the amount (mass) of that constituent in a given volume of water, or chemical concentration of the constituent. If more water is added to the hydrologic system but the mass of a constituent remains the same, the constituent is diluted and concentration decreases. Conversely, if water is removed from the hydrologic system (as in evaporation) but the mass of a constituent remains the same, the constituent is concentrated and concentration increases.

Because the mass of each constituent can vary in space, concentrations of a constituent can differ throughout a water body such as a pond or aquifer at any given time; constituents generally are not well mixed and uniformly distributed. Therefore, the selection of volume integrated to produce the discrete sample that was analyzed for chemistry affects the sample concentration. Well screens integrate groundwater over the length of the well screen, so samples from wells represent averaged concentrations; a specific geologic layer or aquifer subsample within the screened interval may actually have concentrations much higher or much lower than that of the sample. Some geologic layers (especially shale) within the screened area of a well may have high constituent concentrations but yield little water, whereas other geologic layers (especially sandstone or coarse alluvium) may have some zones of high concentrations and some zones of low concentrations but yield much water, which could result in a relatively dilute groundwater sample, depending on the contribution of each zone. Well D24 had a 30-ft screen because drilling of this borehole did not initially yield sufficient water volume for sampling, and no specific water-bearing zone could be isolated from this 30-ft interval. Chemical-concentration data from this well may represent averaged concentrations from the entire 30-ft screened interval, or may represent the chemistry of a few discrete water-yielding layers. In any case, the geologic (and therefore chemical and hydrologic) composition is not likely uniform over the entire 30 ft screened for well D24 or even the entire 10 ft screened for the other monitoring wells. Similar such considerations affect the representativeness of the water-quality samples collected from ponds, livestock-well troughs, and groundwater samples collected from well casings. Information for each sampled site is included in table 2.

Water quality can be characterized in terms of major ions, nutrients, trace elements, and bacteria. Major ions include calcium, chloride, magnesium, potassium, sodium, and sulfate and usually are contributed to water from dissolution of rock and mineral matter (Drever, 1988). Some major ions also can be contributed by leachate from sewage sludge (Gaggiani, 1991). Major ions can be removed from the water of the study area through precipitation of mineral phases or reaction. Nutrients include nitrogen and phosphorous constituents and can be contributed to the water of the study area from the atmosphere, decaying plant residue, rocks (such as shale), commercial fertilizers, animal feces, untreated human septage (perhaps associated with the homesteads), or biosolids (Yager and McMahon, 2012). Nutrients can be removed from the water of the study area through plant uptake, microbial reactions, and water transport. Trace elements are inorganic elements (including metals) that usually are present in natural waters at concentrations less than about 1 mg/L. Many trace elements can be beneficial or detrimental to plant, animal, or human health depending on the form and concentration (Hem, 1992, p. 129). Trace elements dissolved in study-area water can be contributed from rocks, commercial fertilizers, and biosolids. Dissolved concentrations of trace elements can decrease from plant uptake, precipitation, water transport, or chemical reaction. Bacteria are microorganisms that are present in most waters and on many surfaces. Some bacteria are beneficial, some are harmful, and some are neither. Some bacteria are present only in specific environments. Fecal coliform and fecal streptococci bacteria in water originate from animal feces and human sewage (including biosolids) and indicate that harmful bacteria can be present (Hem, 1992).

The water-quality data for the study area that were collected during 1993–1999 are listed in tables 5–7. Data for inorganic water-quality samples collected during 1993–1998 and analyzed by the Metro District laboratory are listed in table 5. Note that the unusually small, censored (less than) values or unusually large values that were reported for the same site by the Metro District laboratory likely are laboratory errors. Data for bacteria samples (including associated quality-control data) are listed in table 6. The baseline data are included in tables 5 and 6 (all samples collected in 1993; see table 2 for sampling purpose). The reconnaissance data also are included in tables 5 and 6 (all groundwater and surface-water samples collected in 1993 and 1994; see table 2 for sampling purpose). The data resulting from routine sampling are included in tables 5 and 6 (all groundwater samples collected during 1995 through 1998). The data resulting from specialty sampling for pore water in the unsaturated zone during 1994 are included in table 5; no pore-water samples could be collected in 1995. The data resulting from specialty sampling for low-concentration trace elements in 1999 (including associated quality-control data) are listed in table 7; these data are for the groundwater samples that were collected during redox-indicator sampling. All inorganic water-quality data from this study were for dissolved constituents (from analysis of filtered samples) unless noted otherwise.

To determine if biosolids effects were present, an understanding of the uncertainty in the water-quality data is important. Water-quality data generally are presented in the form of tables of numbers, where a specific number in the table corresponds with the concentration value of a single constituent in a water sample collected from a specific site at a specific time. The numbers in these orderly tables give the impression that the concentration of the constituent is known precisely. However, the numbers presented as water-quality data are actually estimates of that constituent that would be more realistically represented as a range of numbers in a table, or a vertical bar instead of a point on a time-series graph. In fact, the actual or true concentration of any constituent is not known precisely because uncertainty is contributed to each number by laboratory methods, sampling methods, sampling equipment, field conditions, shipping or storage methods, and even by the variability in concentration of that constituent within the water being sampled. The amount of uncertainty contributed by each of these factors varies, which contributes to a unique total uncertainty (sometimes called “error”) for each number presented in the water-quality data tables. Because the amount of uncertainty contributed by each factor varies, total uncertainty is difficult to quantify and even more difficult to present in a table or graph. Uncertainty can be described in terms of variability and bias in the data. Analyses of quality-control samples (such as replicates and blanks) provide information about the uncertainty (variability and bias) in the water-quality data. Differences between replicate samples indicate variability, and detections in blank samples plus participation in performance-evaluation programs indicate bias. Types of quality-control samples collected for the study area in 1993–1999 are discussed in the Approach section. The much stricter sampling protocols and the many more quality-control samples implemented during 1995–1999 indicated that most of the variability and bias in the chemical data originated in the laboratory and was not from field processing or aquifer variation (inherently present in the aquifers). The quality-control data indicated that variability in nitrate concentration, however, likely resulted from aquifer variation.

Nitrate can be analyzed directly in water samples, but for this study usually was analyzed as nitrite plus nitrate as nitrogen, where a separate analysis of nitrite indicated that most of the nitrogen was in the nitrate form. The 1993–1998 samples were analyzed for nitrite concentrations, as well as for nitrite plus nitrate concentrations. The laboratory data indicate that nitrite usually represented less than 10 percent of the nitrite plus nitrate concentration in groundwater samples from the study area, except where concentrations were very small (near the MRL where uncertainty is large) such as in samples from wells D15, D16, D21, D22, and D23. Even in samples from these groundwater sites, nitrite concentration usually was less than 50 percent of the nitrite-plus-nitrate concentration. Therefore, nitrite plus nitrate as nitrogen is referred to as nitrate in the remainder of this report.

24 Water Quality at a Biosolids-Application Area near Deer Trail, Colorado, 1993–1999

Table 5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998.

[All data except field properties are for filtered samples analyzed at the Metro Wastewater Reclamation District laboratory; detailed well information is listed in appendix 1; associated quality-control data are included in appendixes 2–8; Temp., temperature; °C, degrees Celsius; W.L. ft bmp, depth to groundwater in feet below measuring point; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; CaCO₃, calcium carbonate; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; GW, groundwater; --, no data; <, less than; C1, first composite; c, calculated from calibration data; PW, pore water; ft, feet]

Sample site (fig. 2; table 2)	Sample date	Sample type	Temp., air, field, °C	W.L. ft bmp	Dissolved oxygen, field, mg/L	pH, field, standard units	Specific conductance, field, µS/cm	Temp., water, field, °C	Alkalinity, lab, mg/L as CaCO ₃	Hardness, mg/L as CaCO ₃	Dis-solved solids, residue at 180 °C, mg/L	Calcium, mg/L	Chloride, mg/L	Potassium, mg/L	Magnesium, mg/L
D2	10/14/1993	GW	--	--	--	7.4	4,350	12.7	273	2,650	3,950	510	22	5.0	397
D2	10/27/1993	GW	--	--	--	7.1	4,380	13.7	273	2,910	4,530	560	22	5.7	438
D2	11/9/1993	GW	--	--	--	--	4,370	13.4	267	2,940	4,610	456	23	5.4	367
D2	10/4/1994	GW	--	12.93	--	7.4	4,310	14.8	282	2,860	4,470	432	22	5.1	401
D2	5/2/1995	GW	--	12.42	--	7.7	4,380	11.9	287	3,020	4,500	471	17	5.0	391
D2	9/27/1995	GW	--	12.98	--	7.3	4,430	16.5	280	510	5,604	461	25	5.0	421
D2	12/15/1995	GW	9	12.75	2.2	7.3	4,230	12.6	282	2,960	4,530	535	18	4.0	430
D2	3/7/1996	GW	-7	12.56	1.9	7.4	4,320	10.7	283	3,000	4,580	496	23	4.0	384
D2	6/12/1996	GW	21	12.44	1.4	7.0	4,380	11.6	280	2,900	4,540	488	23	4.0	459
D2	8/21/1996	GW	35	11.43	1.8	7.1	4,200	12.8	293	2,950	4,640	543	16	6.0	435
D2	11/7/1996	GW	9	11.76	2.0	7.4	4,380	13.0	295	3,050	4,770	535	18	6.0	421
D2	2/25/1997	GW	4	11.73	1.9	7.2	4,450	10.8	286	3,350	4,680	514	14	5.0	449
D2	6/3/1997	GW	22	12.20	1.8	7.1	4,300	11.5	289	3,460	4,750	485	18	<0.1	413
D2	8/27/1997	GW	24	11.87	1.6	7.3	4,420	13.7	289	3,930	4,750	487	15	<0.1	420
D2	11/19/1997	GW	4	11.86	1.3	7.4	4,340	13.1	291	2,740	4,770	497	15	10.0	436
D2	1/7/1998	GW	-2.2	11.86	1.4	7.2	4,360	12.0	271	3,130	4,690	483	14	5.0	422
D2	4/14/1998	GW	17	11.70	1.4	7.4	4,420	10.9	284	2,750	4,750	616	14	<0.1	465
D2	7/16/1998	GW	24	12.96	1.5	7.4	4,250	12.3	285	3,220	5,080	594	17	5.0	535
D3	10/14/1993	GW	--	40.00	--	7.0	2,630	11.7	116	1,510	2,330	460	28	4.8	105
D3	10/26/1993	GW	--	--	--	7.5	2,530	13.5	113	1,560	2,360	480	29	5.6	107
D3	11/9/1993	GW	--	--	--	--	2,510	13.1	118	1,540	2,350	446	31	5.2	103
D3	9/29/1994	GW	--	40.13	2.3	6.9	2,430	18.7	120	1,400	2,240	400	31	5.5	104
D3	5/2/1995	GW	--	40.17	--	7.4	2,520	14.1	105	1,530	2,380	429	24	5.0	103
D3	9/20/1995	GW	--	40.25	--	7.2	2,570	12.2	106	1,450	2,390	431	34	5.0	101
D3	12/14/1995	GW, C1	7	40.16	2.0	7.0	2,300	13.9	110	1,550	2,310	474	28	4.0	96
D3	3/6/1996	GW	-12	40.18	1.8	6.8	2,390	13.0	119	1,420	2,180	442	33	5.0	110
D3	6/13/1996	GW	27	40.21	2.2	6.8	2,400	20.1	120	1,420	2,230	409	36	4.0	106
D3	8/25/1997	GW	25	39.76	3.5	6.6	2,390	18.8	122	1,180	2,220	400	28	4.0	115
D3	11/17/1997	GW	10	39.70	2.6	6.8	1,270	13.7	124	1,140	2,180	347	27	5.0	99
D3	1/6/1998	GW	-5	39.71	3.7	6.8	2,290	16.1	111	1,410	2,130	392	24	5.0	111
D3	4/16/1998	GW	-2	39.63	3.4	7.2	2,220	14.7	124	1,260	2,130	417	25	<0.1	117
D4	10/14/1993	GW	--	27.41	--	7.1	961	12.5	128	475	683	147	4	3.4	31
D4	10/26/1993	GW	--	--	--	7.4	1,010	9.4	123	448	741	136	21	18.7	28
D4	11/9/1993	GW	--	--	--	--	938	11.5	123	450	698	138	6	2.2	30
D4	9/29/1994	GW	--	--	--	7.0	850	14.6	128	428	628	117	5	2.8	25
D4	5/2/1995	GW	--	27.66	--	8.6	788	14.4	135	388	583	108	5	3.0	24
D4	7/12/1995	GW	35	27.25	--	7.3	809	--	122	395	610	110	2	3.0	25
D4	9/22/1995	GW	--	27.30	--	7.0	780	14.4	130	400	617	112	4	3.0	25
D4	12/13/1995	GW	--	27.35	--	6.5	890	13.0	125	637	644	121	4	2.0	26
D4	3/6/1996	GW	-14	27.55	3.2	6.7	838	7.6	174	404	639	134	<1	3.0	27
D4	6/14/1996	GW	22	27.57	3.4	6.5	715	16.8	122	312	552	99	4	2.0	23
D4	2/20/1997	GW	8	27.08	3.6	6.6	679	12.8	122	315	494	101	2	2.0	22
D4	6/5/1997	GW	25	27.09	3.2	6.6	624	18.1	126	280	471	84	4	2.0	22
D4	8/26/1997	GW	27	26.84	3.3	6.8	630	19.5	126	227	483	86	3	2.0	22
D5	10/14/1993	GW	--	--	--	7.2	4,290	11.8	245	2,460	3,590	515	32	5.2	313
D5	10/27/1993	GW	--	--	--	7.3	4,290	10.7	246	2,520	4,290	580	35	5.7	337
D5	11/9/1993	GW	--	--	--	--	4,270	11.9	242	2,620	4,200	530	35	3.4	318
D5	10/3/1994	GW	--	16.20	--	7.4	4,270	14.1	249	2,520	4,270	518	34	6.5	324
D5	5/3/1995	GW	--	15.39	--	8.2	4,300	10.8	248	2,680	4,220	634	25	5.0	388
D5	9/27/1995	GW	--	14.37	--	7.3	4,200	15.4	241	3,790	4,215	475	38	4.0	277
D5	3/8/1996	GW, C1	-3.5	15.31	1.5	7.0	4,110	10.3	241	2,440	4,220	495	41	5.0	292
D5	6/11/1996	GW	29	15.50	<0.5	6.9	4,320	12.0	244	2,690	4,240	463	39	3.0	280
D5	8/22/1996	GW	25	15.19	0.6	7.2	4,200	12.0	258	2,430	4,300	556	29	5.0	317

Table 5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data except field properties are for filtered samples analyzed at the Metro Wastewater Reclamation District laboratory; detailed well information is listed in appendix 1; associated quality-control data are included in appendixes 2–8; Temp., temperature; °C, degrees Celsius; W.L. ft bmp, depth to groundwater in feet below measuring point; mg/L, milligrams per liter; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; CaCO_3 , calcium carbonate; N, nitrogen; P, phosphorus; $\mu\text{g}/\text{L}$, micrograms per liter; GW, groundwater; --, no data; <, less than; C1, first composite; c, calculated from calibration data; PW, pore water; ft, feet]

Sample site (fig. 2; table 2)	Sample date	Sodium, mg/L	Sulfate, mg/L	Nitrogen, ammonia plus organic, mg/L as N	Nitrogen, ammonia, mg/L as N	Nitrogen, nitrite, mg/L as N	Nitrogen, nitrite plus nitrate, mg/L as N	Phosphorus, ortho-phosphate, mg/L as P	Cadmium, $\mu\text{g}/\text{L}$	Chromium, $\mu\text{g}/\text{L}$	Copper, $\mu\text{g}/\text{L}$	Iron, $\mu\text{g}/\text{L}$	Lead, $\mu\text{g}/\text{L}$	Manganese, $\mu\text{g}/\text{L}$	Nickel, $\mu\text{g}/\text{L}$	Zinc, $\mu\text{g}/\text{L}$
D2	10/14/1993	160	2,710	0.4	<0.1	<0.02	0.11	0.07	0.3	<20	<20	<50	<10	<20	50	<20
D2	10/27/1993	180	2,930	<0.3	<0.1	<0.02	0.19	0.06	0.1	<20	<20	<50	<10	<20	<20	<20
D2	11/9/1993	162	2,860	0.4	<0.1	<0.02	0.19	0.07	0.5	<20	<20	<50	<10	<20	50	20
D2	10/4/1994	161	2,710	<0.3	<0.1	<0.02	0.15	0.06	0.6	<20	<20	<50	<10	<20	<20	<20
D2	5/2/1995	186	2,800	0.3	<0.1	<0.02	0.45	0.06	<0.2	<20	<20	<50	<10	<20	<20	<20
D2	9/27/1995	180	2,900	<0.3	<0.1	<0.02	0.20	0.23	0.1	<40	<40	<100	<10	<40	<40	<40
D2	12/15/1995	142	3,000	0.5	<0.1	<0.02	0.18	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20
D2	3/7/1996	163	3,000	<0.3	<0.1	<0.02	0.17	0.06	<0.2	<40	<40	<100	<10	<40	<40	<40
D2	6/12/1996	173	2,800	<0.3	<0.1	<0.02	0.19	<0.02	<0.2	<40	<40	<100	<10	<40	<40	<40
D2	8/21/1996	196	3,100	<0.3	<0.1	<0.02	0.19	0.06	<0.2	<20	<20	<50	<10	<20	<20	<20
D2	11/7/1996	184	3,030	<0.3	<0.1	<0.02	0.31	0.08	<0.2	<20	<20	<50	<10	<20	<20	<20
D2	2/25/1997	210	3,010	<0.3	<0.1	<0.02	0.25	0.03	<0.2	<20	<20	<50	<10	<20	<20	<20
D2	6/3/1997	210	2,890	<0.3	<0.1	<0.02	0.30	<0.02	0.1	200	40	50	<10	<60	90	<60
D2	8/27/1997	214	2,800	<0.3	<0.1	<0.02	0.39	<0.02	<0.2	<60	<60	<150	<10	<60	<60	<60
D2	11/19/1997	216	2,780	0.8	<0.1	<0.02	0.45	0.04	<0.2	<20	<20	<50	<10	<20	<20	<20
D2	1/7/1998	198	2,960	<0.3	<0.1	<0.02	0.45	0.03	<0.2	50	<20	<50	<10	<20	<20	<20
D2	4/14/1998	196	3,180	<0.3	<0.1	<0.02	0.50	<0.02	<0.2	140	<20	<50	<10	<20	<20	<20
D2	7/16/1998	181	3,020	2.1	<0.1	<0.02	0.49	<0.02	<0.2	90	<40	<100	<10	<40	<40	<40
D3	10/14/1993	50	1,450	<0.3	<0.1	0.05	2.59	0.11	0.5	<20	<20	<50	<10	970	<20	<20
D3	10/26/1993	90	1,450	<0.3	<0.1	0.05	2.88	0.12	0.7	<20	<20	<50	<10	850	<20	20
D3	11/9/1993	58	1,400	0.4	<0.1	0.06	2.60	0.08	0.9	<20	<20	<50	<10	610	<20	40
D3	9/29/1994	66	1,330	0.4	<0.1	<0.02	3.74	0.08	0.1	<20	<20	<50	<10	300	20	<20
D3	5/2/1995	62	1,530	0.4	<0.1	<0.02	3.24	0.10	0.1	<20	<20	<50	<10	670	<20	20
D3	9/20/1995	59	1,400	<0.3	<0.1	<0.02	2.97	0.11	0.3	<20	<20	<50	<10	940	<20	<20
D3	12/14/1995	37	1,400	0.4	<0.1	<0.02	2.85	<0.02	0.1	<20	<20	<50	<10	550	40	<20
D3	3/6/1996	62	1,450	<0.3	<0.1	<0.02	3.57	<0.02	0.1	<20	<20	<50	<10	260	100	<20
D3	6/13/1996	56	1,360	<0.3	<0.1	<0.02	3.55	<0.02	0.1	<20	<20	<50	<10	310	<20	<20
D3	8/25/1997	68	1,130	<0.3	<0.1	<0.02	3.86	<0.02	<0.2	<20	<20	<50	<10	240	<20	<20
D3	11/17/1997	61	1,240	<0.3	<0.1	<0.02	3.90	0.07	<0.2	<20	<20	<50	<10	240	20	<20
D3	1/6/1998	72	1,320	<0.3	<0.1	<0.02	3.89	0.04	0.1	<20	<20	<50	<10	280	<20	<20
D3	4/16/1998	68	1,400	<0.3	<0.1	<0.02	3.82	<0.02	0.1	<200	<200	<500	<10	310	<200	<200
D4	10/14/1993	24	374	0.5	<0.1	<0.02	0.84	0.27	0.2	<20	<20	<50	<10	120	<20	<20
D4	10/26/1993	23	333	<0.3	<0.1	<0.02	0.95	0.29	0.3	<20	<20	<50	<10	80	<20	70
D4	11/9/1993	24	374	0.3	<0.1	<0.02	0.91	0.28	0.9	<20	<20	<50	<10	80	<20	<20
D4	9/29/1994	22	298	<0.3	<0.1	<0.02	0.99	0.30	0.2	<100	<100	<250	<10	40	140	<100
D4	5/2/1995	20	258	0.9	<0.1	0.02	1.01	0.25	0.3	<20	<20	<50	<10	40	<20	20
D4	7/12/1995	18	307	<0.3	<0.1	0.02	0.90	0.27	<0.2	<20	<20	<50	<10	30	20	<20
D4	9/22/1995	22	285	<0.3	<0.1	0.02	0.90	0.25	0.6	<20	<20	<50	<10	40	<20	<20
D4	12/13/1995	17	317	<0.3	<0.1	0.02	0.79	0.08	<0.2	<20	<20	<50	<10	30	40	<20
D4	3/6/1996	18	288	<0.3	<0.1	0.02	0.79	0.09	0.1	<20	<20	110	<10	<20	140	<20
D4	6/14/1996	15	270	<0.3	<0.1	0.02	0.91	0.27	<0.2	<20	<20	<50	<10	<20	<20	<20
D4	2/20/1997	20	174	0.4	<0.1	0.02	0.87	0.28	<0.2	<20	<20	<50	<10	<20	<20	<20
D4	6/5/1997	21	200	<0.3	<0.1	0.02	0.91	0.28	<0.2	<20	<20	<50	<10	<20	<20	<20
D4	8/26/1997	19	183	<0.3	<0.1	0.02	0.86	0.23	<0.2	<20	<20	<50	<10	<20	<20	<20
D5	10/14/1993	225	2,630	0.8	<0.1	0.03	5.42	0.03	1.0	<20	<20	<50	<10	<20	60	<20
D5	10/27/1993	280	2,640	<0.3	<0.1	0.04	5.74	<0.02	0.3	<20	<20	<50	<10	<20	<20	20
D5	11/9/1993	240	2,680	0.3	<0.1	0.06	5.45	0.04	1.0	<20	<20	<50	<10	<20	50	20
D5	10/3/1994	283	2,720	0.3	<0.1	<0.02	6.39	0.04	0.3	<20	<20	<50	<10	<20	<20	<20
D5	5/3/1995	227	3,320	<0.3	<0.1	<0.02	6.29	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20
D5	9/27/1995	244	2,590	0.4	<0.1	<0.02	6.08	0.14	<0.2	<40	<40	<100	<10	<40	<40	<40
D5	3/8/1996	229	2,730	<0.3	<0.1	<0.02	6.20	0.03	<0.2	<40	<40	<100	<10	<40	<40	<40
D5	6/11/1996	226	2,610	<0.3	<0.1	<0.02	6.26	<0.02	<0.2	<40	<40	<100	<10	<40	<40	<40
D5	8/22/1996	266	2,900	0.5	<0.1	<0.02	6.46	<0.02	<0.2	<40	<40	<100	<10	<40	<40	<40

Table 5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data except field properties are for filtered samples analyzed at the Metro Wastewater Reclamation District laboratory; detailed well information is listed in appendix 1; associated quality-control data are included in appendixes 2–8; Temp., temperature; °C, degrees Celsius; W.L. ft bmp, depth to groundwater in feet below measuring point; mg/L, milligrams per liter; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; CaCO_3 , calcium carbonate; N, nitrogen; P, phosphorus; $\mu\text{g}/\text{L}$, micrograms per liter; GW, groundwater; --, no data; <, less than; C1, first composite; c, calculated from calibration data; PW, pore water; ft, feet]

Sample site (fig. 2; table 2)	Sample date	Sample type	Temp., air, field, °C	W.L. ft bmp	Dissolved oxygen, field, mg/L	pH, field, standard units	Specific conductance, field, $\mu\text{S}/\text{cm}$	Temp., water, field, °C	Alkalinity, lab, mg/L as CaCO_3	Hardness, mg/L as CaCO_3	Dissolved solids, residue at 180 °C, mg/L	Calcium, mg/L	Chloride, mg/L	Potassium, mg/L	Magnesium, mg/L
D5	11/8/1996	GW	10	15.02	1.1	7.2	4,100	12.3	249	2,960	4,290	576	30	5.0	336
D5	2/26/1997	GW	-2	15.36	0.7	7.0	4,220	10.9	242	2,630	4,300	550	31	5.0	253
D5	6/4/1997	GW	22	15.67	<0.5	7.1	4,260	11.3	247	2,590	4,370	494	29	<0.1	321
D5	8/26/1997	GW	24	15.58	0.6	7.1	4,120	12.4	235	2,590	4,400	510	30	<0.1	326
D5	11/18/1997	GW	7	15.35	0.6	7.3	4,230	12.4	244	2,200	4,290	504	32	6.0	325
D5	1/8/1998	GW	9	15.42	1.0	7.4	4,150	11.6	236	2,630	4,330	518	29	<0.1	349
D5	4/15/1998	GW	7	15.72	1.1	7.3	4,290	10.2	236	2,650	4,310	482	29	<0.1	269
D5	7/15/1998	GW	34	15.99	<0.5	7.1	4,280	13.3	241	2,480	4,400	600	31	4.0	297
D6	10/14/1993	GW	--	--	--	7.3	15,000	12.8	573	8,060	15,800	400	370	11.0	1,940
D6	10/26/1993	GW	--	--	--	7.4	--	10.4	579	8,900	17,900	400	373	16.0	2,130
D6	11/9/1993	GW	--	--	--	--	15,000	12.4	564	8,890	17,700	440	348	12.0	1,860
D6	10/3/1994	GW	--	9.90	--	7.2	15,400	11.9	602	9,270	18,700	444	387	18.0	2,100
D6	5/3/1995	GW	--	9.00	--	7.7	--	10.0	723	10,300	19,320	403	364	12.0	2,100
D6	9/20/1995	GW	--	8.63	--	7.1	--	12.5	407	10,100	18,500	411	480	12.0	2,320
D6	12/13/1995	GW	11.1	9.20	--	6.9	15,300	11.8	613	9,980	19,100	378	458	13.0	2,030
D6	3/7/1996	GW	-7	9.60	1.0	7.1	15,000	10.4	634	10,100	19,200	400	515	12.0	2,000
D6	6/11/1996	GW	27	8.24	<0.5	6.8	15,800	11.9	611	9,790	18,600	410	380	11.0	2,160
D6	8/22/1996	GW	25	7.78	1.2	7.0	--	11.5	614	9,680	19,100	418	187	12.0	2,150
D6	11/7/1996	GW	10	7.90	0.5	7.2	15,200	11.4	624	10,000	19,400	447	210	12.0	2,290
D6	2/26/1997	GW	3	8.35	0.7	6.9	15,400	10.5	626	10,100	19,200	469	414	10.0	2,070
D6	6/4/1997	GW	24	8.68	0.5	7.0	15,600	11.3	632	13,100	19,300	413	402	<0.1	1,990
D6	8/27/1997	GW	29	6.39	1.8	7.1	15,600	12.1	655	11,000	19,400	429	412	<0.1	2,030
D6	11/19/1997	GW	--	6.77	0.8	7.3	15,300	11.8	634	10,200	19,700	417	443	<0.1	1,980
D6	1/7/1998	GW	3.3	6.84	<0.5	7.0	15,300	11.5	593	10,200	19,500	383	410	9.0	2,160
D6	4/15/1998	GW	7	5.86	0.7	7.2	15,300	10.2	606	10,400	19,800	538	370	10.0	2,210
D6	7/16/1998	GW	26	8.04	<0.5	7.2	15,100	12.3	649	10,286	21,000	491	497	<0.1	2,250
D7	10/14/1993	GW	--	--	--	7.4	2,450	13.7	209	1,380	2,170	390	15	3.6	122
D7	10/27/1993	GW	--	--	--	7.3	2,410	13.2	202	1,415	2,220	400	16	11.2	123
D7	11/9/1993	GW	--	--	--	--	2,470	12.3	210	1,520	2,270	370	18	3.6	119
D7	9/29/1994	GW	--	13.29	--	7.6	2,180	14.4	204	1,380	2,060	340	16	3.0	110
D7	5/2/1995	GW	--	13.27	--	8.1	2,250	11.3	189	1,450	2,020	333	12	3.0	112
D7	7/12/1995	GW	40	12.67	--	7.2	2,260	12.2	183	1,350	2,030	346	18	3.0	116
D7	8/20/1996	GW	25	12.09	2.1	7.1	2,250	13.2	192	1,300	2,120	348	12	4.0	111
D7	11/7/1996	GW	9	11.73	1.0	7.4	2,190	12.4	190	1,540	2,050	363	13	3.0	111
D7	2/25/1997	GW	4	11.81	1.1	7.0	2,140	10.3	187	1,320	2,140	342	<1	3.0	116
D7	6/3/1997	GW	22	11.92	0.7	7.1	2,310	10.7	201	1,310	2,160	381	12	2.0	131
D8	10/14/1993	GW	--	--	--	7.3	4,280	13.5	305	2,250	3,950	520	65	5.0	245
D8	10/26/1993	GW	--	--	--	7.2	4,250	12.8	308	2,380	4,130	530	66	4.8	241
D8	11/9/1993	GW	--	--	--	--	4,310	12.9	306	2,200	4,130	520	68	5.2	260
D8	9/29/1994	GW	--	10.96	--	7.6	4,540	19.2	335	2,630	4,770	530	72	5.5	260
D8	5/2/1995	GW	--	10.66	--	7.6	4,580	11.3	326	2,530	4,570	589	45	5.0	290
D8	7/12/1995	GW	35	10.47	--	7.2	4,530	13.3	326	2,490	4,490	538	68	5.0	264
D8	9/22/1995	GW	--	10.74	--	7.1	4,320	10.8	325	2,520	4,489	555	66	5.0	265
D8	12/13/1995	GW	--	10.59	--	7.0	4,280	12.0	331	2,450	4,490	596	61	5.0	264
D8	3/5/1996	GW	--	10.58	0.5	6.5	4,310	9.9	328	2,280	4,400	566	70	5.0	249
D8	6/11/1996	GW	27	10.63	<0.5	6.5	4,500	11.7	331	2,400	4,460	556	65	4.0	246
D8	8/27/1997	GW	38	9.31	0.5	7.1	4,040	13.0	319	2,410	4,210	527	47	<0.1	255
D8	11/19/1997	GW	4	8.66	0.9	6.9	4,100	--	320	1,900	4,190	517	48	11.0	253
D8	1/7/1998	GW	5	8.53	<0.5	7.2	4,070	10.8	301	2,320	4,000	504	45	5.0	212
D8	4/14/1998	GW	17	8.34	0.6	7.1	4,040	9.3	303	2,300	3,970	566	42	<0.1	218
D8	7/15/1998	GW	35	9.91	<0.5	6.9	3,960	12.6	300	2,320	3,980	584	42	4.0	214

Table 5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data except field properties are for filtered samples analyzed at the Metro Wastewater Reclamation District laboratory; detailed well information is listed in appendix 1; associated quality-control data are included in appendixes 2–8; Temp., temperature; °C, degrees Celsius; W.L. ft bmp, depth to groundwater in feet below measuring point; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; CaCO₃, calcium carbonate; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; GW, groundwater; --, no data; <, less than; C1, first composite; c, calculated from calibration data; PW, pore water; ft, feet]

Sample site (fig. 2; table 2)	Sample date	Sodium, mg/L	Sulfate, mg/L	Nitrogen, ammonia plus organic, mg/L as N	Nitrogen, ammonia, mg/L as N	Nitrogen, nitrite, mg/L as N	Nitrogen, nitrite plus nitrate, mg/L as N	Phosphorus, ortho-phosphate, mg/L as P	Cadmium, µg/L	Chromium, µg/L	Copper, µg/L	Iron, µg/L	Lead, µg/L	Manganese, µg/L	Nickel, µg/L	Zinc, µg/L
D5	11/8/1996	214	2,500	<0.3	<0.1	0.04	6.75	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20
D5	2/26/1997	237	2,550	0.5	<0.1	0.02	6.73	0.04	0.1	<20	<20	<50	<10	<20	<20	<20
D5	6/4/1997	248	2,600	<0.3	<0.1	<0.02	7.05	0.03	<0.2	120	<60	<150	<10	<60	30	40
D5	8/26/1997	256	2,770	0.3	<0.1	<0.02	6.96	<0.02	<0.2	100	<40	250	<10	<40	<40	<40
D5	11/18/1997	270	2,580	0.4	<0.1	<0.02	6.86	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20
D5	1/8/1998	252	2,640	<0.3	<0.1	<0.02	6.67	<0.02	<0.2	120	<20	<50	<10	<20	<20	<20
D5	4/15/1998	197	2,530	0.4	<0.1	<0.02	6.75	<0.02	<0.2	<40	<40	<100	<10	<40	<40	<40
D5	7/15/1998	259	2,650	0.5	<0.1	<0.02	7.12	<0.02	<0.2	80	<40	<100	<10	<40	<40	<40
D6	10/14/1993	1,700	11,600	1.4	<0.1	0.23	4.81	0.05	2.0	<20	<20	<50	<10	3,400	160	<20
D6	10/26/1993	2,000	11,800	1.0	<0.1	0.12	5.36	0.08	0.6	<20	<20	<50	<10	7,400	200	30
D6	11/9/1993	1,660	10,400	1.6	<0.1	0.07	4.95	0.06	3.8	<20	<20	<50	<10	<20	130	20
D6	10/3/1994	1,900	12,200	1.3	<0.1	0.07	5.80	0.04	0.2	<20	<20	<50	<10	3,430	20	<20
D6	5/3/1995	1,690	12,600	1.2	<0.1	0.07	7.25	0.06	<0.2	<20	<20	<50	<10	3,630	<20	<20
D6	9/20/1995	2,150	12,200	0.6	<0.1	0.06	7.54	0.04	0.2	<200	<200	<500	<10	3,480	<200	<200
D6	12/13/1995	1,740	12,000	1.1	<0.1	0.05	6.76	0.04	0.2	<20	<20	<50	<10	3,460	20	<20
D6	3/7/1996	1,920	12,500	1.5	<0.1	0.02	6.98	0.05	0.1	<200	<200	<500	<10	3,500	40	<200
D6	6/11/1996	1,970	12,200	1.2	<0.1	0.02	8.07	0.04	<0.2	<200	<200	<500	<10	3,700	<200	<200
D6	8/22/1996	1,850	12,000	1.7	<0.1	0.05	8.03	0.06	0.2	<200	<200	<500	<10	3,420	<200	<200
D6	11/7/1996	2,140	11,700	1.2	<0.1	0.09	8.40	0.06	0.2	<20	<20	<50	<10	3,670	<20	<20
D6	2/26/1997	2,100	11,100	0.9	<0.1	0.04	7.91	0.05	0.2	<20	<20	<50	<10	3,710	<20	<20
D6	6/4/1997	1,940	13,600	1.0	<0.1	0.02	8.17	0.06	0.2	90	30	<500	<10	6,200	120	30
D6	8/27/1997	1,960	14,400	1.6	<0.1	<0.02	8.67	<0.02	0.1	340	<200	<500	<10	3,880	<200	<200
D6	11/19/1997	1,990	10,400	1.0	<0.1	<0.02	8.37	<0.02	0.2	<20	<20	<50	<10	4,640	30	<20
D6	1/7/1998	2,180	13,170	1.1	<0.1	<0.02	8.61	0.04	<0.2	150	<20	<50	<10	3,820	110	<20
D6	4/15/1998	1,860	12,900	1.7	<0.1	<0.02	8.68	<0.02	<0.2	320	<40	<100	<10	4,820	<40	<40
D6	7/16/1998	1,990	13,000	1.7	<0.1	<0.02	9.65	<0.02	0.1	390	<200	<500	<10	3,630	<200	<200
D7	10/14/1993	80	1,250	0.5	<0.1	0.04	1.02	0.10	1.1	<20	<20	<50	<10	850	<20	<20
D7	10/27/1993	60	1,340	<0.3	<0.1	0.03	1.23	0.10	0.1	<20	<20	<50	10	750	<20	<20
D7	11/9/1993	64	1,320	0.4	<0.1	0.61	0.78	0.11	0.9	<20	<20	<50	<10	1,010	<20	20
D7	9/29/1994	64	1,300	0.3	<0.1	0.05	1.27	0.11	0.5	<40	<40	<100	<10	880	<40	<40
D7	5/2/1995	58	1,140	0.6	<0.1	0.06	1.50	0.07	0.1	<20	<20	<50	<10	530	<20	<20
D7	7/12/1995	59	1,240	<0.3	<0.1	<0.02	1.44	0.07	0.1	<20	<20	<50	<10	510	<20	<20
D7	8/20/1996	58	1,240	0.3	<0.1	1.10	1.16	0.11	0.2	<20	<20	<50	<10	870	<20	<20
D7	11/7/1996	64	1,230	<0.3	<1.0	0.03	1.57	0.10	0.1	<20	<20	<50	<10	790	<20	<20
D7	2/25/1997	60	1,080	<0.3	<0.1	0.02	1.41	0.08	0.2	<20	<20	<50	<10	260	<20	<20
D7	6/3/1997	70	1,270	<0.3	<0.1	0.03	1.44	0.08	0.2	50	<20	1,090	<10	390	90	<20
D8	10/14/1993	260	2,510	1.0	<0.1	0.02	<0.02	0.06	1.0	<20	<20	<50	<10	3,100	20	<20
D8	10/26/1993	280	2,520	0.5	<0.1	<0.02	0.06	0.09	0.3	<20	<20	<50	<10	6,900	30	50
D8	11/9/1993	290	2,540	0.7	<0.1	<0.02	0.04	0.08	0.6	<20	<20	<50	<10	4,160	30	20
D8	9/29/1994	314	2,730	0.8	<0.1	0.02	<0.02	0.08	0.4	<20	<20	<50	<10	3,220	<20	<20
D8	5/2/1995	326	2,700	1.1	<0.1	<0.02	0.04	0.06	0.1	<20	<20	<50	<10	3,370	<20	<20
D8	7/12/1995	282	2,750	0.5	0.2	<0.02	<0.02	0.06	0.3	<40	<40	<100	<10	3,350	<40	<40
D8	9/22/1995	342	2,650	<0.3	<0.1	<0.02	0.03	0.06	0.5	<40	<40	<100	<10	3,300	<40	<40
D8	12/13/1995	302	2,700	0.7	<0.1	<0.02	<0.02	0.10	0.4	<20	<20	<50	<10	3,180	<20	<20
D8	3/5/1996	303	2,780	<0.3	<0.1	<0.02	0.02	0.08	0.2	<40	<40	<100	<10	2,620	<40	<40
D8	6/11/1996	336	2,670	0.6	<0.1	<0.02	0.04	0.05	0.2	<20	<20	<50	<10	3,670	<20	<20
D8	8/27/1997	333	2,400	0.7	<0.1	<0.02	0.03	<0.02	0.2	<40	<40	<100	<10	3,120	<40	<40
D8	11/19/1997	311	2,490	0.7	<0.1	<0.02	<0.02	0.04	0.1	<20	<20	<50	<10	4,480	<20	<20
D8	1/7/1998	324	2,560	0.7	<0.1	<0.02	0.04	0.04	0.1	<20	<20	<50	<10	3,070	<20	<20
D8	4/14/1998	280	2,700	0.7	<0.1	<0.02	0.04	<0.02	0.3	<40	<40	<100	<10	3,010	<40	<40
D8	7/15/1998	261	2,420	0.9	<0.1	<0.02	<0.02	0.07	0.1	30	<40	<100	<10	3,030	<40	<40

Table 5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data except field properties are for filtered samples analyzed at the Metro Wastewater Reclamation District laboratory; detailed well information is listed in appendix 1; associated quality-control data are included in appendixes 2–8; Temp., temperature; °C, degrees Celsius; W.L. ft bmp, depth to groundwater in feet below measuring point; mg/L, milligrams per liter; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; CaCO_3 , calcium carbonate; N, nitrogen; P, phosphorus; $\mu\text{g}/\text{L}$, micrograms per liter; GW, groundwater; --, no data; <, less than; C1, first composite; c, calculated from calibration data; PW, pore water; ft, feet]

Sample site (fig. 2; table 2)	Sample date	Sample type	Temp., air, field, °C	W.L. ft bmp	Dissolved oxygen, field, mg/L	pH, field, standard units	Specific conductance, field, $\mu\text{S}/\text{cm}$	Temp., water, field, °C	Alkalinity, lab, mg/L as CaCO_3	Hardness, mg/L as CaCO_3	Dissolved solids, residue at 180 °C, mg/L	Calcium, mg/L	Chloride, mg/L	Potassium, mg/L	Magnesium, mg/L
D9	10/14/1993	GW	--	--	--	7.3	1,670	12.0	255	906	1,230	285	6	2.3	49
D9	10/26/1993	GW	--	--	--	7.5	1,690	12.2	261	955	1,410	305	7	2.2	53
D9	11/9/1993	GW	--	--	--	6.9	1,740	9.6	257	1,120	1,400	298	8	6.4	53
D9	7/20/1994	GW	--	--	--	8.0	337	13.2	136	155	178	48	2	1.2	7
D9	10/4/1994	GW	--	57.91	--	7.3	2,410	12.5	245	1,490	2,300	415	10	2.7	110
D9	5/3/1995	GW	--	57.80	--	8.4	2,100	11.3	260	1,470	1,820	363	8	4.0	84
D9	9/28/1995	GW	--	56.76	--	7.2	1,540	16.3	284	879	1,190	250	6	2.0	47
D9	12/15/1995	GW	--	56.93	--	7.1	1,530	11.2	277	938	1,310	301	5	1.0	52
D9	3/7/1996	GW	-9	57.19	7.6	7.1	1,640	14.1	258	1,280	1,930	382	6	<0.1	76
D9	6/14/1996	GW, C1	27	57.40	8.7	6.7	2,410	18.9	251	1,340	2,190	395	14	<0.1	96
D9	8/21/1996	GW	33	57.47	6.4	6.9	2,570	18.5	231	1,830	2,690	506	11	3.0	138
D9	11/6/1996	GW	6	57.52	5.1	7.0	2,180	14.9	263	1,130	1,980	354	9	2.0	69
D9	2/21/1997	GW	--	57.45	6.4	6.7	2,080	10.0	228	1,950	2,730	542	<1	<0.1	146
D9	6/5/1997	GW	23	57.58	5.7	6.8	2,530	16.5	223	2,130	2,730	472	12	3.0	130
D9	8/25/1997	GW	29	57.63	5.5	7.0	2,260	22.4	248	1,440	2,250	380	9	<0.1	87
D9	11/17/1997	GW	5	57.57	5.5	6.8	2,370	10.8	227	1,420	2,930	516	11	4.0	156
D9	1/6/1998	GW	-4	57.61	5.5	6.8	2,860	9.8	213	1,950	2,850	515	7	2.0	156
D9	4/15/1998	GW	5	57.57	6.3	7.1	2,350	14.3	223	1,700	2,870	533	8	<0.1	142
D9	7/16/1998	GW	26	57.59	5.7	7.1	2,040	19.9	263	1,700	2,490	512	8	<0.1	127
D10	10/14/1993	GW	--	--	--	7.3	4,670	12.6	265	2,630	4,340	480	22	16.4	393
D10	10/27/1993	GW	--	--	--	7.3	4,540	15.0	353	2,835	4,580	500	23	8.1	406
D10	11/9/1993	GW	--	--	--	--	4,610	12.5	362	3,040	4,600	478	39	16.8	388
D10	10/3/1994	GW	--	11.95	--	7.2	4,870	14.1	356	3,910	5,010	520	28	24.0	443
D10	5/3/1995	GW	--	11.77	--	7.8	5,060	9.4	354	1,570	5,160	521	22	14.0	445
D10	9/27/1995	GW	--	11.76	--	7.3	5,140	18.2	351	2,420	5,257	498	37	19.0	437
D10	12/12/1995	GW	--	11.79	--	7.4	4,690	12.7	342	2,920	4,840	450	23	15.0	445
D10	3/8/1996	GW	-7	11.82	3.7	7.1	4,580	9.4	331	2,790	4,650	462	26	14.0	364
D10	6/12/1996	GW	29	11.80	3.3	7.0	4,670	11.6	338	2,800	4,730	419	28	15.0	384
D10	8/22/1996	GW	25	11.70	3.6	7.1	4,560	13.7	331	2,800	4,700	512	19	17.0	414
D10	11/7/1996	GW	10	11.48	2.1	7.4	4,700	13.0	340	3,180	4,920	524	20	18.0	418
D10	2/25/1997	GW	14	11.50	3.2	7.1	4,810	9.8	351	3,200	4,940	501	20	19.0	413
D10	6/5/1997	GW, C1	22	11.51	3.2	7.0	4,620	11.2	382	3,270	4,720	440	20	15.0	388
D10	8/26/1997	GW	25	11.19	2.1	7.1	4,550	14.1	376	2,880	4,890	471	20	16.0	402
D10	11/18/1997	GW	7	10.98	1.4	7.2	4,860	13.3	394	2,560	4,280	490	26	20.0	422
D10	4/15/1998	GW	6	10.87	1.7	7.3	4,830	8.4	409	3,200	4,820	644	21	14.0	482
D10	7/15/1998	GW	36	10.88	1.3	7.0	4,800	13.5	422	2,970	4,920	530	33	18.0	480
D11a	1/8/1998	GW	5	112.87	4.7	7.4	368	12.5	171	178	248	47	<1	2.0	16
D11a	4/13/1998	GW	9	113.01	1.2	7.3	383	7.4	172	176	232	52	<1	<0.1	16
D11a	7/14/1998	GW	33	112.87	1.5	7.8	387	18.4	169	189	251	57	1	<0.1	18
D12	10/26/1993	GW	--	--	--	7.6	1,980	10.9	217	1,030	1,630	264	11	1.3	105
D12	11/9/1993	GW	--	--	--	6.9	1,990	11.3	217	1,210	1,660	244	12	17.1	102
D12	10/4/1994	GW	--	35.72	--	7.4	2,000	14.3	228	1,070	1,710	261	11	4.9	106
D12	5/2/1995	GW	--	35.68	--	7.8	2,010	13.4	230	1,220	1,720	248	10	5.0	104
D12	9/20/1995	GW	--	35.50	--	7.0	2,010	13.5	223	1,130	1,630	268	11	5.0	112
D12	3/5/1996	GW	--	35.43	--	7.3	1,940	14.4	235	1,100	1,700	262	9	5.0	106
D12	6/13/1996	GW	21	35.46	3.4	7.0	2,010	14.5	234	1,100	1,700	252	12	4.0	107
D12	8/20/1996	GW	25	35.46	6.4	7.3	2,110	15.2	231	1,070	1,710	278	8	5.0	114
D12	11/6/1996	GW	6	35.39	5.2	7.2	2,000	13.1	232	1,100	1,840	259	8	5.0	104
D12	2/21/1997	GW	--	35.30	3.7	7.0	1,920	12.7	224	1,100	1,660	261	<1	5.0	104

Table 5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data except field properties are for filtered samples analyzed at the Metro Wastewater Reclamation District laboratory; detailed well information is listed in appendix 1; associated quality-control data are included in appendixes 2–8; Temp., temperature; °C, degrees Celsius; W.L. ft bmp, depth to groundwater in feet below measuring point; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; CaCO₃, calcium carbonate; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; GW, groundwater; --, no data; <, less than; C1, first composite; c, calculated from calibration data; PW, pore water; ft, feet]

Sample site (fig. 2; table 2)	Sample date	Sodium, mg/L	Sulfate, mg/L	Nitrogen, ammonia plus organic, mg/L as N	Nitrogen, ammonia, mg/L as N	Nitrogen, nitrite, mg/L as N	Nitrogen, nitrite plus nitrate, mg/L as N	Phosphorus, ortho-phosphate, mg/L as P	Cadmium, µg/L	Chromium, µg/L	Copper, µg/L	Iron, µg/L	Lead, µg/L	Manganese, µg/L	Nickel, µg/L	Zinc, µg/L
D9	10/14/1993	30	685	0.5	<0.1	<0.02	12.50	0.06	0.2	<20	<20	<50	<10	<20	<20	<20
D9	10/26/1993	35	636	<0.3	<0.1	<0.02	12.90	0.08	0.2	<20	<20	<50	<10	60	<20	<20
D9	11/9/1993	32	640	0.7	<0.1	<0.02	13.00	0.09	0.7	<20	<20	<50	<10	<20	<20	<20
D9	7/20/1994	<10	10	0.4	<0.1	<0.02	2.34	0.12	<0.2	<200	<200	<500	<10	<200	<200	<200
D9	10/4/1994	49	1,320	0.6	<0.1	<0.02	11.00	0.09	0.8	<20	<20	<50	<10	<20	<20	30
D9	5/3/1995	39	960	0.8	<0.1	<0.02	16.90	0.08	0.3	<20	<20	<50	<10	<20	<20	<20
D9	9/28/1995	30	475	<0.3	<0.1	<0.02	26.70	0.08	<0.2	<20	<20	<50	<10	<20	<20	<20
D9	12/15/1995	27	600	0.3	<0.1	<0.02	27.00	0.05	0.2	<20	<20	<50	<10	<20	<20	<20
D9	3/7/1996	30	1,080	0.3	<0.1	<0.02	20.00	<0.02	<0.2	<20	<20	<50	<10	<20	80	<20
D9	6/14/1996	35	1,190	<0.3	<0.1	<0.02	12.90	0.06	<0.2	<20	<20	<50	<10	<20	<20	<20
D9	8/21/1996	41	1,580	1.1	<0.1	<0.02	9.60	0.07	<0.2	<20	<20	<50	<10	<20	<20	<20
D9	11/6/1996	39	1,120	<0.3	<0.1	<0.02	10.40	0.05	<0.2	<20	<20	<50	<10	<20	<20	<20
D9	2/21/1997	57	1,600	<0.3	<0.1	<0.02	8.41	0.06	<0.2	<20	<20	<50	<10	<20	<20	<20
D9	6/5/1997	62	1,400	0.8	<0.1	<0.02	15.30	0.08	0.1	170	20	<100	<10	30	<40	30
D9	8/25/1997	44	935	0.3	<0.1	<0.02	20.00	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20
D9	11/17/1997	65	1,590	<0.3	<0.1	<0.02	20.10	0.09	<0.2	<20	<20	<50	<10	<20	30	<20
D9	1/6/1998	66	1,690	0.4	<0.2	<0.02	21.00	0.05	<0.2	<20	<20	<50	<10	<20	30	<20
D9	4/15/1998	56	1,720	1.6	<0.1	<0.02	24.30	0.03	<0.2	<40	<40	<100	<10	<40	<40	<40
D9	7/16/1998	52	1,370	0.5	<0.1	<0.02	24.10	0.06	<0.2	30	<20	<50	<10	<20	<20	<20
D10	10/14/1993	240	2,900	0.6	<0.1	<0.02	2.40	0.16	0.6	<20	<20	<50	<10	<20	70	<20
D10	10/27/1993	280	2,900	<0.3	<0.1	<0.02	2.54	0.16	1.9	<20	<20	<50	<10	<20	60	<20
D10	11/9/1993	265	2,700	0.6	<0.1	<0.02	2.18	0.18	1.8	<20	<20	<50	<10	<20	60	20
D10	10/3/1994	312	3,350	0.3	<0.1	0.02	0.72	0.16	0.1	<40	<40	<100	<10	<40	<40	<40
D10	5/3/1995	280	3,400	<0.3	<0.1	<0.02	1.09	0.15	<0.2	<20	<20	<50	<10	<20	<20	<20
D10	9/27/1995	392	3,100	<0.3	<0.1	<0.02	2.61	0.28	0.1	<40	<40	<100	<10	<40	30	<40
D10	12/12/1995	270	2,900	0.5	<0.1	<0.02	5.61	0.14	0.1	<20	<20	<50	<10	<20	<20	<20
D10	3/8/1996	316	3,080	0.5	<0.1	<0.02	6.04	0.14	<0.2	<40	<40	<100	<10	<40	<40	<40
D10	6/12/1996	259	2,910	<0.3	<0.1	<0.02	3.66	0.12	<0.2	<20	<20	<50	<10	<20	<20	<20
D10	8/22/1996	236	2,990	0.6	<0.1	<0.02	2.18	0.13	<0.2	<40	<40	<100	<10	<40	<40	<40
D10	11/7/1996	286	2,620	<0.3	<0.1	<0.02	2.64	0.18	<0.2	<20	<20	<50	<10	<20	<20	<20
D10	2/25/1997	313	2,840	<0.3	<0.1	<0.02	3.13	0.13	<0.2	<20	<20	<50	<10	<20	<20	<20
D10	6/5/1997	319	2,760	0.6	<0.1	<0.02	3.62	0.17	0.2	150	30	<150	<10	<60	90	50
D10	8/26/1997	297	2,900	0.4	<0.1	<0.02	3.00	0.13	<0.2	100	<60	<150	<10	<60	<60	<60
D10	11/18/1997	328	2,820	1.1	<0.1	<0.02	4.71	0.12	<0.2	<20	<20	<50	<10	<20	<20	<20
D10	4/15/1998	357	2,980	0.5	<0.1	<0.02	5.59	0.12	<0.2	<40	<40	<100	<10	<40	<40	<40
D10	7/15/1998	299	3,220	0.8	<0.1	<0.02	4.61	0.13	<0.2	70	<40	<100	<10	<40	<40	<40
D11a	1/8/1998	18	44	<0.3	<0.1	<0.02	0.27	0.07	0.1	<20	<20	<50	<10	40	<20	430
D11a	4/13/1998	8	34	<0.3	<0.1	<0.02	1.16	0.07	<0.2	<20	<20	<50	<10	<20	<20	200
D11a	7/14/1998	9	24	<0.3	<0.1	<0.02	1.14	0.10	<0.2	<20	<20	<50	<10	<20	<20	130
D12	10/26/1993	94	1,000	<0.3	<0.1	<0.02	0.10	0.05	0.1	<20	<20	<50	<10	210	<20	100
D12	11/9/1993	84	1,020	0.6	<0.1	0.08	0.14	0.03	0.4	<20	<20	<50	<10	220	20	110
D12	10/4/1994	90	987	<0.3	<0.1	<0.02	1.19	<0.02	0.1	<20	<20	<50	<10	30	<20	40
D12	5/2/1995	80	930	0.9	<0.1	<0.02	1.04	<0.02	0.1	<20	<20	<50	<10	60	<20	<20
D12	9/20/1995	87	950	<0.3	<0.1	<0.02	0.73	0.04	<0.2	<20	<20	130	<10	<20	130	<20
D12	3/5/1996	74	936	<0.3	<0.1	<0.02	1.02	<0.02	0.2	<20	<20	<50	<10	<20	100	<20
D12	6/13/1996	69	1,020	<0.3	<0.1	<0.02	1.09	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20
D12	8/20/1996	81	956	0.5	<0.1	<0.02	1.04	0.05	<0.2	<20	<20	<50	<10	20	<20	<20
D12	11/6/1996	76	1,060	<0.3	<0.1	<0.02	1.18	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20
D12	2/21/1997	79	910	<0.3	<0.1	<0.02	1.14	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20

30 Water Quality at a Biosolids-Application Area near Deer Trail, Colorado, 1993–1999

Table 5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data except field properties are for filtered samples analyzed at the Metro Wastewater Reclamation District laboratory; detailed well information is listed in appendix 1; associated quality-control data are included in appendixes 2–8; Temp., temperature; °C, degrees Celsius; W.L. ft bmp, depth to groundwater in feet below measuring point; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; CaCO₃, calcium carbonate; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; GW, groundwater; --, no data; <, less than; C1, first composite; c, calculated from calibration data; PW, pore water; ft, feet]

Sample site (fig. 2; table 2)	Sample date	Sample type	Temp., air, field, °C	W.L. ft bmp	Dissolved oxygen, field, mg/L	pH, field, standard units	Specific conductance, field, µS/cm	Temp., water, field, °C	Alkalinity, lab, mg/L as CaCO ₃	Hardness, mg/L as CaCO ₃	Dissolved solids, residue at 180 °C, mg/L	Calcium, mg/L	Chloride, mg/L	Potassium, mg/L	Magnesium, mg/L
D13	7/18/1994	GW	--	--	1.2	7.1	--	22.5	232	665	1,200	191	3	3.0	54
D13	7/21/1994	GW	--	--	--	7.4	1,390	17.6	229	685	1,100	189	6	2.4	54
D13	7/27/1994	GW	--	--	--	--	--	--	230	672	1,090	190	4	3.0	54
D13	10/3/1994	GW	--	7.15	--	7.3	1,480	14.3	262	727	1,160	202	4	2.8	57
D13	5/3/1995	GW	--	6.82	--	8.4	1,360	8.8	250	695	1,030	183	3	2.0	54
D13	7/13/1995	GW	30	7.33	--	8.1	1,350	14.4	248	655	1,010	179	1	3.0	52
D13	9/25/1995	GW	--	8.02	--	--	1,360	12.0	246	990	1,077	191	5	3.0	56
D13	12/13/1995	GW	--	7.37	--	7.1	1,340	11.3	241	721	1,060	164	3	2.0	46
D13	3/6/1996	GW	-12	7.06	--	7.0	1,260	6.0	249	727	994	195	<1	3.0	54
D13	6/13/1996	GW	26	6.96	0.6	6.8	1,330	11.7	246	740	1,040	192	4	2.0	57
D13	8/20/1996	GW	32	5.55	0.6	7.0	1,610	14.8	267	989	1,360	246	4	3.0	68
D13	11/7/1996	GW	10	5.96	0.6	7.2	1,920	11.9	291	1,350	1,680	298	6	3.0	78
D13	2/25/1997	GW	14	5.64	0.8	6.9	1,610	7.0	267	920	1,450	238	<1	2.0	67
D13	6/2/1997	GW	21	6.55	0.7	6.9	1,640	10.0	268	757	1,290	206	4	2.0	60
D13	8/25/1997	GW	30	6.90	0.5	6.9	1,630	14.8	272	699	1,320	223	4	3.0	65
D13	11/17/1997	GW	8	6.38	0.7	7.3	1,650	11.4	272	845	1,350	237	3	3.0	68
D13	1/6/1998	GW	-6	6.04	0.7	7.4	1,520	8.0	256	939	1,280	225	<1	3.0	71
D13	4/13/1998	GW	12	5.40	0.7	7.3	1,620	7.4	261	828	1,300	265	1	<0.1	70
D13	7/14/1998	GW	33	8.23	0.5	7.2	1,590	12.9	252	777	1,360	256	3	3.0	66
D14	7/18/1994	GW	--	--	2.1	7.4	--	12.9	204	350	538	106	5	3.0	19
D14	7/21/1994	GW	--	--	--	7.7	764	12.4	155	360	526	108	8	4.9	19
D14	7/27/1994	GW	--	--	--	--	--	--	199	353	524	112	4	2.0	20
D14	10/3/1994	GW	--	12.45	--	7.6	769	12.2	227	346	533	104	5	2.2	19
D14	5/3/1995	GW	--	12.53	--	8.1	777	11.5	209	367	530	110	4	2.0	20
D14	7/13/1995	GW	30	12.14	--	8.2	778	11.8	202	410	528	109	6	2.0	20
D14	9/25/1995	GW	--	11.39	--	--	735	12.0	222	357	523	107	12	2.0	21
D14	12/13/1995	GW	--	11.47	--	7.3	755	12.4	216	412	525	118	4	2.0	21
D14	3/6/1996	GW	--	11.65	--	7.3	734	9.1	220	364	522	110	<1	<0.1	19
D14	8/20/1996	GW	32	10.53	0.5	7.1	747	13.2	216	360	1,710	108	4	2.0	19
D14	2/25/1997	GW	10	10.78	1.6	7.1	727	11.3	243	339	473	104	<1	2.0	19
D14	6/2/1997	GW	18	10.99	1.0	7.0	809	11.0	254	341	512	106	5	1.0	23
D14	8/25/1997	GW	33	11.03	<0.5	7.0	773	12.5	242	373	545	111	4	2.0	24
D14	11/17/1997	GW	10	10.55	0.5	7.6	775	12.3	257	360	464	112	3	3.0	24
D14	1/6/1998	GW	-5	10.57	0.7	7.6	731	11.3	231	475	516	108	<1	2.0	24
D14	4/15/1998	GW	5	10.55	0.8	7.4	786	10.0	236	360	534	132	1	1.0	24
D14	7/14/1998	GW	--	10.78	0.6	7.4	778	12.2	244	357	598	127	4	1.0	24
D15	7/18/1994	GW	--	--	3.6	6.9	--	13.3	536	2,670	5,310	569	23	7.0	372
D15	7/21/1994	GW	--	--	--	6.9	5,240	13.4	522	2,720	4,830	532	24	6.0	362
D15	7/27/1994	GW	--	--	--	--	--	--	533	2,730	5,520	488	24	8.0	345
D15	9/30/1994	GW	--	8.10	--	6.7	6,020	12.7	584	2,980	5,940	505	25	6.7	422
D15	5/4/1995	GW	--	5.74	--	8.2	5,400	10.8	566	3,570	5,440	468	17	5.0	367
D15	7/13/1995	GW	30	5.52	--	8.1	4,950	12.9	513	2,360	4,230	483	25	5.0	336
D15	12/14/1995	GW, C1	7	5.38	1.7	6.8	4,680	10.9	529	2,500	4,840	449	19	5.0	355
D15	3/6/1996	GW	-8	5.10	--	6.5	4,710	8.9	538	2,620	4,900	476	23	5.0	298
D15	6/12/1996	GW	25	5.00	<0.5	6.2	4,880	10.8	521	2,540	4,700	456	29	3.0	276
D15	8/21/1996	GW	35	6.62	<0.5	6.4	4,760	11.9	528	2,580	4,680	550	20	5.0	314
D15	2/26/1997	GW, C1	-2	5.37	<0.5	6.7	5,050	8.9	544	2,580	5,020	472	20	<0.1	332
D15	6/4/1997	GW	20	5.65	0.8	6.5	4,640	9.5	556	1,980	4,560	465	22	<0.1	293
D15	8/25/1997	GW	32	5.19	<0.5	6.5	4,580	11.7	564	2,500	4,620	491	21	<0.1	307
D15	11/20/1997	GW	8	5.31	<0.5	6.4	4,430	10.9	575	2,080	4,500	494	23	<0.1	302
D15	4/14/1998	GW	4	3.83	0.6	6.8	5,280	8.3	612	2,750	5,260	602	27	<0.1	361
D15	7/16/1998	GW	21	6.59	0.5	6.7	5,000	10.7	615	3,320	5,420	565	28	5.0	275

Table 5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data except field properties are for filtered samples analyzed at the Metro Wastewater Reclamation District laboratory; detailed well information is listed in appendix 1; associated quality-control data are included in appendixes 2–8; Temp., temperature; °C, degrees Celsius; W.L. ft bmp, depth to groundwater in feet below measuring point; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; CaCO₃, calcium carbonate; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; GW, groundwater; --, no data; <, less than; C1, first composite; c, calculated from calibration data; PW, pore water; ft, feet]

Sample site (fig. 2; table 2)	Sample date	Sodium, mg/L	Sulfate, mg/L	Nitrogen, ammonia plus organic, mg/L as N	Nitrogen, ammonia, mg/L as N	Nitrogen, nitrite, mg/L as N	Nitrogen, nitrite plus nitrate, mg/L as N	Phosphorus, ortho-phosphate, mg/L as P	Cadmium, µg/L	Chromium, µg/L	Copper, µg/L	Iron, µg/L	Lead, µg/L	Manganese, µg/L	Nickel, µg/L	Zinc, µg/L
D13	7/18/1994	67	542	<0.3	<0.1	<0.02	0.03	<0.02	<0.2	60	<40	<100	<10	50	<40	<40
D13	7/21/1994	69	562	<0.3	<0.1	<0.02	0.02	<0.02	<0.2	60	<20	<50	<10	<20	<20	<20
D13	7/27/1994	62	570	1.0	<0.1	<0.02	0.03	<0.02	<0.2	60	<20	<50	<10	<20	<20	<20
D13	10/3/1994	67	604	0.4	<0.1	<0.02	<0.02	<0.02	0.1	<20	<20	<50	<10	100	<20	<20
D13	5/3/1995	61	539	0.7	<0.1	<0.02	0.02	<0.02	<0.2	<20	<20	<50	<10	40	<20	<20
D13	7/13/1995	61	570	0.9	<0.1	<0.02	<0.02	<0.02	<0.2	<20	<20	<50	<10	50	<20	<20
D13	9/25/1995	64	540	<0.3	<0.1	<0.02	<0.02	<0.02	0.1	<20	<20	<50	<10	40	<20	<20
D13	12/13/1995	47	440	<0.3	<0.1	<0.02	<0.02	<0.02	0.1	<20	<20	<50	<10	70	<20	<20
D13	3/6/1996	51	503	<0.3	<0.1	<0.02	<0.02	<0.02	0.2	<20	<20	<50	<10	120	<20	<20
D13	6/13/1996	53	523	<0.3	<0.1	<0.02	<0.02	<0.02	0.1	<20	<20	110	<10	240	<20	<20
D13	8/20/1996	66	727	1.4	<0.1	<0.02	<0.02	0.05	0.1	<20	<20	<50	<10	60	<20	<20
D13	11/7/1996	83	906	<0.3	<0.1	<0.02	0.03	<0.02	<0.2	<20	<20	<50	<10	230	<20	<20
D13	2/25/1997	78	850	<0.3	<0.1	<0.02	<0.02	<0.02	0.2	<20	<20	<50	<10	130	<20	<20
D13	6/2/1997	77	685	<0.3	<0.1	<0.02	0.03	<0.02	<0.2	<20	<20	<50	<10	120	<20	<20
D13	8/25/1997	79	635	<0.3	<0.1	<0.02	0.02	<0.02	<0.2	<20	<20	<50	<10	110	<20	<20
D13	11/17/1997	84	753	<0.3	<0.1	<0.02	<0.02	0.06	<0.2	<20	<20	<50	<10	100	<20	<20
D13	1/6/1998	84	737	<0.3	<0.1	<0.02	0.03	<0.02	<0.2	<20	<20	<50	<10	100	<20	<20
D13	4/13/1998	76	886	<0.3	<0.1	<0.02	<0.02	<0.02	<0.2	<20	<20	<50	<10	110	<20	<20
D13	7/14/1998	72	699	0.4	<0.1	<0.02	0.02	<0.02	<0.2	20	<20	<50	<10	150	<20	<20
D14	7/18/1994	28	113	<0.3	<0.1	0.05	3.85	0.06	<0.2	30	<20	<50	<10	270	<20	<20
D14	7/21/1994	31	173	0.4	<0.1	0.04	3.65	<0.02	<0.2	20	<40	<100	<10	260	<40	<40
D14	7/27/1994	27	176	1.0	<0.1	0.05	4.07	0.05	<0.2	20	<20	<50	<10	270	<20	<20
D14	10/3/1994	34	171	0.6	<0.1	0.05	3.15	0.06	30.2	<20	<20	<50	<10	180	<20	<20
D14	5/3/1995	28	187	0.5	<0.1	0.06	3.91	0.04	<0.2	<20	<20	<50	<10	240	<20	<20
D14	7/13/1995	26	198	0.9	0.1	0.04	<0.02	0.04	<0.2	<20	<20	<50	<10	260	<20	<20
D14	9/25/1995	30	176	<0.3	<0.1	<0.02	3.06	<0.02	0.1	<20	<20	<50	<10	100	<20	30
D14	12/13/1995	26	183	<0.3	<0.1	0.04	3.44	0.05	0.1	<20	<20	<50	<10	220	<20	<20
D14	3/6/1996	21	178	<0.3	<0.1	0.04	3.45	0.08	0.1	<20	<20	<50	<10	150	<20	<20
D14	8/20/1996	22	188	0.4	<0.1	0.03	3.51	0.07	0.1	<20	<20	<50	<10	110	<20	<20
D14	2/25/1997	30	190	<0.3	<0.1	0.02	3.66	0.05	0.1	<20	<20	<50	<10	100	<20	<20
D14	6/2/1997	33	139	<0.3	<0.1	0.02	3.48	0.08	<0.2	<20	<20	<50	<10	30	<20	30
D14	8/25/1997	31	155	<0.3	<0.1	0.03	3.56	0.05	<0.2	20	<20	<50	<10	90	<20	<20
D14	11/17/1997	32	154	<0.3	<0.1	<0.02	3.59	0.09	<0.2	<20	<20	<50	<10	80	<20	<20
D14	1/6/1998	33	172	<0.3	<0.1	<0.02	3.76	0.05	<0.2	<20	<20	<50	<10	70	<20	<20
D14	4/15/1998	30	279	<0.3	<0.1	<0.02	4.22	<0.02	<0.2	<20	<20	<50	<10	50	<20	<20
D14	7/14/1998	29	155	0.6	<0.1	0.02	5.33	0.06	<0.2	<20	<20	<50	<10	30	<20	<20
D15	7/18/1994	470	3,190	1.8	<0.1	<0.02	<0.02	0.03	<0.2	140	<80	1,780	<10	18,490	<80	<80
D15	7/21/1994	519	3,760	1.8	<0.1	<0.02	<0.02	<0.02	<0.2	140	<40	2,000	<10	5,000	<40	<40
D15	7/27/1994	433	3,430	2.1	<0.1	<0.02	0.04	<0.02	1.7	130	<80	1,960	<10	13,600	30	<80
D15	9/30/1994	647	3,630	2.0	1.0	0.04	<0.02	0.05	<0.2	<20	<20	3,720	<10	8,650	<20	40
D15	5/4/1995	522	3,350	1.6	0.6	<0.02	<0.02	0.04	<0.2	<20	<20	1,890	<10	8,670	<20	<20
D15	7/13/1995	480	3,150	1.6	1.0	<0.02	0.35	0.03	<0.2	<40	<40	1,800	<10	7,950	20	<40
D15	12/14/1995	555	2,900	1.3	0.6	<0.02	<0.02	<0.02	0.1	<20	<20	1,960	<10	8,010	20	<20
D15	3/6/1996	525	3,210	1.0	0.3	<0.02	<0.02	<0.02	0.1	<60	<60	1,680	<10	7,430	<60	<60
D15	6/12/1996	457	2,730	0.9	0.4	<0.02	<0.02	<0.02	<0.2	<20	<20	1,140	<10	7,410	40	<20
D15	8/21/1996	358	3,080	1.1	0.6	<0.02	<0.02	0.04	<0.2	<40	<40	2,370	<10	7,800	<40	<40
D15	2/26/1997	487	2,760	1.3	0.3	0.03	<0.02	0.04	<0.2	<20	<20	1,280	<10	7,880	<20	<20
D15	6/4/1997	386	2,700	1.2	<0.1	<0.02	<0.02	0.06	0.1	100	<60	2,670	<10	13,670	40	40
D15	8/25/1997	417	2,590	1.2	0.4	<0.02	<0.02	<0.02	<0.2	150	<40	1,540	<10	7,390	<40	<40
D15	11/20/1997	421	2,570	1.5	0.5	<0.02	<0.02	0.04	<0.2	<20	<20	1,750	<10	7,400	<20	<20
D15	4/14/1998	526	3,000	1.5	0.2	<0.02	<0.02	<0.02	<0.2	<60	<60	2,190	<10	11,500	<60	<60
D15	7/16/1998	469	2,960	1.5	<0.1	<0.02	<0.02	0.08	<0.2	50	<40	1,960	<10	7,880	<40	<40

32 Water Quality at a Biosolids-Application Area near Deer Trail, Colorado, 1993–1999

Table 5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data except field properties are for filtered samples analyzed at the Metro Wastewater Reclamation District laboratory; detailed well information is listed in appendix 1; associated quality-control data are included in appendixes 2–8; Temp., temperature; °C, degrees Celsius; W.L. ft bmp, depth to groundwater in feet below measuring point; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; CaCO₃, calcium carbonate; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; GW, groundwater; --, no data; <, less than; C1, first composite; c, calculated from calibration data; PW, pore water; ft, feet]

Sample site (fig. 2; table 2)	Sample date	Sample type	Temp., air, field, °C	W.L. ft bmp	Dissolved oxygen, field, mg/L	pH, field, standard units	Specific conductance, field, µS/cm	Temp., water, field, °C	Alkalinity, lab, mg/L as CaCO ₃	Hardness, mg/L as CaCO ₃	Dissolved solids, residue at 180 °C, mg/L	Calcium, mg/L	Chloride, mg/L	Potassium, mg/L	Magnesium, mg/L
D16	7/20/1994	GW	--	--	1.6	7.2	3,320	12.8	342	1,960	3,330	454	18	4.2	177
D16	7/21/1994	GW	--	--	--	--	3,470	12.7	312	1,880	2,960	364	26	4.4	145
D16	7/27/1994	GW	--	--	--	--	--	--	341	1,860	3,370	364	19	5.0	147
D16	9/30/1994	GW	--	8.59	--	6.8	3,440	12.8	365	1,960	3,410	450	21	4.6	180
D16	5/4/1995	GW	--	--	--	7.6	3,750	11.6	375	2,330	3,570	503	17	5.0	208
D16	7/13/1995	GW	32	6.57	--	7.0	3,860	13.1	328	2,180	3,220	515	23	5.0	210
D16	9/26/1995	GW	--	7.58	--	7.1	3,770	13.7	368	2,320	3,610	492	28	5.0	200
D16	12/14/1995	GW	--	7.08	1.6	7.0	3,570	11.8	368	2,070	3,560	508	21	3.0	196
D16	3/7/1996	GW	-14	7.09	0.5	6.6	3,630	9.9	366	2,020	3,590	490	23	4.0	185
D16	6/12/1996	GW	25	5.77	0.7	6.4	3,890	11.5	374	2,100	3,690	488	28	3.0	187
D16	8/21/1996	GW	30	8.35	<0.5	6.7	3,730	12.0	370	2,020	3,570	525	20	5.0	200
D16	11/20/1997	GW	12	5.86	<0.5	7.2	3,700	11.0	404	1,920	3,720	490	21	<0.1	203
D17	7/19/1994	GW	--	--	0.9	7.6	473	14.4	201	215	285	58	<1	2.0	18
D17	7/20/1994	GW	--	--	--	7.9	475	14.4	202	225	292	57	2	1.6	18
D17	9/29/1994	GW	--	12.00	--	7.6	470	14.6	202	224	274	54	3	1.6	17
D17	5/3/1995	GW	--	11.90	--	8.3	472	11.6	203	245	280	56	2	2.0	18
D17	7/13/1995	GW	31	11.13	--	8.1	480	12.6	203	208	285	55	2	<0.1	18
D17	8/22/1996	GW, C1	25	10.50	1.7	7.5	488	14.1	231	237	304	59	2	2.0	24
D17	11/6/1996	GW	3	10.85	1.3	7.7	473	13.0	220	260	290	64	2	1.0	19
D17	2/20/1997	GW	5	10.93	1.4	7.6	462	10.3	205	198	273	55	<1	2.0	20
D17	6/4/1997	GW	23	11.00	1.0	7.3	484	11.6	215	238	297	55	2	1.0	22
D17	8/25/1997	GW	25	10.93	0.7	7.2	468	13.3	203	225	288	57	2	1.0	23
D17	11/17/1997	GW	5	10.71	0.8	7.7	471	12.3	205	215	286	57	2	2.0	22
D17	1/6/1998	GW	-4	10.56	0.8	7.8	440	10.7	195	217	274	55	<1	<0.1	22
D17	4/14/1998	GW	11	10.32	1.2	7.7	477	9.7	205	272	288	63	<1	<0.1	21
D17	7/14/1998	GW	35	10.53	1.4	7.5	498	13.5	215	230	330	68	2	<0.1	26
D19	7/19/1994	GW	--	--	3.9	7.7	338	14.7	142	160	204	51	1	1.0	7
D19	7/28/1994	GW	--	--	--	--	--	--	142	172	199	53	3	1.0	7
D19	9/30/1994	GW	--	22.30	--	7.6	352	13.4	157	170	224	55	4	0.8	6
D19	5/4/1995	GW	--	22.34	--	8.1	333	12.6	140	152	193	49	1	<0.1	6
D19	7/13/1995	GW	31	22.22	--	7.3	342	14.3	139	152	205	51	<1	<0.1	6
D19	9/26/1995	GW	--	22.19	--	7.6	403	15.5	164	195	236	64	4	<0.1	6
D19	8/22/1996	GW	25	21.97	7.6	7.3	631	12.7	276	320	413	119	5	2.0	9
D19	11/6/1996	GW	7	21.78	6.6	7.5	569	11.5	280	300	360	120	3	<0.1	8
D19	2/20/1997	GW	7	21.90	6.9	7.4	663	11.3	306	330	414	117	4	<0.1	10
D19	6/3/1997	GW	27	22.02	7.2	7.2	720	11.8	302	375	451	122	13	<0.1	12
D19	7/14/1998	GW	34	20.73	7.3	7.3	636	13.7	259	303	407	127	5	<0.1	10
D20	7/19/1994	GW	--	--	1.7	7.5	3,120	14.6	255	1,760	2,950	430	6	8.0	55
D20	7/20/1994	GW	--	--	--	7.5	3,100	14.1	268	1,740	2,950	416	5	7.4	188
D20	7/28/1994	GW	--	--	--	--	--	--	267	1,870	3,090	425	7	8.0	180
D20	9/30/1994	GW	--	10.11	--	7.1	3,140	15.1	253	1,840	2,950	430	6	8.5	175
D20	5/4/1995	GW	--	8.90	--	7.7	3,380	11.1	285	2,920	3,210	495	6	7.0	184
D20	7/13/1995	GW	30	8.63	--	7.3	3,280	13.3	274	1,800	3,050	437	8	7.0	188
D20	9/26/1995	GW	--	8.87	--	7.3	2,990	18.0	258	1,740	2,820	419	7	8.0	151
D20	12/12/1995	GW	--	8.72	--	8.0	3,080	13.3	261	1,770	2,910	488	6	7.0	158
D20	3/7/1996	GW	-5	8.65	0.6	7.0	2,950	9.4	262	1,750	2,850	455	1	7.0	165
D20	6/12/1996	GW	25	8.39	1.0	6.8	3,030	12.1	256	1,700	2,810	398	8	5.0	145
D20	8/22/1996	GW	26	9.63	0.5	7.2	2,750	14.4	244	1,630	2,740	442	5	6.0	130
D20	11/6/1996	GW	6	9.31	0.6	7.4	2,900	13.7	259	1,700	2,820	438	6	7.0	152
D20	11/20/1997	GW	12	8.75	0.7	6.7	3,000	13.8	262	1,680	2,970	426	6	5.0	190
D21	7/19/1994	GW	--	--	1.8	7.2	1,190	14.4	351	520	737	156	4	5.0	30
D21	7/20/1994	GW	--	--	--	7.2	1,100	14.2	351	565	725	166	3	4.9	33
D21	10/3/1994	GW	--	11.20	--	7.2	1,150	13.9	360	555	790	167	5	5.4	32
D21	5/4/1995	GW	--	8.86	--	7.8	1,240	11.1	522	959	1,420	248	4	5.0	51

Table 5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data except field properties are for filtered samples analyzed at the Metro Wastewater Reclamation District laboratory; detailed well information is listed in appendix 1; associated quality-control data are included in appendixes 2–8; Temp., temperature; °C, degrees Celsius; W.L. ft bmp, depth to groundwater in feet below measuring point; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; CaCO₃, calcium carbonate; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; GW, groundwater; --, no data; <, less than; C1, first composite; c, calculated from calibration data; PW, pore water; ft, feet]

Sample site (fig. 2; table 2)	Sample date	Sodium, mg/L	Sulfate, mg/L	Nitrogen, ammonia plus organic, mg/L as N	Nitrogen, ammonia, mg/L as N	Nitrogen, nitrite, mg/L as N	Nitrogen, nitrite plus nitrate, mg/L as N	Phosphorus, ortho-phosphate, mg/L as P	Cadmium, µg/L	Chromium, µg/L	Copper, µg/L	Iron, µg/L	Lead, µg/L	Manganese, µg/L	Nickel, µg/L	Zinc, µg/L
D16	7/20/1994	219	1,980	0.9	<0.1	<0.02	<0.02	0.03	<0.2	100	<40	1,140	<10	2,090	<40	<40
D16	7/21/1994	221	1,600	1.1	<0.1	<0.02	0.03	<0.02	<0.2	100	<20	1,820	<10	1,910	50	<20
D16	7/27/1994	288	1,890	0.6	<0.1	0.02	<0.02	<0.02	<0.2	230	<40	530	<10	2,980	<40	<40
D16	9/30/1994	259	2,140	0.8	0.4	<0.02	<0.02	0.04	0.1	<40	<40	1,040	<10	2,300	<40	<40
D16	5/4/1995	246	2,220	1.3	<0.4	<0.02	<0.02	0.02	<0.2	<20	<20	1,180	<10	2,640	<20	<20
D16	7/13/1995	244	2,070	0.5	0.5	<0.02	<0.02	0.04	0.1	<20	<20	400	<10	2,350	<20	<20
D16	9/26/1995	246	2,170	0.6	<0.1	<0.02	<0.02	0.06	0.1	<40	<40	1,360	<10	2,370	<40	<40
D16	12/14/1995	156	2,140	0.8	0.3	<0.02	<0.02	<0.02	0.2	<20	<20	1,080	<10	2,320	<20	<20
D16	3/7/1996	217	2,340	0.7	0.3	<0.02	0.05	0.04	<0.2	<40	<40	1,540	<10	2,380	<40	<40
D16	6/12/1996	250	2,180	0.3	0.3	<0.02	<0.02	<0.02	0.2	<20	<20	1,260	<10	2,300	<20	<20
D16	8/21/1996	266	2,270	0.7	0.4	<0.02	<0.02	0.03	0.1	<40	<40	4,100	<10	2,630	2,520	5,460
D16	11/20/1997	262	2,260	0.7	0.2	<0.02	<0.02	0.04	<0.2	<20	<20	1,180	<10	2,480	<20	<20
D17	7/19/1994	17	32	<0.3	<0.1	0.02	0.44	0.12	<0.2	30	<20	<50	<10	370	<20	<20
D17	7/20/1994	16	33	0.5	<0.1	<0.02	0.44	0.07	<0.2	<40	<40	<100	<10	320	<40	<40
D17	9/29/1994	16	44	<0.3	<0.1	0.02	0.41	0.11	0.7	<20	<20	<50	<10	340	<20	<20
D17	5/3/1995	18	50	0.4	<0.1	0.03	0.40	0.09	<0.2	<20	<20	<50	<10	320	<20	<20
D17	7/13/1995	17	57	<0.3	<0.1	<0.02	0.20	0.10	0.2	<20	<20	<50	<10	340	<20	<20
D17	8/22/1996	13	40	<0.3	<0.1	<0.02	0.48	0.09	<0.2	<20	<20	<50	<10	200	<20	<20
D17	11/6/1996	15	37	<0.3	<0.1	<0.02	0.51	0.09	<0.2	<20	<20	<50	<10	380	<20	<20
D17	2/20/1997	18	42	<0.3	<0.1	<0.02	0.49	0.10	<0.2	<20	<20	<50	<10	200	<20	<20
D17	6/4/1997	18	41	<0.3	<0.1	<0.02	0.65	0.10	<0.2	<20	<20	<50	<10	240	<20	<20
D17	8/25/1997	17	66	<0.3	<0.1	<0.02	0.61	0.08	<0.2	<20	<20	<50	<10	320	<20	<20
D17	11/17/1997	18	42	<0.3	<0.1	<0.02	0.65	0.13	<0.2	<20	<20	<50	<10	270	<20	<20
D17	1/6/1998	20	49	<0.3	<0.1	<0.02	0.58	0.07	<0.2	<20	<20	<50	<10	220	<20	<20
D17	4/14/1998	15	55	<0.3	<0.1	<0.02	0.89	0.05	<0.2	<20	<20	<50	<10	200	<20	<20
D17	7/14/1998	15	46	0.4	<0.1	<0.02	1.78	0.05	<0.2	<20	<20	<50	<10	280	<20	<20
D19	7/19/1994	<1	16	<0.3	<0.1	<0.02	2.62	0.14	<0.2	<20	<20	<50	<10	<20	<20	<20
D19	7/28/1994	<1	18	<0.3	<0.1	<0.02	2.95	0.14	<0.2	<20	<20	<50	<10	<20	<20	<20
D19	9/30/1994	9	17	0.4	<0.1	<0.02	3.48	0.23	0.1	<200	<200	<500	<10	<200	<200	<200
D19	5/4/1995	8	27	<0.3	<0.1	<0.02	2.71	0.13	<0.2	<20	<20	<50	<10	<20	<20	<20
D19	7/13/1995	7	26	<0.3	<0.1	<0.02	0.02	0.19	<0.2	<20	<20	<50	<10	<20	<20	<20
D19	9/26/1995	9	30	0.3	<0.1	<0.02	4.91	0.16	0.1	<20	<20	<50	<10	<20	20	<20
D19	8/22/1996	10	53	0.9	<0.1	<0.02	9.78	0.26	<0.2	<20	<20	<50	<10	<20	<20	<20
D19	11/6/1996	10	22	<0.3	<0.1	<0.02	5.94	0.25	<0.2	<20	<20	70	<10	<20	<20	<20
D19	2/20/1997	11	19	0.7	<0.1	<0.02	9.45	0.27	<0.2	<20	<20	<50	<10	<20	<20	<20
D19	6/3/1997	15	45	<0.3	<0.1	<0.02	9.21	0.27	0.3	<20	<20	<50	<10	<20	<20	<20
D19	7/14/1998	13	38	0.5	<0.1	<0.02	8.54	0.24	<0.2	<20	<20	<50	<10	<20	<20	<20
D20	7/19/1994	168	1,750	0.3	<0.1	0.03	<0.02	0.18	<0.2	120	<40	<100	<10	210	<40	<40
D20	7/20/1994	167	1,940	0.4	<0.1	<0.02	<0.02	0.14	<0.2	110	<20	<50	<10	170	<20	<20
D20	7/28/1994	180	1,720	<0.3	<0.1	<0.02	<0.02	0.15	<0.2	240	<40	<100	<10	170	20	<40
D20	9/30/1994	162	1,860	0.5	<0.1	<0.02	<0.02	0.19	0.1	<200	<200	<500	<10	290	50	<200
D20	5/4/1995	174	2,150	0.5	<0.1	<0.02	0.03	0.16	<0.2	<20	<20	<50	<10	450	<20	<20
D20	7/13/1995	164	2,020	<0.3	0.2	<0.02	<0.02	0.16	<0.2	<20	<20	<50	<10	250	<20	<20
D20	9/26/1995	146	1,740	<0.3	<0.1	<0.02	<0.02	0.19	0.1	<20	<20	<50	<10	240	<20	<20
D20	12/12/1995	144	1,760	2.0	<0.1	<0.02	<0.02	0.19	0.2	<20	<20	<50	<10	330	<20	<20
D20	3/7/1996	152	1,980	<0.3	<0.1	<0.02	<0.02	0.17	0.1	<40	<40	<100	<10	500	<40	<40
D20	6/12/1996	126	1,620	<0.3	<0.1	<0.02	<0.02	0.14	0.1	<20	<20	<50	<10	370	<20	<20
D20	8/22/1996	116	1,750	0.5	<0.1	<0.02	<0.02	0.14	<0.2	<40	<40	<100	<10	540	<40	<40
D20	11/6/1996	144	1,830	<0.3	<0.1	<0.02	0.06	0.16	<0.2	<20	<20	<50	<10	660	<20	<20
D20	11/20/1997	190	1,660	0.3	<0.1	<0.02	<0.02	0.18	<0.2	<20	<20	<50	<10	510	<20	<20
D21	7/19/1994	39	239	2.0	0.3	<0.02	0.04	<0.02	<0.2	40	<20	700	<10	6,200	<20	<20
D21	7/20/1994	39	256	2.3	0.4	<0.02	<0.02	<0.02	<0.2	40	<20	320	<10	3,040	30	<20
D21	10/3/1994	38	228	2.1	1.7	0.03	<0.02	<0.02	0.1	<20	<20	7,770	<10	3,490	<20	<20
D21	5/4/1995	41	500	2.1	1.3	0.04	<0.02	<0.02	0.1	<20	<20	23,500	<10	3,560	<20	<20

Table 5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data except field properties are for filtered samples analyzed at the Metro Wastewater Reclamation District laboratory; detailed well information is listed in appendix 1; associated quality-control data are included in appendixes 2–8; Temp., temperature; °C, degrees Celsius; W.L. ft bmp, depth to groundwater in feet below measuring point; mg/L, milligrams per liter; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; CaCO_3 , calcium carbonate; N, nitrogen; P, phosphorus; $\mu\text{g}/\text{L}$, micrograms per liter; GW, groundwater; --, no data; <, less than; C1, first composite; c, calculated from calibration data; PW, pore water; ft, feet]

Sample site (fig. 2; table 2)	Sample date	Sample type	Temp., air, field, °C	W.L. ft bmp	Dissolved oxygen, field, mg/L	pH, field, standard units	Specific conductance, field, $\mu\text{S}/\text{cm}$	Temp., water, field, °C	Alkalinity, lab, mg/L as CaCO_3	Hardness, mg/L as CaCO_3	Dissolved solids, residue at 180 °C, mg/L	Calcium, mg/L	Chloride, mg/L	Potassium, mg/L	Magnesium, mg/L
D21	7/13/1995	GW	30	10.06	--	6.9	1,810	15.7	469	900	1,280	269	3	6.0	58
D21	12/12/1995	GW	--	9.46	--	7.5	1,190	11.9	425	618	928	184	5	2.0	36
D21	3/7/1996	GW	0	9.07	--	6.6	1,110	8.2	431	580	848	171	<1	<0.1	35
D21	6/12/1996	GW	25	9.56	0.7	6.5	1,110	11.6	195	540	813	155	7	1.0	32
D21	8/21/1996	GW	37	11.12	2.6	6.8	1,360	13.1	217	692	1,460	218	4	6.0	41
D21	1/7/1998	GW	5	8.80	2.4	7.1	1,180	10.4	369	640	875	184	3	2.0	45
D21	7/14/1998	GW	34	11.09	0.5	7.0	1,150	13.0	358	572	880	199	3	5.0	36
D22	7/20/1994	GW	--	--	5.5	7.3	10,100	14.8	561	5,190	10,700	378	49	14.0	1,340
D22	7/28/1994	GW	--	--	--	--	--	--	563	5,620	12,400	359	57	19.0	1,170
D22	10/3/1994	GW	--	19.81	--	7.4	11,100	14.5	589	5,410	12,600	490	65	25.0	1,290
D22	7/13/1995	GW	32	19.29	--	7.2	13,500	17.8	714	5,850	15,100	406	81	27.0	1,210
D22	8/23/1996	GW	--	18.80	<0.5	6.8	--	16.5	662	6,390	14,200	390	59	22.0	1,248
D22	11/6/1996	GW	3	18.62	<0.5	6.8	13,400	14.4	697	6,400	14,900	470	69	23.0	1,230
D22	2/20/1997	GW	6	18.51	<0.5	6.8	13,100	13.3	643	6,800	14,000	449	73	25.0	1,370
D22	6/2/1997	GW	21	18.45	<0.5	6.8	13,000	17.0	642	5,490	14,600	394	67	20.0	1,130
D22	4/16/1998	GW	--	18.13	<0.5	7.2	12,800	15.0	189	9,000	15,100	490	69	25.0	1,450
D22	7/15/1998	GW	30	18.18	0.5	7.2	12,500	14.9	662	6,620	14,400	479	65	23.0	1,340
D23	7/18/1994	GW	--	--	2.6	7.1	--	12.6	369	1,720	2,850	480	10	7.0	92
D23	7/21/1994	GW	--	--	--	7.1	3,080	13.8	237	1,620	2,400	424	7	5.7	100
D23	7/27/1994	GW	--	--	--	--	--	--	353	1,710	2,810	560	10	7.0	99
D23	9/30/1994	GW	--	6.92	--	6.9	3,080	13.6	371	1,660	2,840	494	11	5.0	104
D23	5/4/1995	GW	--	5.03	--	7.5	3,140	10.4	380	1,900	2,930	510	9	6.0	109
D23	7/13/1995	GW	30	5.36	--	7.1	3,150	11.8	370	1,920	2,940	452	12	6.0	112
D23	9/25/1995	GW	--	5.41	--	--	3,060	11.9	364	1,820	2,872	497	14	6.0	109
D23	12/15/1995	GW	3	5.06	0.5	7.0	2,970	10.5	359	1,800	2,890	529	10	6.0	102
D23	3/7/1996	GW	--	4.98	0.9	6.5	3,170	7.5	388	1,820	3,010	536	11	5.0	110
D23	6/12/1996	GW	20	4.82	0.7	6.4	3,200	10.3	367	1,680	2,900	476	15	4.0	104
D23	8/21/1996	GW	30	5.83	0.6	6.5	3,090	12.6	364	1,920	2,880	534	10	6.0	108
D23	11/8/1996	GW	15	4.61	<0.5	7.0	2,970	12.3	369	2,200	2,930	519	10	7.0	102
D23	2/26/1997	GW	--	4.47	<0.5	6.8	3,090	7.1	360	1,870	2,880	539	10	6.0	110
D23	6/4/1997	GW	22	4.95	0.9	6.6	3,120	9.2	376	2,020	2,960	452	11	5.0	107
D23	8/26/1997	GW	32	4.99	0.7	6.8	3,050	12.8	384	1,950	3,040	512	11	<0.1	134
D23	11/20/1997	GW	10	4.43	0.5	7.2	3,090	11.2	378	1,480	3,010	534	12	6.0	127
D23	1/8/1998	GW	9	4.29	0.6	7.1	3,060	9.0	358	1,820	3,020	512	11	<0.1	128
D23	4/16/1998	GW	--	4.53	<0.5	7.2	3,100	7.0	368	2,000	3,040	588	10	6.0	122
D23	7/16/1998	GW	26	5.87	0.5	6.9	2,990	12.0	374	1,770	3,150	585	12	<0.1	121
D24	9/28/1995	GW	--	22.42	--	7.1	1,260	15.4	584	465	741	213	3	2.0	43
D24	12/14/1995	GW	7	22.80	3.1	7.0	1,320	13.7	596	745	765	228	2	1.0	43
D24	3/6/1996	GW	-8	23.12	<0.5	7.0	1,270	11.4	672	752	792	208	<1	2.0	46
D24	6/14/1996	GW	26	23.52	3.8	6.7	1,300	15.5	592	720	777	209	4	1.0	41
D24	8/25/1997	GW	29	23.18	3.6	6.8	1,370	16.2	628	843	880	220	4	2.0	49
D24	11/17/1997	GW	8	23.19	2.2	6.8	1,380	13.3	647	720	887	236	3	3.0	53
D25	9/22/1995	GW	--	12.12	--	--	3,750	10.5	309	2,630	3,575	588	102	6.0	195
D25	12/13/1995	GW	--	12.24	--	7.4	3,280	12.0	288	2,260	3,350	612	93	5.0	131
D25	11/8/1996	GW, C1	10	7.67	0.7	7.3	5,310	12.8	588	3,640	5,630	818	153	8.0	335
D25	6/2/1997	GW	25	9.63	1.0	6.9	5,140	12.2	558	3,270	5,020	695	148	6.0	296
D25	8/27/1997	GW, C1	27	9.22	0.5	7.1	3,690	12.8	312	2,510	3,800	622	110	<0.1	162
D25	11/19/1997	GW, C1	6	8.12	1.2	7.2	4,570	12.0	493	2,240	4,630	699	127	10.0	242
D25	1/8/1998	GW, C1	5	8.39	0.7	7.3	4,480	10.0	486	2,690	4,530	692	118	<0.1	251
D25	4/16/1998	GW, C1	-2	8.70	0.8	7.1	4,510	8.4	478	2,700	4,490	801	118	8.0	260
D25	7/16/1998	GW, C1	24	9.86	0.6	7.1	3,900	12.4	370	2,250	4,190	697	109	5.0	187

Table 5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data except field properties are for filtered samples analyzed at the Metro Wastewater Reclamation District laboratory; detailed well information is listed in appendix 1; associated quality-control data are included in appendixes 2–8; Temp., temperature; °C, degrees Celsius; W.L. ft bmp, depth to groundwater in feet below measuring point; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; CaCO₃, calcium carbonate; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; GW, groundwater; --, no data; <, less than; C1, first composite; c, calculated from calibration data; PW, pore water; ft, feet]

Sample site (fig. 2; table 2)	Sample date	Sodium, mg/L	Sulfate, mg/L	Nitrogen, ammonia plus organic, mg/L as N	Nitrogen, ammonia, mg/L as N	Nitrogen, nitrite, mg/L as N	Nitrogen, nitrite plus nitrate, mg/L as N	Phosphorus, ortho-phosphate, mg/L as P	Cadmium, µg/L	Chromium, µg/L	Copper, µg/L	Iron, µg/L	Lead, µg/L	Manganese, µg/L	Nickel, µg/L	Zinc, µg/L
D21	7/13/1995	45	600	3.6	3.3	0.05	<0.02	0.26	<0.2	20	<20	19,030	<10	2,870	<20	<20
D21	12/12/1995	36	300	<0.3	1.0	0.03	<0.02	0.10	<0.2	<20	<20	5,620	<10	1,650	<20	<20
D21	3/7/1996	28	240	<0.3	0.2	<0.02	<0.02	0.05	<0.2	<20	<20	2,750	<10	1,250	<20	<20
D21	6/12/1996	33	284	0.3	0.3	<0.02	<0.02	0.05	0.1	<20	<20	4,700	<10	1,320	<20	<20
D21	8/21/1996	36	584	2.9	2.5	0.02	<0.02	0.05	<0.2	<20	<20	19,000	<10	3,670	<20	<20
D21	1/7/1998	48	328	0.7	0.3	<0.02	<0.02	0.03	<0.2	<20	<20	4,160	<10	1,590	<20	<20
D21	7/14/1998	38	278	2.1	0.4	<0.02	<0.02	<0.02	<0.2	<20	<20	13,500	<10	4,300	<20	<20
D22	7/20/1994	1,310	7,560	0.9	<0.1	<0.02	0.52	<0.02	0.5	170	<200	<500	<10	1,050	<200	<200
D22	7/28/1994	1,450	7,940	1.1	<0.1	<0.02	0.60	<0.02	<0.2	430	<200	<500	<10	860	30	<200
D22	10/3/1994	1,900	8,380	1.6	0.8	0.04	0.58	0.03	4.3	<40	<40	<100	<10	1,040	<40	70
D22	7/13/1995	2,260	10,200	3.0	2.4	<0.02	<0.02	<0.02	0.1	<200	<200	210	<10	2,610	40	<200
D22	8/23/1996	2,090	8,810	2.4	0.8	<0.02	0.02	<0.02	<0.2	<40	<40	<100	<10	2,280	<40	<40
D22	11/6/1996	2,100	9,300	1.7	0.6	<0.02	0.10	<0.02	0.2	<20	<20	<50	<10	2,700	<20	<20
D22	2/20/1997	1,900	9,320	2.9	0.7	<0.02	0.05	<0.02	<0.2	<20	<20	<50	<10	2,560	<20	<20
D22	6/2/1997	1,790	9,250	1.3	<0.1	<0.02	<0.02	<0.02	<0.2	<200	<200	200	<10	2,180	30	<200
D22	4/16/1998	1,910	10,500	2.0	0.5	<0.02	<0.02	<0.02	<0.2	100	<200	300	<10	2,390	<200	<200
D22	7/15/1998	1,920	9,350	1.6	<0.1	<0.02	0.03	<0.02	<0.2	100	<200	190	<10	1,940	<200	<200
D23	7/18/1994	182	1,640	1.4	<0.1	0.03	<0.02	<0.02	<0.2	70	<60	3,650	<10	23,410	<60	<60
D23	7/21/1994	177	1,520	1.5	<0.1	<0.02	<0.02	<0.02	<0.2	80	<20	800	<10	10,290	<20	<20
D23	7/27/1994	166	1,670	1.8	<0.1	<0.02	<0.02	<0.02	<0.2	170	<40	810	<10	19,700	<40	<40
D23	9/30/1994	181	1,630	1.4	0.9	<0.02	<0.02	<0.02	0.1	<40	<40	890	<10	15,720	<40	<40
D23	5/4/1995	189	1,800	1.6	0.7	<0.02	<0.02	0.04	<0.2	<20	<20	2,100	<10	15,900	<20	<20
D23	7/13/1995	191	1,680	1.1	1.1	<0.02	<0.02	<0.02	<0.2	<20	<20	1,040	<10	16,700	<20	<20
D23	9/25/1995	182	1,680	0.9	0.7	<0.02	<0.02	<0.02	<0.2	<20	<20	880	<10	16,600	<20	<20
D23	12/15/1995	173	1,640	1.5	0.7	<0.02	0.05	<0.02	<0.2	<20	<20	2,320	<10	13,800	<20	<20
D23	3/7/1996	177	1,910	1.0	0.6	<0.02	<0.02	0.03	<0.2	<40	<40	2,630	<10	15,300	<40	<40
D23	6/12/1996	168	1,620	0.9	0.6	<0.02	<0.02	<0.02	<0.2	<20	<20	1,610	<10	18,800	<20	<20
D23	8/21/1996	192	1,670	1.2	0.7	<0.02	<0.02	0.04	<0.2	<40	<40	1,540	<10	15,700	<40	<40
D23	11/8/1996	166	1,550	1.0	0.4	<0.02	0.05	<0.02	0.1	<20	<20	2,190	<10	14,700	<20	<20
D23	2/26/1997	188	1,620	1.0	0.7	<0.02	<0.02	0.04	0.1	<20	<20	1,560	<10	15,400	<20	<20
D23	6/4/1997	171	1,580	1.0	<0.1	<0.02	<0.02	0.06	0.1	60	<40	3,420	<10	22,690	50	50
D23	8/26/1997	195	1,750	1.5	0.7	<0.02	<0.02	<0.02	<0.2	<40	<40	1,710	<10	16,000	<40	<40
D23	11/20/1997	203	1,880	1.0	0.5	<0.02	<0.02	0.05	<0.2	<20	<20	1,870	<10	16,100	<20	<20
D23	1/8/1998	191	1,750	1.3	0.8	<0.02	<0.02	<0.02	<0.2	<20	<20	2,010	<10	14,400	<20	<20
D23	4/16/1998	187	1,810	1.3	0.4	<0.02	<0.02	<0.02	<0.2	<40	<40	2,050	<10	16,000	<40	<40
D23	7/16/1998	184	1,680	1.4	<0.1	<0.02	<0.02	<0.02	<0.2	40	<40	1,500	<10	16,000	<40	<40
D24	9/28/1995	4	38	<0.3	<0.1	<0.02	19.60	0.07	<0.2	<20	<20	<50	<10	<20	30	<20
D24	12/14/1995	4	22	<0.3	<0.1	<0.02	22.50	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20
D24	3/6/1996	4	26	<0.3	<0.1	<0.02	18.70	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20
D24	6/14/1996	1	25	<0.3	<0.1	0.02	25.60	0.04	<0.2	<20	<20	<50	<10	<20	<20	<20
D24	8/25/1997	3	54	<0.3	<0.1	<0.02	32.50	<0.02	<0.2	30	<20	<50	<10	<20	<20	<20
D24	11/17/1997	4	32	<0.3	<0.1	<0.02	34.50	0.06	<0.2	<20	<20	<50	<10	<20	<20	<20
D25	9/22/1995	197	2,210	0.4	<0.1	<0.02	4.87	0.12	0.3	<40	<40	<100	<10	1,750	<40	<40
D25	12/13/1995	125	1,840	0.4	<0.1	<0.02	0.72	0.09	0.5	<20	<20	<50	<10	2,240	<20	<20
D25	11/8/1996	337	2,720	1.4	<0.1	0.02	31.20	0.20	0.1	<20	<20	<50	<10	1,590	<20	<20
D25	6/2/1997	345	2,700	1.0	<0.1	<0.02	19.40	0.19	0.2	30	<60	<150	<10	1,480	<60	<60
D25	8/27/1997	176	1,860	1.0	<0.1	<0.02	0.36	0.10	0.2	<40	<40	<100	<10	2,350	40	<40
D25	11/19/1997	297	2,430	0.9	<0.1	<0.02	12.00	0.13	0.1	<20	<20	<50	<10	2,680	<20	<20
D25	1/8/1998	279	2,480	0.9	<0.1	<0.02	12.20	0.12	0.2	<20	<20	<50	<10	2,270	<20	<20
D25	4/16/1998	285	2,440	1.0	<0.1	<0.02	11.90	0.12	0.2	<40	<40	<100	<10	2,280	<40	<40
D25	7/16/1998	217	2,640	0.9	<0.1	<0.02	3.41	0.07	0.1	<40	<40	<100	<10	2,430	<40	<40

Table 5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data except field properties are for filtered samples analyzed at the Metro Wastewater Reclamation District laboratory; detailed well information is listed in appendix 1; associated quality-control data are included in appendixes 2–8; Temp., temperature; °C, degrees Celsius; W.L. ft bmp, depth to groundwater in feet below measuring point; mg/L, milligrams per liter; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; CaCO_3 , calcium carbonate; N, nitrogen; P, phosphorus; $\mu\text{g}/\text{L}$, micrograms per liter; GW, groundwater; --, no data; <, less than; C1, first composite; c, calculated from calibration data; PW, pore water; ft, feet]

Sample site (fig. 2; table 2)	Sample date	Sample type	Temp., air, field, °C	W.L. ft bmp	Dissolved oxygen, field, mg/L	pH, field, standard units	Specific conductance, field, $\mu\text{S}/\text{cm}$	Temp., water, field, °C	Alkalinity, lab, mg/L as CaCO_3	Hardness, mg/L as CaCO_3	Dissolved solids, residue at 180 °C, mg/L	Calcium, mg/L	Chloride, mg/L	Potassium, mg/L	Magnesium, mg/L
D26	9/22/1995	GW	--	37.40	--	7.0	533	11.9	235	266	339	74	3	3.0	16
D26	12/14/1995	GW	7	36.70	5.1	7.5	561	14.2	237	273	300	86	3	3.0	17
D26	3/6/1996	GW	-16	37.23	6.2	7.3	566	10.6	274	254	325	84	<1	3.0	17
D26	6/14/1996	GW	26	37.07	5.6	7.2	584	18.9	241	264	334	78	4	3.0	16
D26	2/20/1997	GW	7	35.11	6.3	7.3	585	13.1	249	288	485	90	<1	3.0	21
D26	8/26/1997	GW	24	34.35	6.4	7.4	586	18.4	250	241	388	86	3	3.0	21
D27	7/12/1995	GW	35	12.91	--	7.3	3,070	12.7	247	1,940	3,020	568	24	8.0	132
D27	8/20/1996	GW	32	11.47	2.2	7.1	2,900	13.0	248	1,830	2,980	568	18	8.0	120
D27	11/7/1996	GW	9	11.26	2.1	7.4	2,900	12.7	253	1,860	2,910	526	19	8.0	118
D27	2/25/1997	GW	6	11.66	2.0	7.0	2,750	10.3	246	1,880	2,990	672	16	7.0	125
D27	6/3/1997	GW	22	11.97	1.9	7.2	3,040	10.7	239	2,720	3,060	544	22	7.0	130
D27	11/18/1997	GW	12	11.24	0.9	7.0	3,000	12.4	251	1,850	3,080	573	20	12.0	151
D27	1/7/1998	GW	-5	11.16	0.7	7.5	3,040	10.9	234	2,020	3,080	571	17	7.0	129
D27	4/13/1998	GW	9	11.19	1.2	7.5	3,130	9.2	239	2,020	3,130	637	18	6.0	148
D27	7/15/1998	GW	32	11.88	0.8	7.2	3,120	12.2	244	2,030	3,170	647	18	8.0	148
D28	7/12/1995	GW	35	15.66	--	7.0	3,130	12.9	227	2,020	3,020	490	48	8.0	190
D28	9/25/1995	GW	--	15.47	--	--	3,010	10.0	238	2,680	2,963	456	48	8.0	169
D28	12/15/1995	GW	3	15.53	--	7.2	2,910	10.8	226	1,960	3,040	498	42	6.0	182
D28	3/5/1996	GW	--	15.55	1.6	6.5	3,030	11.1	233	1,950	2,990	508	52	6.0	191
D28	6/11/1996	GW	--	15.57	1.9	6.6	3,120	12.3	230	1,970	2,990	428	48	6.0	162
D28	11/7/1996	GW	10	14.84	1.9	7.2	2,860	11.5	242	1,770	2,760	491	39	6.0	149
D28	2/25/1997	GW	0	14.98	1.5	6.7	2,770	10.5	235	1,860	2,920	473	<1	7.0	171
D28	6/3/1997	GW	15	15.08	1.6	6.8	3,100	11.0	254	1,980	3,080	442	43	7.0	164
D28	8/26/1997	GW	32	14.77	1.3	6.9	3,050	12.2	227	2,060	3,140	503	43	6.0	210
D28	11/18/1997	GW	7	14.76	1.3	6.7	3,070	11.7	234	1,700	3,090	487	45	11.0	198
D28	1/7/1998	GW	-5	14.71	1.4	7.2	3,110	10.9	218	2,040	3,080	475	43	8.0	208
D28	4/13/1998	GW	7	14.71	1.4	7.1	3,200	10.6	224	2,000	3,150	584	43	7.0	194
D28	7/15/1998	GW	30	14.57	1.3	6.9	3,210	12.1	227	2,020	3,180	582	43	7.0	196
D29	1/29/1998	GW	--	154.44	1.1	6.9	3,710	20.0	289	3,100	4,260	559	10	<0.1	363
D29	4/14/1998	GW	4	154.29	2.4	6.8	3,940	16.6	278	2,750	4,280	666	9	11.0	351
D29	7/14/1998	GW	34	154.39	4.7	6.9	3,940	23.7	280	3,290	4,390	635	11	10.0	280
D30	9/20/1995	GW	--	6.95	--	7.2	5,010	11.0	331	2,930	4,790	445	60	6.0	403
D30	12/15/1995	GW	9	6.42	--	7.0	4,510	11.4	330	2,800	4,880	432	57	4.0	420
D30	3/5/1996	GW	--	6.21	0.8	7.0	4,740	8.9	415	2,930	5,050	434	71	5.0	408
D30	6/12/1996	GW	28	6.40	0.6	6.8	4,920	10.1	360	2,900	5,040	437	62	3.0	391
D30	8/21/1996	GW	30	5.41	0.9	6.9	4,820	13.7	370	2,800	5,140	482	54	5.0	437
D30	11/7/1996	GW	10	5.32	0.7	7.2	4,810	12.4	283	2,800	5,100	429	55	5.0	415
D30	2/25/1997	GW	10	5.02	0.6	6.9	4,980	9.1	375	3,050	4,940	461	55	<0.1	426
D30	6/2/1997	GW	25	5.04	<0.5	6.9	4,830	10.3	383	3,610	5,130	440	52	<0.1	412
D30	8/25/1997	GW	32	4.95	<0.5	6.9	5,080	13.5	387	2,900	5,200	443	50	<0.1	414
D30	11/19/1997	GW	--	4.75	<0.5	7.2	4,960	12.5	405	2,460	5,160	456	57	9.0	434
D30	1/6/1998	GW	-1.1	4.71	0.8	7.0	4,920	9.8	374	2,860	5,140	433	50	24.0	412
D30	4/13/1998	GW	12	4.59	<0.5	7.1	5,050	8.6	396	3,070	5,260	619	53	<0.1	509
D30	7/15/1998	GW	36	6.30	<0.5	7.1	4,760	11.8	375	3,270	4,980	486	51	3.0	451
D31	9/20/1995	GW	--	6.87	--	7.3	8,830	13.5	523	5,960	9,400	420	101	6.0	1,000
D31	12/15/1995	GW	9	7.15	--	7.3	8,220	11.2	549	6,670	9,820	410	126	5.0	1,120
D31	3/5/1996	GW	--	7.43	<0.5	7.2	8,600	9.0	556	5,500	9,590	411	124	5.0	1,030
D31	6/12/1996	GW	27	6.49	<0.5	7.0	8,700	10.6	549	5,400	9,500	558	100	<0.1	961
D31	8/21/1996	GW	33	5.55	<0.5	7.1	7,920	13.9	548	5,150	9,410	403	84	6.0	1,030
D31	11/7/1996	GW	9	6.26	1.1	7.4	8,210	12.8	545	5,390	9,250	439	85	7.0	1,060
D31	2/25/1997	GW	6	6.27	<0.5	7.2	8,060	9.4	517	5,300	8,840	417	93	<0.1	971
D31	6/3/1997	GW	27	6.33	<0.5	7.1	7,730	10.2	551	5,350	8,750	409	18	<0.1	722
D31	8/27/1997	GW	29	6.17	<0.5	7.3	7,870	13.2	544	4,950	8,790	427	86	<0.1	892

Table 5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data except field properties are for filtered samples analyzed at the Metro Wastewater Reclamation District laboratory; detailed well information is listed in appendix 1; associated quality-control data are included in appendixes 2–8; Temp., temperature; °C, degrees Celsius; W.L. ft bmp, depth to groundwater in feet below measuring point; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; CaCO₃, calcium carbonate; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; GW, groundwater; --, no data; <, less than; C1, first composite; c, calculated from calibration data; PW, pore water; ft, feet]

Sample site (fig. 2; table 2)	Sample date	Sodium, mg/L	Sulfate, mg/L	Nitrogen, ammonia plus organic, mg/L as N	Nitrogen, ammonia, mg/L as N	Nitrogen, nitrite, mg/L as N	Nitrogen, nitrite plus nitrate, mg/L as N	Phosphorus, ortho-phosphate, mg/L as P	Cadmium, µg/L	Chromium, µg/L	Copper, µg/L	Iron, µg/L	Lead, µg/L	Manganese, µg/L	Nickel, µg/L	Zinc, µg/L
D26	9/22/1995	13	37	<0.3	<0.1	<0.02	4.98	0.12	0.1	<20	<20	<50	<10	<20	<20	<20
D26	12/14/1995	10	38	<0.3	<0.1	<0.02	4.95	0.07	<0.2	<20	<20	<50	<10	<20	50	<20
D26	3/6/1996	6	33	<0.3	<0.1	<0.02	4.72	0.05	<0.2	<20	<20	<50	<10	<20	<20	<20
D26	6/14/1996	8	29	<0.3	<0.1	<0.02	4.84	0.10	<0.2	<20	<20	<50	<10	<20	<20	<20
D26	2/20/1997	14	47	<0.3	<0.1	<0.02	4.57	0.09	<0.2	<20	<20	<50	<10	<20	<20	<20
D26	8/26/1997	13	57	0.5	<0.1	<0.02	5.39	0.06	<0.2	<20	<20	<50	<10	<20	<20	<20
D27	7/12/1995	77	1,790	0.8	0.1	<0.02	0.35	0.57	<0.2	<20	<20	<50	<10	310	<20	<20
D27	8/20/1996	71	1,740	1.3	<0.1	<0.02	0.31	0.38	0.1	<20	<20	<50	<10	<20	<20	<20
D27	11/7/1996	73	1,610	<0.3	<0.1	<0.02	0.55	0.38	0.3	<20	<20	<50	<10	<20	<20	<20
D27	2/25/1997	81	2,120	<0.3	<0.1	<0.02	0.52	0.29	0.2	<20	<20	<50	<10	<20	<20	<20
D27	6/3/1997	86	1,670	<0.3	<0.1	<0.02	0.66	0.28	<0.2	40	40	1,010	<10	30	30	<40
D27	11/18/1997	95	1,720	1.4	<0.1	<0.02	0.90	0.19	<0.2	<20	<20	<50	<10	<20	<20	<20
D27	1/7/1998	89	1,800	<0.3	<0.1	<0.02	1.00	0.26	0.1	<20	<20	<50	<10	<20	<20	<20
D27	4/13/1998	82	1,960	<0.3	<0.1	<0.02	1.47	0.21	<0.2	<40	<40	<100	<10	<40	<40	<40
D27	7/15/1998	86	1,820	0.7	<0.1	<0.02	1.53	0.20	<0.2	40	<40	<100	<10	<40	<40	<40
D28	7/12/1995	86	1,810	<0.3	0.2	<0.02	4.05	0.04	<0.2	<20	<20	<50	<10	220	<20	<20
D28	9/25/1995	78	1,780	<0.3	<0.1	<0.02	5.66	<0.02	0.1	<20	<20	<50	<10	70	<20	<20
D28	12/15/1995	72	1,780	<0.3	<0.1	<0.02	4.87	<0.02	0.1	<20	<20	<50	<10	30	<20	<20
D28	3/5/1996	90	1,890	<0.3	<0.1	<0.02	5.25	0.04	0.1	<40	<40	<100	<10	<40	<40	<40
D28	6/11/1996	74	1,580	<0.3	<0.1	<0.02	5.81	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20
D28	11/7/1996	81	1,700	<0.3	<0.1	<0.02	7.55	0.08	<0.2	<20	<20	<50	<10	20	<20	<20
D28	2/25/1997	89	1,670	<0.3	<0.1	<0.02	9.53	0.03	0.1	<20	<20	<50	<10	<20	<20	<20
D28	6/3/1997	94	1,760	<0.3	<0.1	<0.02	6.13	0.04	0.1	120	<40	1,290	<10	50	40	20
D28	8/26/1997	101	1,800	0.2	<0.1	<0.02	6.06	<0.02	<0.2	<40	<40	<100	<10	<40	<40	<40
D28	11/18/1997	103	1,800	1.8	<0.1	<0.02	5.81	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20
D28	1/7/1998	88	1,890	0.3	<0.1	<0.02	5.14	<0.02	<0.2	<20	<20	<50	<10	60	70	60
D28	4/13/1998	90	1,990	<0.3	<0.1	<0.02	4.99	<0.02	<0.2	<40	<40	<100	<10	<40	<40	<40
D28	7/15/1998	97	1,880	0.5	<0.1	<0.02	6.74	<0.02	<0.2	40	<40	<100	<10	<40	<40	<40
D29	1/29/1998	152	2,780	0.6	0.4	<0.02	<0.02	0.04	<0.2	50	<20	6,830	<10	820	70	40
D29	4/14/1998	143	2,920	0.5	0.1	<0.02	<0.02	<0.02	0.1	140	<20	7,040	<10	830	<20	<20
D29	7/14/1998	138	2,690	0.7	<0.1	<0.02	<0.02	<0.02	0.2	70	<40	6,850	<10	830	<40	180
D30	9/20/1995	413	3,090	<0.3	<0.1	<0.02	<0.02	0.22	<0.2	<60	<60	<150	<10	330	<60	<60
D30	12/15/1995	384	3,360	0.4	<0.1	<0.02	0.03	0.37	<0.2	<20	<20	<50	<10	250	20	<20
D30	3/5/1996	355	3,080	<0.3	<0.1	<0.02	<0.02	0.14	<0.2	<60	<60	550	<10	490	<60	<60
D30	6/12/1996	430	3,090	<0.3	<0.1	<0.02	<0.02	0.13	<0.2	<40	<40	<100	<10	250	<40	<40
D30	8/21/1996	361	3,400	0.5	<0.1	<0.02	0.03	0.17	<0.2	<40	<40	50	<10	270	<40	<40
D30	11/7/1996	410	3,380	<0.3	<0.1	<0.02	0.07	0.19	<0.2	<20	<20	110	<10	460	<20	<20
D30	2/25/1997	383	3,060	<0.3	<0.1	<0.02	<0.02	0.10	0.1	<20	<20	<50	<10	340	<20	<20
D30	6/2/1997	400	3,230	<0.3	<0.1	<0.02	<0.02	0.09	<0.2	<60	<60	80	<10	270	<60	<60
D30	8/25/1997	410	3,370	<0.3	<0.1	<0.02	0.06	0.08	<0.2	130	<60	1,790	<10	330	<60	<60
D30	11/19/1997	428	3,040	0.6	<0.1	<0.02	<0.02	0.09	<0.2	<20	<20	290	<10	280	<20	<20
D30	1/6/1998	408	3,410	<0.3	<0.1	<0.02	<0.02	0.06	0.1	<20	<20	<50	<10	280	20	<20
D30	4/13/1998	456	3,340	0.4	<0.1	<0.02	0.03	0.04	<0.2	140	<40	<100	<10	350	<40	<40
D30	7/15/1998	370	3,030	0.6	<0.1	<0.02	<0.02	0.05	<0.2	80	<40	120	<10	240	<40	<40
D31	9/20/1995	734	5,900	<0.3	<0.1	0.03	1.54	0.05	<0.2	<100	<100	<250	<10	460	<100	<100
D31	12/15/1995	808	6,300	2.3	<0.1	<0.02	3.59	<0.02	<0.2	<20	<20	<50	<10	200	30	<20
D31	3/5/1996	796	5,990	0.5	<0.1	0.03	3.17	0.03	<0.2	<100	<100	<250	<10	210	<100	<100
D31	6/12/1996	1,230	6,480	<0.3	<0.1	<0.02	1.28	<0.02	<0.2	<100	<100	<250	<10	190	<100	<100
D31	8/21/1996	765	5,380	14.1	<0.1	<0.02	0.35	0.06	0.1	<40	<40	<100	<10	710	20	<40
D31	11/7/1996	841	5,830	0.7	<0.1	<0.02	0.40	0.05	<0.2	<20	<20	<50	<10	1,250	<20	<20
D31	2/25/1997	777	5,740	0.5	<0.1	<0.02	0.44	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20
D31	6/3/1997	687	5,460	<0.3	<0.1	<0.02	0.57	<0.02	<0.2	220	<60	<150	<10	320	30	40
D31	8/27/1997	767	5,190	0.7	<0.1	<0.02	0.07	<0.02	<0.2	110	<100	<250	<10	210	<100	<100

Table 5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data except field properties are for filtered samples analyzed at the Metro Wastewater Reclamation District laboratory; detailed well information is listed in appendix 1; associated quality-control data are included in appendixes 2–8; Temp., temperature; °C, degrees Celsius; W.L. ft bmp, depth to groundwater in feet below measuring point; mg/L, milligrams per liter; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; CaCO_3 , calcium carbonate; N, nitrogen; P, phosphorus; $\mu\text{g}/\text{L}$, micrograms per liter; GW, groundwater; --, no data; <, less than; C1, first composite; c, calculated from calibration data; PW, pore water; ft, feet]

Sample site (fig. 2; table 2)	Sample date	Sample type	Temp., air, field, °C	W.L. ft bmp	Dissolved oxygen, field, mg/L	pH, field, standard units	Specific conductance, field, $\mu\text{S}/\text{cm}$	Temp., water, field, °C	Alkalinity, lab, mg/L as CaCO_3	Hardness, mg/L as CaCO_3	Dissolved solids, residue at 180 °C, mg/L	Calcium, mg/L	Chloride, mg/L	Potassium, mg/L	Magnesium, mg/L
D32	9/28/1995	GW	--	27.87	--	7.2	3,660	16.0	278	2,580	3,720	476	9	2.0	236
D32	12/13/1995	GW	10.0	27.80	--	7.0	3,600	14.0	276	2,310	3,680	522	7	2.0	244
D32	3/7/1996	GW	-7	27.85	1.4	7.1	3,540	12.9	332	2,380	3,650	492	2	<0.1	245
D32	6/13/1996	GW	26	27.99	1.5	6.9	3,650	16.8	280	2,320	3,630	468	8	<0.1	238
D32	8/20/1996	GW	32	28.06	0.8	7.1	3,440	23.2	285	2,330	3,640	530	6	2.0	259
D32	8/26/1997	GW	29	28.28	1.2	7.2	3,470	18.9	295	2,360	3,740	516	6	<0.1	270
D32	11/18/1997	GW	12	28.01	1.4	7.1	3,680	13.6	310	2,160	3,630	518	6	<0.1	260
D32	1/7/1998	GW	4.4	27.89	1.5	7.1	3,480	14.4	290	2,360	3,670	496	5	<0.1	227
D32	7/15/1998	GW	35	27.79	1.6	7.3	3,540	17.8	317	2,370	3,730	614	8	<0.1	240
D33	9/27/1995	GW	--	14.94	--	7.4	3,880	14.5	232	2,420	3,940	502	22	14.0	331
D33	12/12/1995	GW	--	15.09	--	7.5	3,780	12.6	234	2,800	3,880	505	16	11.0	290
D33	3/8/1996	GW	-12	15.14	1.7	7.2	3,780	10.3	268	2,550	3,890	520	18	11.0	281
D33	6/12/1996	GW	29	15.07	4.6	7.1	3,870	11.8	237	2,450	3,890	496	22	11.0	286
D33	8/22/1996	GW	26	14.84	4.7	7.3	3,800	12.8	236	2,390	3,890	546	15	12.0	311
D33	11/8/1996	GW	11	14.81	4.4	7.4	3,710	13.1	237	3,200	3,940	541	15	12.0	313
D33	2/25/1997	GW	14	14.80	4.8	7.3	3,840	11.3	232	2,650	3,910	511	15	12.0	308
D33	6/5/1997	GW	25	14.68	5.0	7.2	3,770	11.9	230	2,270	4,760	443	16	11.0	292
D33	8/26/1997	GW	29	14.25	4.5	7.4	3,770	13.4	237	2,520	3,970	496	14	10.0	317
D33	11/18/1997	GW	7	14.34	4.2	7.4	3,790	12.9	243	2,030	3,940	549	14	16.0	335
G1	7/23/1993	GW	--	--	--	--	1,620	14.5	--	912	--	302	4	3.3	47
G1	8/26/1993	GW	--	--	--	7.4	1,720	14.5	150	961	1,490	320	<1	3.4	27
G2	7/23/1993	GW	--	--	--	--	574	16.3	--	231	--	65	18	1.7	19
G2	8/26/1993	GW	--	--	--	7.8	830	14.6	170	225	535	69	19	2.6	20
G3	7/23/1993	GW	--	--	--	--	2,170	14.5	--	1,150	--	303	12	5.0	131
G3	8/26/1993	GW	--	--	--	7.5	1,650	14.4	198	888	1,350	243	2	4.0	76
S1	7/23/1993	Stream	--	--	--	--	235	18.6	--	51	--	16	--	7.4	3
S2	7/23/1993	Pond	--	--	--	--	175	23.7	--	77	--	15	4	3.4	7
S3	7/23/1993	Pond	--	--	--	--	3,710	22.7	--	1,630	--	380	26	17.7	220
S3	8/26/1993	Pond	--	--	--	10.0	4,620	19.8	89	2,070	--	470	30	22.3	278
V1L1 ¹	4/22/1994	PW depth =1.5 ft	--	--	--	--	--	--	--	--	--	67	67	13	<33
V1L2 ¹	4/22/1994	PW depth =1.5 ft	--	--	--	--	--	--	--	--	--	67	100	10	<33
V2L3 ¹	4/22/1994	PW depth =1.5 ft	--	--	--	--	--	--	--	--	--	70	170	8	<10
V2L4 ¹	4/22/1994	PW depth =1.5 ft	--	--	--	--	--	--	--	--	--	80	27	11	<7
V2L7 ¹	4/22/1994	PW depth =3 ft	--	--	--	--	--	--	--	--	--	105	140	9	<5
V2L8 ¹	4/22/1994	PW depth =1.5 ft	--	--	--	--	--	--	--	--	--	67	33	12	<11
V3L3 ¹	4/21/1994	PW depth =1.5 ft	--	--	--	--	--	--	--	--	--	200	1,200	60	<200
V3L8 ¹	4/22/1994	PW depth =1.5 ft	--	--	--	--	--	--	--	--	--	90	110	7	<10

Table 5. Water-quality data for samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data except field properties are for filtered samples analyzed at the Metro Wastewater Reclamation District laboratory; detailed well information is listed in appendix 1; associated quality-control data are included in appendixes 2–8; Temp., temperature; °C, degrees Celsius; W.L. ft bmp, depth to groundwater in feet below measuring point; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; CaCO₃, calcium carbonate; N, nitrogen; P, phosphorus; µg/L, micrograms per liter; GW, groundwater; --, no data; <, less than; C1, first composite; c, calculated from calibration data; PW, pore water; ft, feet]

Sample site (fig. 2; table 2)	Sample date	Sodium, mg/L	Sulfate, mg/L	Nitrogen, ammonia plus organic, mg/L as N	Nitrogen, ammonia, mg/L as N	Nitrogen, nitrite, mg/L as N	Nitrogen, nitrite plus nitrate, mg/L as N	Phosphorus, orthophosphate, mg/L as P	Cadmium, µg/L	Chromium, µg/L	Copper, µg/L	Iron, µg/L	Lead, µg/L	Manganese, µg/L	Nickel, µg/L	Zinc, µg/L
D32	9/28/1995	147	2,350	<0.3	<0.1	<0.02	6.56	0.07	<0.2	20	<20	110	<10	80	210	<20
D32	12/13/1995	137	2,160	<0.3	<0.1	<0.02	7.37	<0.02	<0.2	<20	<20	<50	<10	<20	100	<20
D32	3/7/1996	136	1,920	<0.3	<0.1	0.04	7.59	0.04	0.1	<40	<40	<100	<10	<40	<40	<40
D32	6/13/1996	118	2,040	<0.3	<0.1	<0.02	8.29	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20
D32	8/20/1996	145	2,380	<0.3	<0.1	<0.02	8.24	0.06	<0.2	<40	<40	<100	<10	<40	<40	<40
D32	8/26/1997	167	2,170	<0.3	<0.1	<0.02	10.10	<0.02	<0.2	170	<40	<100	<10	<40	<40	<40
D32	11/18/1997	154	2,180	1.2	<0.1	<0.02	10.20	<0.02	0.1	<20	<20	<50	<10	<20	<20	<20
D32	1/7/1998	157	2,330	<0.3	<0.1	<0.02	9.92	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20
D32	7/15/1998	146	2,260	0.3	<0.1	<0.02	10.60	<0.02	<0.2	60	<40	<100	<10	<40	<40	<40
D33	9/27/1995	147	2,450	<0.3	<0.1	<0.02	0.28	0.19	0.2	<20	<20	<50	<10	<20	<20	<20
D33	12/12/1995	122	2,420	0.3	<0.1	<0.03	0.25	0.06	<0.2	<20	<20	<50	<10	<20	<20	20
D33	3/8/1996	128	2,200	<0.3	<0.1	<0.02	0.29	0.06	<0.2	<40	<40	<100	<10	<40	<40	<40
D33	6/12/1996	138	2,370	<0.3	<0.1	<0.02	0.28	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20
D33	8/22/1996	115	2,830	<0.3	<0.1	<0.02	0.29	0.05	<0.2	<40	<40	<100	<10	<40	<40	<40
D33	11/8/1996	129	2,410	<0.3	<0.1	<0.02	0.36	0.05	<0.2	<20	<20	<50	<10	<20	<20	<20
D33	2/25/1997	145	2,400	<0.3	<0.1	<0.02	0.29	0.04	<0.2	<20	<20	<50	<10	<20	<20	<20
D33	6/5/1997	142	2,300	<0.3	<0.1	<0.02	0.34	0.07	0.2	90	60	<150	<10	<60	<60	40
D33	8/26/1997	160	2,410	<0.3	<0.1	<0.02	0.36	0.04	<0.2	120	<40	<100	<10	<40	<40	<40
D33	11/18/1997	173	2,530	0.5	<0.1	<0.02	0.40	<0.02	<0.2	<20	<20	<50	<10	<20	<20	<20
G1	7/23/1993	27	838	0.3	<0.1	<0.02	1.60	<0.02	1.0	<20	<20	410	<10	30	<20	<20
G1	8/26/1993	20	722	<0.3	<0.1	<0.02	2.54	0.05	0.1	<20	<20	140	<10	100	20	<20
G2	7/23/1993	29	100	0.4	<0.1	0.04	5.60	<0.02	10.0	<20	<20	<50	<10	<20	<20	30
G2	8/26/1993	78	203	0.4	<0.1	0.03	5.28	<0.02	0.1	<20	<20	<50	<10	30	<20	30
G3	7/23/1993	59	1,240	0.8	0.3	<0.02	<0.02	<0.02	1.0	<20	<20	2,700	<10	560	<20	90
G3	8/26/1993	41	765	0.4	<0.1	<0.02	0.08	<0.02	<0.2	<20	<20	1,200	<10	430	<20	80
S1	7/23/1993	2	--	4.5	<0.1	--	4.96	--	10.0	<20	<20	50	<10	<20	<20	<20
S2	7/23/1993	10	<10	1.4	<0.1	<0.02	<0.02	<0.02	1.0	<20	<20	<50	<10	<20	<20	320
S3	7/23/1993	330	2,380	1.0	<0.1	<0.02	<0.02	<0.02	<0.2	<20	<20	<50	<10	590	80	<20
S3	8/26/1993	440	2,940	2.7	<0.1	<0.02	<0.02	<0.02	0.1	<20	<20	<50	<10	<20	60	<20
V1L1 ¹	4/22/1994	<33	<100	<10	<3	<0.7	36	2	<7	<670	1,300	<1,700	<330	<670	<670	<670
V1L2 ¹	4/22/1994	<33	<100	<10	<3	<0.7	24	<1	<7	<670	1,000	<1,700	<330	<670	<670	<670
V2L3 ¹	4/22/1994	<10	<30	4	<1	<0.2	13	1	<2	<200	300	<500	<100	300	<200	<200
V2L4 ¹	4/22/1994	<7	<20	3	<0.7	<0.1	27	1	<1	<130	270	<330	<67	<130	<130	<130
V2L7 ¹	4/22/1994	<5	<15	4	<0.5	<0.1	30	<0.1	<1	<100	150	<250	<50	<100	<100	100
V2L8 ¹	4/22/1994	<11	<33	<3	<1	<0.2	31	1	<2	<220	330	<560	<110	<220	<220	<220
V3L3 ¹	4/21/1994	<200	<600	<60	<20	<4	16	<4	<40	<4,000	6,000	<10,000	<2,000	<4,000	<4,000	<4,000
V3L8 ¹	4/22/1994	<10	<30	<3	<1	<0.2	7	1	<2	<200	300	<500	<100	<200	<200	<200

¹VX refers to unsaturated-zone plot number (fig. 2); LX refers to lysimeter number.

40 Water Quality at a Biosolids-Application Area near Deer Trail, Colorado, 1993–1999

Table 6. Bacteria data for water-quality samples collected near Deer Trail, Colorado, 1993 through 1998.

[All samples cultured by the Metro Wastewater Reclamation District Laboratory on the same day sampled; pond samples were a single grab sample from near the bank; GW, groundwater; SW, pond; QC, quality control; mL, milliliters; <, less than; >, greater than]

Sample site (fig. 2)	Sample type	Sample date	Bacteria, in colonies per 100 mL		Sample site (fig. 2)	Sample type	Sample date	Bacteria, in colonies per 100 mL	
			Fecal coliform	Fecal streptococcus				Fecal coliform	Fecal streptococcus
D2	GW	11/3/1993	<20	<20	D9	GW	1/25/1994	<20	1.2
D2	GW	11/22/1993	<20	<20	D9	GW	2/22/1996	<20	<20
D2	GW	1/25/1994	<20	<20	D9	GW	6/5/1997	<2	<2
D2	GW	2/22/1996	<20	<20	D9	GW	11/17/1997	<2	<2
D2	GW	10/3/1996	<20	>10,000	D9	GW	4/15/1998	<2	<2
D2	GW	6/3/1997	<2	13	D10	GW	11/3/1993	<20	<20
D2	GW	11/19/1997	<2	0.7	D10	GW	11/22/1993	<20	<20
D2	GW	4/14/1998	<2	<2	D10	GW	1/25/1994	<20	1.2
D3	GW	11/3/1993	<20	42	D10	GW	2/22/1996	<20	<20
D3	GW	11/22/1993	<20	<20	D10	GW	10/3/1996	<20	<20
D3	GW	1/25/1994	<20	<20	D10	GW	6/5/1997	<2	<2
D3	GW	2/21/1996	<20	<20	D10	GW	11/18/1997	<2	<2
D3	GW	11/17/1997	<2	6.6	D10	GW	4/15/1998	<2	88
D3	GW	4/16/1998	<2	15	D11a	GW	4/13/1998	<2	<2
D4	GW	11/3/1993	<20	<20	D12	GW	11/3/1993	<20	19
D4	GW	11/22/1993	<20	<20	D12	GW	11/22/1993	<20	<20
D4	GW	1/25/1994	<20	<20	D12	GW	1/25/1994	<20	5.9
D4	GW	7/14/1995	<20	<20	D12	GW	2/22/1996	<20	<20
D4	GW	2/21/1996	<20	<20	D12	GW	10/3/1996	<20	18
D4	GW	6/5/1997	<2	<2	D13	GW	8/16/1994	<20	3
D5	GW	11/3/1993	<20	<20	D13	GW	7/14/1995	<20	<20
D5	GW	11/22/1993	<20	<20	D13	GW	2/21/1996	<20	<20
D5	GW	1/25/1994	<20	<20	D13	GW	10/4/1996	4	12
D5	GW	2/22/1996	<20	<20	D13	GW	6/2/1997	<2	3.3
D5	GW	10/3/1996	<20	<20	D13	GW	11/17/1997	<2	9.9
D5	GW	6/4/1997	<2	<2	D13	GW	4/13/1998	<2	<2
D5	GW	11/18/1997	<2	<2	D14	GW	8/16/1994	<20	<20
D5	GW	4/15/1998	<2	<2	D14	GW	7/14/1995	<20	<20
D6	GW	11/3/1993	<20	<20	D14	GW	2/21/1996	<20	<20
D6	GW	11/22/1993	<20	<20	D14	GW	10/4/1996	<20	<20
D6	GW	1/25/1994	<20	<20	D14	GW	6/2/1997	<2	<2
D6	GW	2/22/1996	<20	<20	D14	GW	11/17/1997	<2	28
D6	GW	10/3/1996	<20	240	D14	GW	4/15/1998	<2	<2
D6	GW	6/4/1997	<2	<2	D15	GW	8/16/1994	<20	3
D6	GW	11/19/1997	<2	<2	D15	GW	7/14/1995	<20	<20
D6	GW	4/15/1998	<2	<2	D15	GW	2/21/1996	<20	<20
D7	GW	11/3/1993	<20	<20	D15	GW	10/4/1996	<20	<20
D7	GW	11/22/1993	<20	<20	D15	GW	6/4/1997	<2	1.6
D7	GW	1/25/1994	<20	<20	D15	GW	11/20/1997	<2	<2
D7	GW	7/14/1995	<20	<20	D15	GW	4/14/1998	<2	<2
D7	GW	10/4/1996	<20	<20	D16	GW	8/16/1994	<20	<20
D7	GW	6/3/1997	<2	<2	D16	GW	7/14/1995	<20	<20
D8	GW	11/3/1993	<20	<20	D16	GW	2/21/1996	<20	<20
D8	GW	11/22/1993	<20	<20	D16	GW	10/4/1996	<20	<20
D8	GW	1/25/1994	<20	<20	D16	GW	11/20/1997	<2	<2
D8	GW	7/14/1995	<20	<20	D17	GW	8/16/1994	<20	3
D8	GW	2/21/1996	<20	<20	D17	GW	7/14/1995	<20	1
D8	GW	11/19/1997	<2	<2	D17	GW	10/4/1996	<20	<20
D8	GW	4/14/1998	<2	<2	D17	GW	6/4/1997	<2	<2
D9	GW	11/3/1993	<20	<20	D17	GW	11/17/1997	<2	<2
D9	GW	11/22/1993	<20	<20	D17	GW	4/14/1998	<2	<2

Table 6. Bacteria data for water-quality samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All samples cultured by the Metro Wastewater Reclamation District Laboratory on the same day sampled; pond samples were a single grab sample from near the bank; GW, groundwater; SW, pond; QC, quality control; mL, milliliters; <, less than; >, greater than]

Sample site (fig. 2)	Sample type	Sample date	Bacteria, in colonies per 100 mL		Sample site (fig. 2)	Sample type	Sample date	Bacteria, in colonies per 100 mL	
			Fecal coliform	Fecal streptococcus				Fecal coliform	Fecal streptococcus
D19	GW	8/16/1994	<20	<20	D28	GW	6/3/1997	<2	<2
D19	GW	7/14/1995	<20	<20	D28	GW	11/18/1997	<2	<2
D19	GW	10/4/1996	<20	<20	D28	GW	4/13/1998	<2	<2
D19	GW	6/3/1997	<2	<2	D29	GW	4/14/1998	<2	94
D20	GW	8/16/1994	<20	<20	D30	GW	2/22/1996	<20	<20
D20	GW	7/14/1995	<20	2	D30	GW	10/3/1996	<20	25
D20	GW	2/21/1996	<20	<20	D30	GW	6/2/1997	<2	1.6
D20	GW	10/4/1996	<20	<20	D30	GW	11/19/1997	<2	<2
D20	GW	11/20/1997	<2	<2	D30	GW	4/13/1998	<2	<2
D21	GW	8/16/1994	<20	18	D31	GW	2/22/1996	<20	<20
D21	GW	7/14/1995	<20	<20	D31	GW	10/3/1996	<20	200
D21	GW	2/21/1996	<20	<20	D31	GW	6/3/1997	<2	1.6
D21	GW	10/4/1996	<20	<20	D32	GW	2/22/1996	<20	<20
D22	GW	7/14/1995	<20	<20	D32	GW	10/3/1996	<20	28
D22	GW	10/4/1996	<20	4	D32	GW	11/18/1997	<2	<2
D22	GW	6/2/1997	<2	18	D33	GW	2/22/1996	<20	<20
D22	GW	4/16/1998	<2	5	D33	GW	10/3/1996	<20	3
D23	GW	8/16/1994	<20	18	D33	GW	6/5/1997	<2	<2
D23	GW	7/14/1995	<20	2	D33	GW	11/18/1997	<2	<2
D23	GW	2/21/1996	<20	<20	S3	SW	7/14/1995	5	22
D23	GW	10/4/1996	<20	<20	S4	SW	2/22/1996	<20	<20
D23	GW	6/4/1997	<2	<2	S4	SW	10/3/1996	1	21
D23	GW	11/20/1997	<2	<2	S4	SW	11/19/1997	<2	8.6
D23	GW	4/16/1998	<2	<2	S5	SW	11/20/1997	>200	4,200
D24	GW	2/21/1996	<20	<20	S5	SW	4/16/1998	<2	180
D24	GW	11/17/1997	<2	7.9	S6	SW	11/20/1997	47	160
D25	GW	7/14/1995	<20	1	S7	SW	4/16/1998	23	150
D25	GW	2/21/1996	<20	<20	D9	QC ¹	2/22/1996	<20	<20
D25	GW	10/4/1996	<20	32	D2	QC ¹	6/3/1997	<2	6.6
D25	GW	6/2/1997	<2	<2	D10	QC ¹	6/5/1997	<2	50
D25	GW	11/19/1997	<2	<2	D6	QC ¹	11/19/1997	<2	<2
D25	GW	4/16/1998	<2	<2	D25	QC ¹	4/16/1998	<2	160
D26	GW	2/21/1996	<20	<20	D19	QC ²	8/16/1994	<20	<20
D27	GW	7/14/1995	<20	14	D9	QC ³	2/22/1996	<20	<20
D27	GW	10/4/1996	<20	<20	D9	QC ⁴	2/22/1996	<20	<20
D27	GW	6/3/1997	<2	<2	D25	QC ²	10/4/1996	<20	<20
D27	GW	11/18/1997	<2	<2	D17	QC ⁵	6/4/1997	<2	<2
D27	GW	4/13/1998	<2	<2	D2	QC ⁵	11/19/1997	<2	<2
D28	GW	7/14/1995	<20	65	D15	QC ⁵	11/20/1997	<2	<2
D28	GW	2/21/1996	<20	<20	D23	QC ⁵	4/16/1998	<2	<2
D28	GW	10/4/1996	<20	<20	D25	QC ⁵	4/16/1998	<2	<2

¹Replicate groundwater sample.

²Field blank at a groundwater site; deionized water through sampling bailer.

³Field blank at a groundwater site; municipal tap water, no sampling equipment.

⁴Field blank at a groundwater site; municipal tap water through sampling bailer.

⁵Field blank at a groundwater site; sterile, buffered water through sampling bailer.

Baseline Water Quality

For this study, baseline data were collected from the study area after the area had been farmed and inhabited but before biosolids were applied. The baseline data do not represent pristine natural conditions but likely are affected by anthropogenic activities such as agriculture, roads, and habitation. All baseline data from the study area are included in tables 5 and 6 (the 1993 data for wells D2 through D12, G1 through G3, and for surface-water sites S1, S2, and S3). These baseline data were collected during a brief time period and so do not account for variability due to seasonal natural processes. There was not sufficient time to collect seasonally representative samples from each well or pond before biosolids were applied. Baseline concentrations could have been smaller or larger at other times of the year at these sites. These baseline data also were not collected using the strict sampling methods that were used for collecting water-quality data after 1995 and so should not be statistically compared to later data.

Baseline data (considered “background data” by the Colorado Department of Public Health and Environment [1997]) indicate water-quality information for the study area in the approximately 6 months before biosolids applications to the study area began. Baseline water quality in the study area was marginal at some sites and better at other sites. Large concentrations of chloride, sulfate, nitrate, iron, and manganese were detected in some baseline samples (table 5). A summary of selected baseline data is shown in figure 8. Sulfate concentrations in baseline samples generally were greater than 1,000 mg/L (fig. 8). The largest concentration of sulfate in baseline samples was at well D6 where sulfate concentration was greater than 10,000 mg/L. Nitrogen concentrations in the baseline samples generally were in the oxidized form (nitrate). About one-half of the sites sampled for baseline water quality had nitrate concentrations of 1 milligram per liter as nitrogen (mg-N/L) or greater. Five sites (wells D5, D6, D9, and G2, and stream-site S1) had nitrate concentrations greater than 3 mg-N/L in baseline samples. Three sites (wells D5 and G2 and stream-site S1) had nitrate concentrations in the range of about 5–10 mg-N/L in baseline samples (fig. 8). One site (well D9) had nitrate concentrations greater than 10 mg-N/L in baseline samples before biosolids applications began (fig. 8). Iron concentration in baseline samples was less than 50 µg/L at most sites but was in the range of 50–500 µg/L at two sites (G1 and S1) and greater than 1,000 µg/L at one site (G3) (fig. 8). Manganese concentration in baseline samples was in the range of 101–500 µg/L at one site (well D12) and greater than 500 µg/L at six sites (wells D3, D6, D7, D8, and G3, and pond-site S3) (fig. 8). The largest manganese concentrations measured in baseline samples were at wells D6 (7,400 µg/L) and D8 (6,900 µg/L).

In addition to the baseline data shown in figure 8, many other water-quality constituents were detected in baseline samples from the study area (table 5). Chloride was detected in nearly all baseline samples; the maximum

chloride concentration in baseline samples was 373 mg/L from well D6. Small concentrations of phosphorus (orthophosphate as phosphorus) were detected in baseline samples from all the monitoring wells (“D” numbered wells) but not in all the other baseline water samples (“G” and “S” sites); the largest concentration of orthophosphate as phosphorus in a baseline sample was from well D4 (0.29 mg/L as phosphorus). Cadmium was detected in most baseline samples; the maximum concentration in samples from the monitoring wells was 3.8 µg/L from well D6, but the maximum concentration detected in any baseline sample was 10 µg/L from sites G2 and S1. Chromium and copper were not detected in any baseline samples, but nickel and zinc were detected in baseline samples. The maximum nickel concentration in baseline samples was from well D6 (200 µg/L). The maximum zinc concentration in baseline samples was from well D12 (110 µg/L). Bacteria (fecal streptococcus) were found in baseline samples from wells D3 and D12, and counts in the D3 sample were about twice the MRL. The baseline data indicate that major-ion, nutrient, trace-element, and bacteria sources other than biosolids were present in the study area and that water in the study area was of variable quality before biosolids ever were applied.

Variability in Water Quality

Variability in water quality of the study area was evident from the baseline data as well as from the data collected after biosolids applications began. Therefore, this discussion of variability in water quality includes all data collected during 1993–1998; effects from biosolids applications will be discussed in a later section, Biosolids Effects. Water quality varied spatially, both across the study area and with depth of water sampled. Water quality also varied temporally during 1993–1998.

The hydrology of the study area was described by Yager and Arnold (2003) and likely accounts for some of the variability in water quality. Precipitation caused runoff from farmed fields, caused intermittent and ephemeral streams to flow, and fed natural and anthropogenic ponds. During dry periods, pond water evaporated and desiccation cracks formed. Some ponds were fed by groundwater discharge and some ponds recharged groundwater. Groundwater also recharged preferentially through desiccation cracks and coarse-grained deposits and outcrops, not uniformly through the unsaturated zone beneath all fields. Ponds were present in various locations of the study area at different times, but a few ponds were consistently present such as near wells D2, D4, D8, D20, D22, D23, and D30. Such ponds likely were maintained by groundwater discharge but also could provide recharge to groundwater when the water table dropped. Detention structures across stream valleys that were created to decrease erosion resulted in new (anthropogenic) ponds (such as those in 1996 or 1997 near wells D12, D24, D25, D26, and D32) or increased the duration and size of natural ponds. Natural ponds

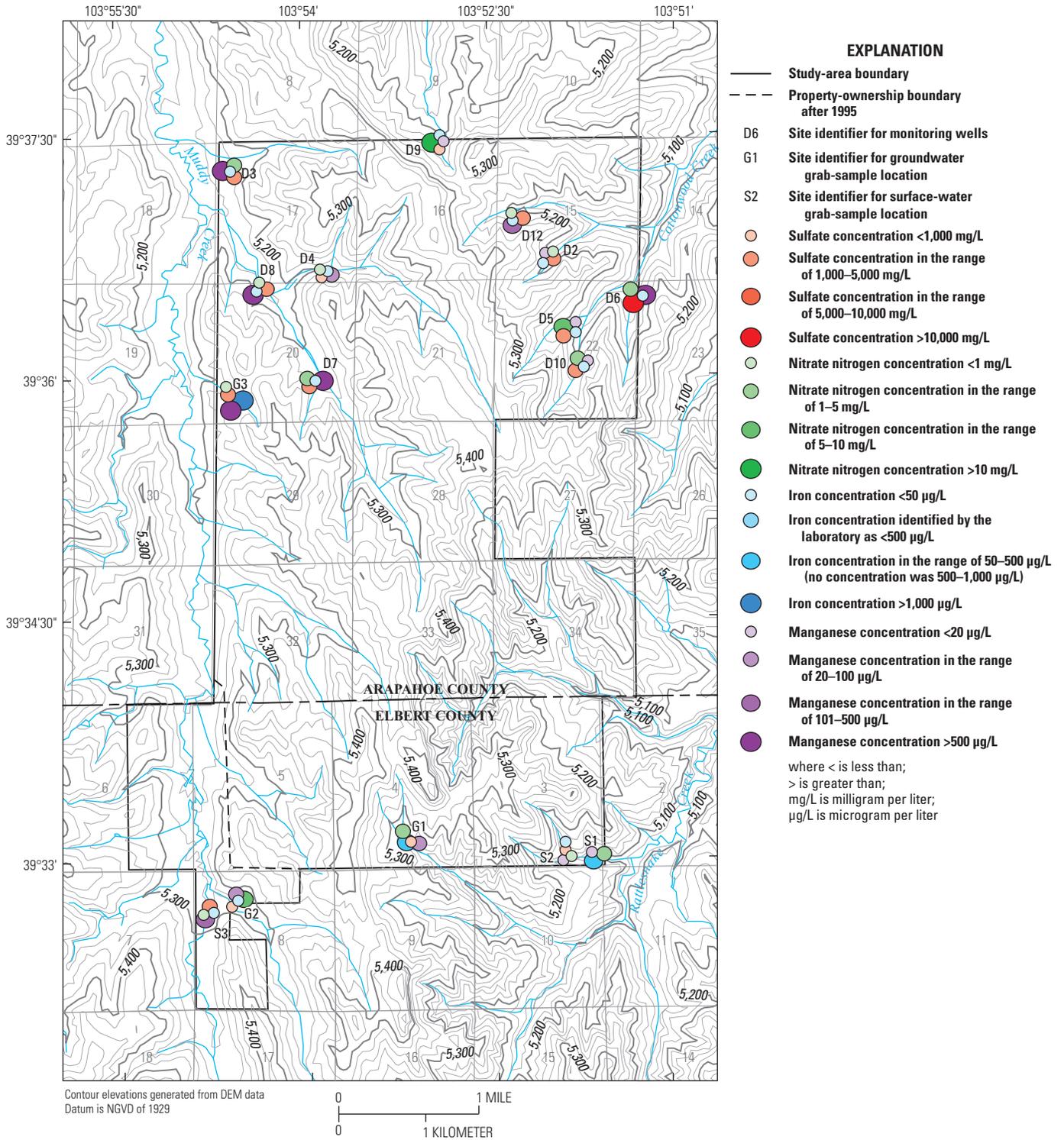


Figure 8. Baseline water quality for selected constituents in groundwater and surface-water samples collected in 1993 at the Metro Wastewater Reclamation District property. [Biosolids applications began in late 1993 to early 1994 after these samples were collected]

occasionally formed near wells D6, D9, D14, D15, D16, D19, D28, and D31 but were transient. Such ponds likely provided recharge to groundwater until they dried out. Ponds captured runoff from nearby fields that could be affected by farming, biosolids applications, or animal waste. Subsequent evaporation concentrated many constituents in pond water as can be seen by the differences in the July and August 1993 concentrations in water samples from pond S3 (table 5). These processes naturally increased water-quality variability in the study area.

Spatial Variability

Water quality varied from site to site throughout the study area during 1993–1998 (tables 5–7). Spatial variability in the baseline water quality of the study area is evident from the different distributions of concentration data at the different sites shown in figure 8. Spatial variability in the water-quality data collected after 1993 also is evident (tables 5–7). Concentrations of major ions, nutrients, trace elements, and bacteria varied from site to site in the study area. Concentrations of sulfate, nitrate, iron, and manganese varied the most. Drainage basins can receive similar rain and snow amounts, have a similar topographic and hydraulic gradient, receive similar runoff amounts and quality, and have other similar characteristics that can affect water quality, but water quality generally was not similar within the four drainage basins of the study area. Muddy Creek generally had similar water quality along the Muddy Creek main stem drainage valley (including wells D15 and D21), but had dissimilar water quality in tributary drainage valleys (for example, wells D13, D17, D20, and D25). Cottonwood Creek drainage basin had similar concentration patterns for some constituents in some locations (nitrate concentrations generally increased at wells D5, D6, and D32), but generally dissimilar water quality (compare constituent concentrations at well D6 with other wells in this drainage basin). Although well D9 was the only monitoring well in the Badger Creek drainage basin, the pattern of nitrate concentrations at well D9 was most similar to that of well D10 (Cottonwood Creek drainage basin). Although well D22 was the only monitoring well in Rattlesnake Creek drainage basin, sulfate concentrations (and some other constituents) were more similar to well D6 (Cottonwood Creek drainage basin) concentrations than to those of other wells. Therefore, water quality did not appear to vary according to drainage basin in the study area.

Major-ion concentrations generally were higher in groundwater than in surface water but varied considerably. Median chloride concentration ranged from less than 1 mg/L in samples from well D11a to 394.5 mg/L in samples from well D6. Median sulfate concentration ranged from 34 mg/L in samples from well D11a to 12,200 mg/L in samples from well D6. Major ion data can be used to describe water composition. In general, groundwater of the study area was calcium-magnesium-sulfate type or calcium-bicarbonate type (fig. 9). Sometimes a diagram of major-ion concentrations (like the trilinear diagrams shown in figure 9) indicates that water composition is similar by geographic area, by aquifer type (bedrock

or alluvial), by geology (sandstone or shale), or by treatment (biosolids or no biosolids). Trilinear diagrams of major-ion data for the study area did not indicate much difference in water composition by drainage basin, treatment, site type, or well depth (fig. 9). However, the trilinear diagram indicates that water-composition groupings (D in fig. 9) align somewhat with the geologic map of the Limon Quadrangle (Sharps, 1980) as demonstrated in figure 10. Discrepancies between data groupings and the formation delineations from Sharps (1980) could be a result of minor inaccuracies in geologic mapping (such as from scale changes when the large geologic map was magnified to fit the small study area, from interpolation during mapping, or from later erosion of the landscape), or lithologic differences within formations that result in localized mineralogical or geochemical variations. Little detailed lithological, mineralogical, or core-chemical information is available for the wells in the study area to verify that water composition in the study area largely is controlled by geology. However, information obtained from coring the monitoring wells for the USGS expanded monitoring program (the “DTX” numbered wells in fig. 3; Stevens and others, 2003) supports the hypothesis that major-ion concentrations in groundwater varied more by lithology or geologic formation than by drainage basin, biosolids treatment, site type, or well depth.

Nitrate concentration varied considerably across the study area (table 5; fig. 8). At individual monitoring wells, median nitrate concentration ranged from less than 0.02 mg-N/L in samples from many wells to 24.05 mg-N/L in samples from well D24. Nitrate concentrations were less than 2 mg-N/L in samples from both deep bedrock-aquifer wells (D11a and D29), but concentrations varied greatly in samples from shallow wells. Nitrate concentrations generally were largest in samples from shallow bedrock-aquifer wells in the north part of the study area (wells D9 and D24). Nitrate concentrations generally were small in samples from wells near wetland areas such as those along Muddy Creek (wells D15, D16, D20, D21, and D23; table 5) and in samples from wells along lower Cottonwood Creek (wells D2, D12, D30, and D31; table 5). Nitrate or ammonia plus organic nitrogen (sometimes called Kjeldahl nitrogen) was the predominant nitrogen compound in samples from these sites. Nitrate concentrations in samples from upper Cottonwood Creek wells (D5, D6, D10, D32, and D33; table 5) generally were higher than in samples from lower Cottonwood Creek wells (wells D2, D12, D30, and D31).

Trace-element concentrations varied considerably across the study area for a few constituents (table 5; fig. 8). At individual monitoring wells, median iron concentration ranged from less than 50 µg/L in samples from many wells to 6,850 µg/L in the samples from well D29. Median manganese concentration ranged from less than 20 µg/L in samples from many wells to 16,000 µg/L in the samples from well D23. Concentrations of dissolved iron and manganese generally were higher in wetland-area wells, such as along Muddy Creek. Median concentrations of cadmium, chromium, copper, nickel, lead, and zinc varied little from site to site and generally were less than the MRL in samples from all sites.

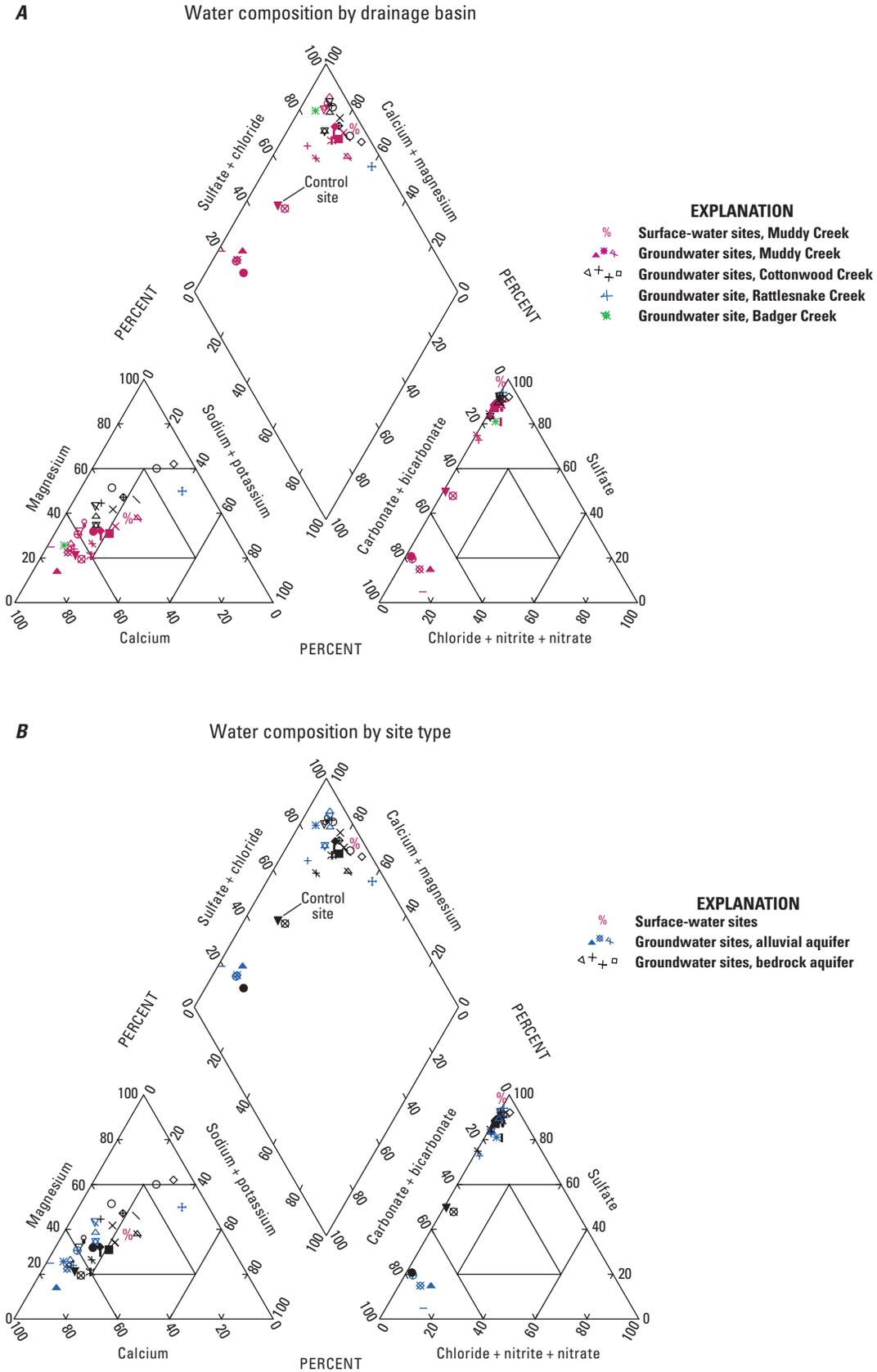


Figure 9. Trilinear diagrams showing water type for (A) drainage basin, (B) site type, (C) well depth, and (D) water-composition groupings near Deer Trail, Colorado, based on median data for 1993–1998.

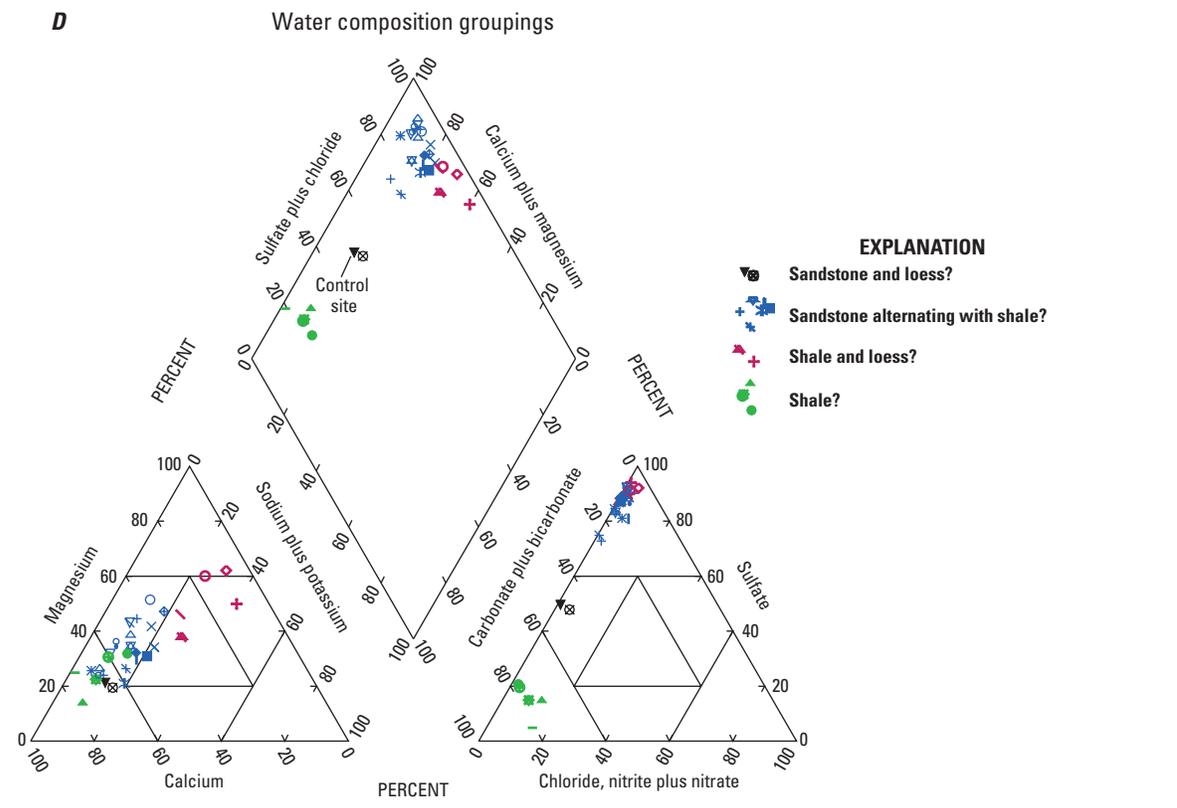
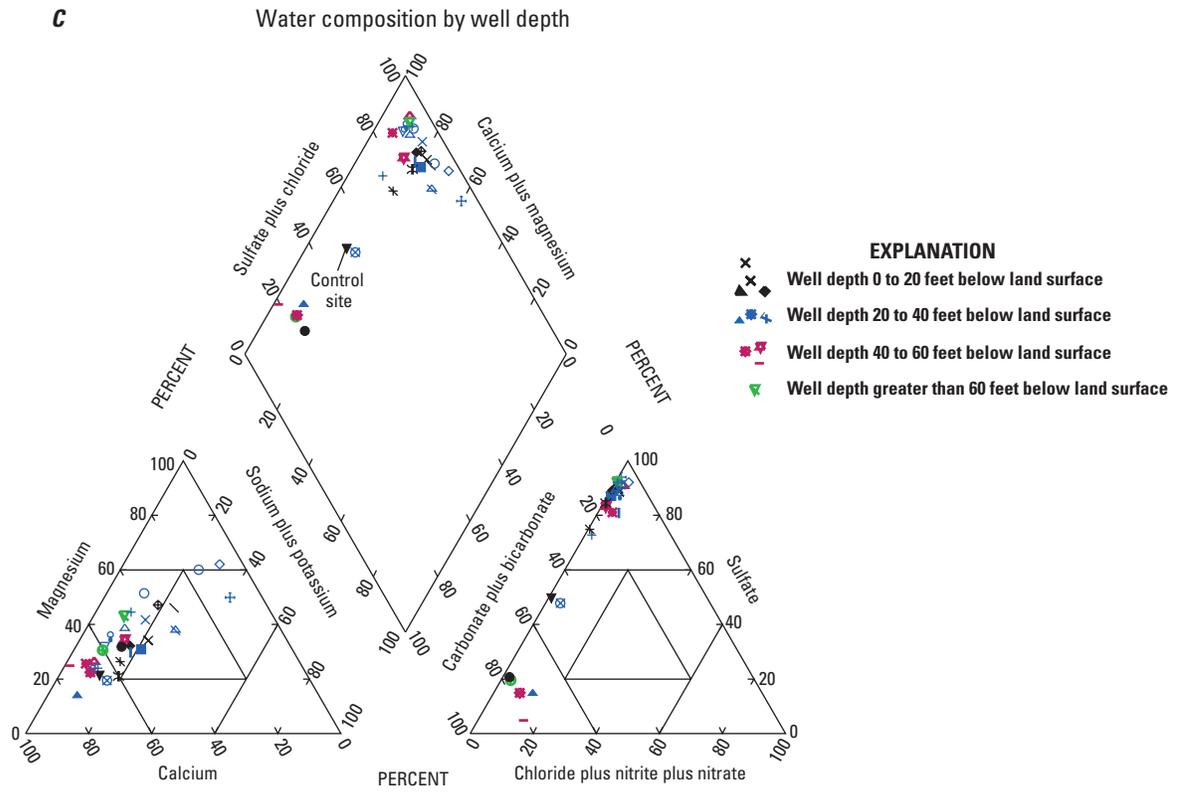


Figure 9. Ternary diagrams showing water type for (A) drainage basin, (B) site type, (C) well depth, and (D) water-composition groupings near Deer Trail, Colorado, based on median data for 1993–1998.—Continued

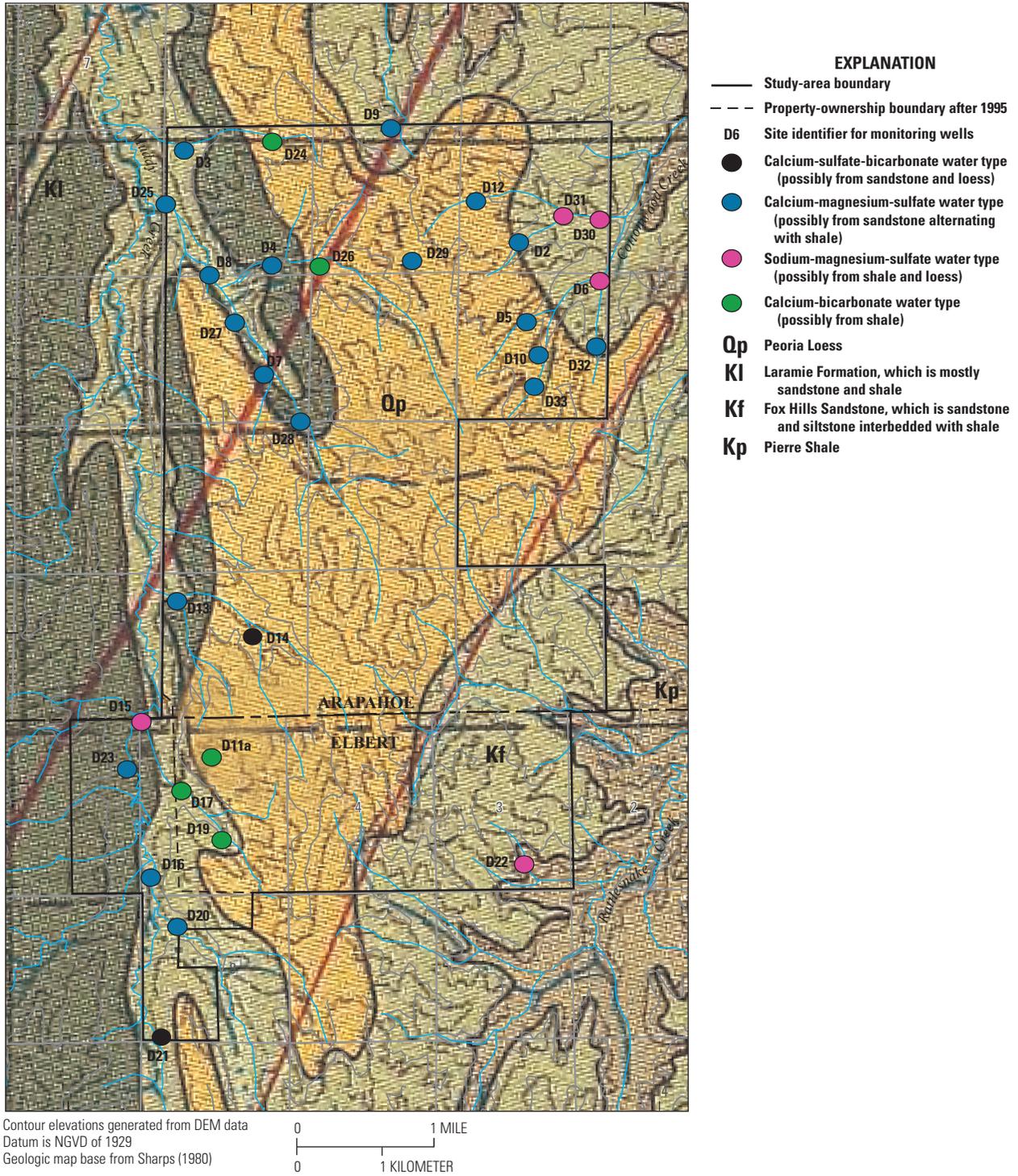


Figure 10. Groundwater major-ion water-composition groups (figure 9D) overlaying the geologic map presented by Sharps (1980).

Bacteria concentrations varied across the study area; however, no spatial patterns in fecal coliform and fecal streptococcus bacteria counts were observed for 1993–1998 in the study area (table 6). Although these bacteria were detected in samples collected from every drainage basin, fecal coliform and fecal streptococcus bacteria were not detected in most of the samples from the study area. Fecal streptococcus bacteria were detected more frequently than fecal coliform bacteria. In general, fecal coliform and fecal streptococcus bacteria were not routinely detected in samples from the same site. No fecal coliform or fecal streptococcus bacteria were detected in any samples from wells D4, D5, D7, D8, D16, D19, or D26. Of the eight surface-water samples collected, seven had detections of these bacteria. Pond samples always had larger bacteria counts than samples collected at the same time from nearby wells, except at well D30 and the nearby pond (S4) where bacteria counts were similar (table 6). The erratic and wide-ranging bacteria counts in the samples from the study area caused the USGS to substantially revise the field sampling method in early 1997 to minimize any possible effect from field procedures or equipment. Therefore, the USGS has more confidence in the bacteria data from 1997 and 1998 because field equipment and field methods were not contributing bias or variability. Laboratory processes likely contributed some bias and variability in the 1993–1998 bacteria data; note the variation in data for concurrent replicate pairs in 1997 and 1998.

Water-quality concentration did not correlate well with depth of sample although some generalizations can be made for some constituents. Water-quality data for chloride, sulfate, nitrate, iron, and manganese are plotted with sample depth and (for groundwater samples) depth to groundwater in figure 11. Groundwater was sampled from about 10 ft to about 150 ft below land surface, pore water was sampled from 1.5- and 3-ft depths, and surface water always was sampled at land surface (0-ft depth). Depth to groundwater below land surface ranged from a few feet at well D23 to about 150 ft at well D29. Most of the variations in concentration shown in figure 11 result from concentration variability at the same site. For example, chloride, sulfate, and manganese concentrations in samples from well D6 were large and fluctuated more than those from most other wells; iron concentrations in samples from well D21 were large and fluctuated more than those from other wells. In general, smaller chloride, nitrate, and manganese concentrations were characteristic of deeper wells; however, not all shallower samples or wells had higher concentrations, and few deeper wells were included in this study. The largest nitrate concentration detected in the study-area water was in the pore water at 1.5-ft depth (table 5). The unsaturated-zone data (April 1994) indicate that nitrate concentrations in the upper 3 ft of soil pore water can be as high or higher than groundwater concentrations (table 5).

Depth affected pore-water availability for sampling, as well as water quality. Samples of pore water collected from the unsaturated zone in upland areas of the study area were used to indicate whether a plume of contaminants was migrating from near the land surface downwards through the unsaturated zone and eventually into the shallow groundwater. Of the

36 lysimeters installed (four different plots), only 8 samples could be obtained from 3 plots in April 1994. Only some (not all) of the shallowest lysimeters (installed 1.5–3 ft below land surface) yielded pore-water samples. Although the spring of 1994 was wet, no samples could be obtained from the control plot because all the lysimeters were dry. No samples could be obtained from the same lysimeters from any depth the following spring (1995) despite the unusually wet weather that preceded the sampling effort. These pore-water data (and lack of samples) indicate preferential recharge patterns, not diffuse recharge through all the agricultural fields in the study area. More pore water was available for sampling in the 1.5-ft depth (yielded 7 samples) than in the 3-ft depth (yielded 1 sample) or the 5-ft depth (yielded 0 samples). When constituents were detected, the single pore-water sample obtained from the 3-ft depth (V3L7) was not the maximum or the minimum concentration, so little effect of depth on pore-water concentration can be surmised. The data indicate that nitrogen in the pore water was primarily in the form of nitrate (table 5). Chloride, nitrate, and copper reservoirs in the upper 3 ft of the unsaturated zone could eventually migrate to the saturated zone (groundwater).

Temporal Variability

Water quality in the study area varied over time. Temporal variability in water quality generally was larger at some sites than other sites in the study area and larger for some water-quality constituents (like nitrate, iron, manganese, and fecal streptococcus bacteria) than other constituents. Field contamination (samples collected for inorganic analyses before 1996 or collected for bacteria analyses before 1997) or laboratory error likely account for the few, unusually small or large concentrations of major ions and trace elements reported for some samples from the study area (tables 5 and 6). In general, few sites in the study area had increasing water-quality constituents over time, although increasing concentrations of some constituents could be obscured by the relatively large MRLs used by the laboratory.

Concentrations of nitrate in the groundwater samples fluctuated substantially during 1993–1998. Temporal fluctuations in nitrogen can result from fluctuations in nitrogen sources and nitrogen removals (sinks). Nitrogen sources include atmospheric deposition, decaying plant residue, rocks (such as shale), commercial fertilizers, animal feces, human septage (perhaps associated with the homesteads), or biosolids. Nitrogen sinks include plant uptake, microbial reactions, and water transport. Nitrate concentrations were relatively large and fluctuated considerably during 1993–1998 in samples from three wells: D9, D24, and D25 (fig. 12), all located in the north part of the study area. Nitrate concentration in samples from well D9 was about 13 mg-N/L in 1993, decreased to about 2 mg-N/L in July 1994, increased to a high of 27 mg-N/L in December 1995, decreased again to 8.4 mg-N/L in February 1997, then increased again to about 24 mg-N/L in 1998. Nitrate concentration in samples from well D10, a

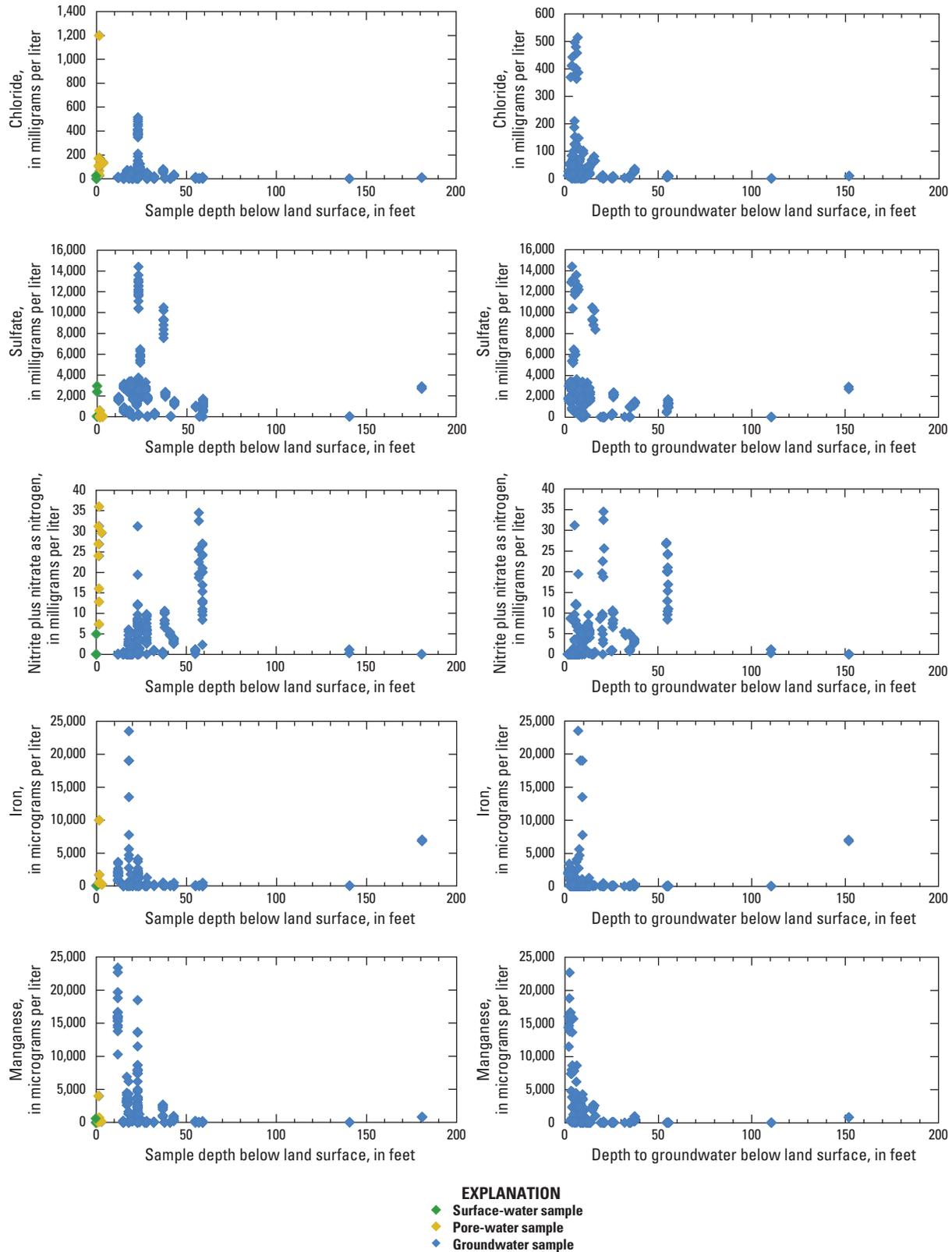


Figure 11. Water-quality data for selected dissolved constituents compared with sample depth and (for groundwater samples) depth to groundwater near Deer Trail, Colorado, 1993–1998. [Vertical columns of data points in the sample-depth graphs indicate variability in concentration data at the same site (for wells) or site type (if non-well sites)]

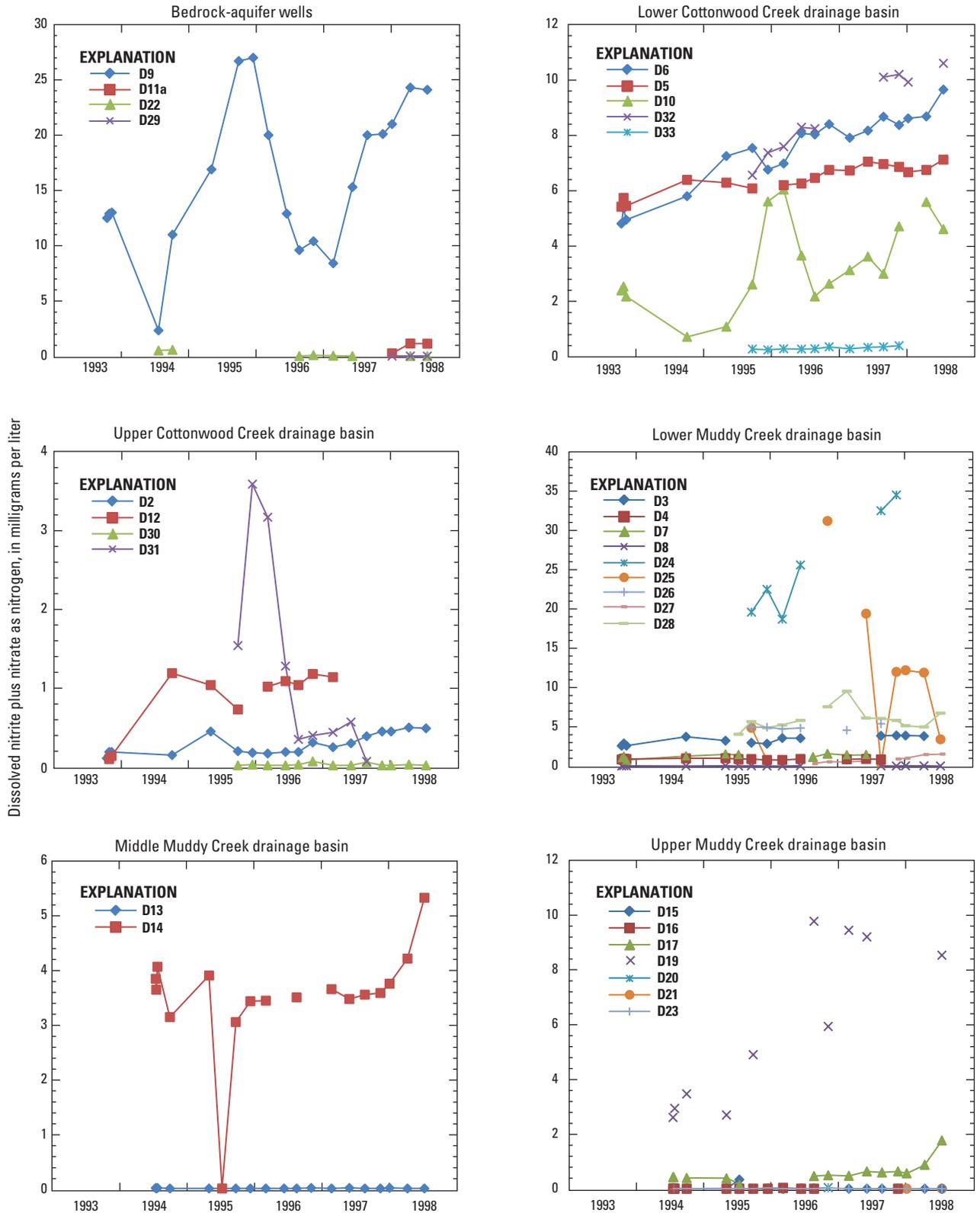


Figure 12. Groundwater concentrations of nitrite plus nitrate as nitrogen over time at monitoring wells near Deer Trail, Colorado, 1993 through 1998.

shallower well in a different drainage basin, were smaller but had a similar fluctuation pattern (fig. 12). In contrast, nitrate concentration in samples from well D24 generally increased from about 20 mg-N/L in September 1995 to 34.5 mg-N/L in November 1997. Nitrate concentration in samples from well D25 fluctuated considerably, ranging from about 0.4 mg-N/L in August 1997 to about 31 mg-N/L in November 1996 (fig. 12; table 5). Patterns in nitrate concentration in groundwater of the study area usually showed that high-concentration periods were followed by low-concentration periods. Nitrate concentrations in samples from wells D6, D24, and D32 increased more markedly and more consistently than in those from other wells in the study area (fig. 12). In general, nitrate concentration increased in samples from most wells along lower Cottonwood Creek (fig. 12) but was more variable in samples from wells D9, D14, D19, D25, D28, and D31.

Concentrations of selected trace elements at some study-area sites fluctuated over time. Study-area samples were routinely analyzed for dissolved forms of selected trace elements; at most sites, concentrations usually were near or less than laboratory MRLs. Trace elements are difficult to quantify at low concentrations and are present in dust and other airborne constituents, so some trace-element data may be affected by field contamination (if before 1996), laboratory contamination, or analytical interference. The November 1993 concentration of manganese in the sample from well D6, August 1996 concentrations of nickel and zinc in the sample from well D16, the June 1997 concentrations of iron in the samples from wells D7, D27, and D28, and the larger cadmium and chromium concentrations reported for various wells likely resulted from field or laboratory bias. Large concentrations of iron and manganese in samples from wells D15, D16, D21, D23, and D29 likely are representative of the groundwater and are confirmed by later samples. Iron concentration in samples from well D21 ranged from 320 µg/L in 1994 to 23,500 µg/L in 1995. Manganese concentration in samples from well D21 ranged from 1,250 µg/L in 1996 to 6,200 µg/L in 1994. Groundwater samples from wells D15, D16, and D21 generally had larger dissolved iron concentrations in summer following rain, and groundwater samples from wells D6, D15, and D23 generally had larger dissolved manganese concentrations in early summer before rain (table 5; precipitation data were reported by Yager and Arnold, 2003).

In general, fecal coliform and fecal streptococcus bacteria were not consistently present or absent in groundwater samples, despite multiple sources of these bacteria. Fecal streptococcus bacteria counts ranged from less than 2 colonies per 100 mL in 1998 to greater than 10,000 colonies per 100 mL in 1996 in samples from well D2. Fecal streptococcus bacteria counts ranged from 180 colonies per 100 mL in 1998 to 4,200 colonies per 100 mL in 1997 in samples from S5, a shallow temporary pond near well D15. The revised sampling methods implemented in 1997 mean that the bacteria data for 1997–1998 likely are not biased by sample-collection methods and, therefore, may be more representative of bacteria concentration than earlier samples. In some cases, these later data seem to confirm earlier bacteria counts at some sites such

as in samples from wells D2, D13, and D22. In general, the temporal pattern in the bacteria data is isolated large counts followed by smaller counts or non-detects (table 6). It is not known if laboratory conditions or procedures contributed to the temporal variability present in the bacteria data, although differences in bacteria counts are evident for some replicate (split) samples (the environmental sample and the replicate) (table 6).

Of the limited analytes considered for this study, nitrate increased in concentration the most consistently over time; however, the water-quality data from this study were not suitable for statistical evaluation of temporal trend. Much of the data are derived from analyses that were optimized for higher concentration data, so the data for this study often are censored below relatively large MRLs. In addition, the sampling methods changed substantially over time. Initial sampling methods for baseline and reconnaissance sampling used a less-strict sampling protocol than was used for later samples. This change in sampling preparation and sample-collection methods in late 1995 means that the later water-quality data better represented water quality of the study area, but that water-quality data collected after December 1995 were not strictly comparable to previously collected data. Finally, the power of a trends test is low when sampling frequency was less than about 5 years of quarterly sampling, as in this case (D.R. Helsel, U.S. Geological Survey, oral commun., 2000).

Comparison with Regulatory Standards

A comparison of water-quality data to regulatory standards provides a context for the concentration values. Values that are larger than the appropriate regulatory standard indicate the water from that site may not be appropriate for a particular use such as drinking water or livestock watering. Regulatory water-quality standards for surface water are not included in this report because few surface-water samples could be obtained. Regulatory water-quality standards for groundwater are included with a summary of the groundwater-quality data in table 8 and figure 13; however, no groundwater-quality standard actually may be enforceable at the routinely sampled sites in the study area. The human health standard may not be enforceable because that standard is based on consumption of the water, and none of the groundwater from the routinely monitored wells was used for drinking-water supply during 1993–1999. In this study area, shallow groundwater generally is more susceptible to contamination from the land surface than deep groundwater. The agricultural standard for groundwater may not be enforceable because the water from the routinely monitored wells was not used for irrigation or livestock watering during 1993–1999. Sites that were sampled occasionally and that actively were used for livestock watering were G1 and G2. Water-quality standards included in this report are from Colorado Department of Public Health and Environment (1997, p. 9–10). These standards and the subsequent discussion comparing study-area groundwater concentrations to the Colorado standards are provided as a frame of reference for

Table 8. Summary of groundwater-quality data collected for this study near Deer Trail, Colorado, during 1993–1999, and groundwater regulatory limits.

[Data are from analyses of environmental samples by the Metro Wastewater Reclamation District laboratory or from analyses of replicate or environmental samples by the U.S. Geological Survey National Water Quality Laboratory. Standards are from Colorado Department of Health and the Environment (1997); FAO, Food and Agricultural Organization of the United Nations (Pais and Jones, 1997, p. 31); mg/L, milligrams per liter; µg/L, micrograms per liter; --, not applicable; NWQL, U.S. Geological Survey National Water Quality Laboratory; Metro District, Metro Wastewater Reclamation District laboratory]

Chemical constituent or property	Summary of data for all samples, all wells						Colorado regulatory standards			FAO recommended maximum for irrigation water	Well where standard or guideline was exceeded
	Number of samples analyzed	Units	Minimum for all samples	Maximum for all samples	Median for all samples	Analyzing laboratory	Human-health standards	Secondary drinking-water standards	Agricultural standards		
pH	384	standard units	6.2	8.6	7.2	field	--	6.5 to 8.5	6.5 to 8.5	--	¹ D4, D15, D16, D23
Chloride	429	mg/L	<1	515	17	Metro District	--	250	--	--	D6
Fluoride	14	mg/L	0.5	2	1.08	NWQL	4.0	--	2.0	1.0	No data exceeded a standard.
Sulfate	429	mg/L	10	14,400	1,880	Metro District	--	250	--	--	D2, D3, D4, D5, D6, D7, D8 D9, D10, D12, D13, D14, D15, D16, D20, D21, D22, D23, D25, D27, D28, D29, D30, D31, D32, D33, G1, G3
Nitrogen, nitrite as N	429	mg/L	<0.02	1.1	<0.02	Metro District	1.0	--	10	--	D7
Nitrogen, nitrite plus nitrate as N	429	mg/L	<0.02	34.5	0.87	Metro District	10.0	--	100	--	D9, D24, D25, D32
Aluminum	6	µg/L	<1	<5	<2	NWQL	--	--	5,000	5,000	No data exceeded a standard.
Antimony	6	µg/L	<1	<5	<2	NWQL	6	--	--	--	No data exceeded a standard.
Arsenic	6	µg/L	<1	4	<1	NWQL	50	--	100	100	No data exceeded a standard.
Barium	14	µg/L	9	57	14.71	NWQL	2,000	--	--	--	No data exceeded a standard.
Beryllium	14	µg/L	<0.5	<3	<2	NWQL	4	--	100	100	No data exceeded a standard.
Boron	6	µg/L	101	1,590	390	NWQL	--	--	750	--	D22
Cadmium	443	µg/L	<0.02	6	<0.2	both	5	--	10	10	D3, D15 (replicates)
Chromium	429	µg/L	<20	430	<20	Metro District	100	--	100	100	D2, D5, D6, D9, D10, D15, D16, D20, D22, D23, D28, D29, D30, D31, D32, D33
Cobalt	14	µg/L	<2	<36	<12	NWQL	--	--	50	50	No data exceeded a standard.
Copper	429	µg/L	<20	<200	<20	Metro District	--	1,000	200	200	No data exceeded a standard.
Iron	429	µg/L	<50	23,500	<50	Metro District	--	300	5,000	5,000	D7, D15, D16, D21, D23, D27, D28, D29, D30, G3
Lead	429	µg/L	<10	<10	<10	Metro District	50	--	100	5,000	No data exceeded a standard.
Lithium	14	µg/L	29	220	110	NWQL	--	--	2,500	2,500	No data exceeded a standard.
Manganese	429	µg/L	<20	23,410	220	Metro District	--	50	200	200	D3, D4, D6, D7, D8, D9, D12, D13, D14, D15, D16, D17, D20, D21, D22, D23, D25, D27, D28, D29, D30, D31, D32, G1, G3
Mercury	6	µg/L	<0.1	<0.1	<0.1	NWQL	2	--	10	--	No data exceeded a standard.
Nickel	429	µg/L	<20	2,520	<20	Metro District	100	--	200	200	D4, D6, D12, D16, D32
Selenium	6	µg/L	<1	4	<1	NWQL	50	--	20	20	No data exceeded a standard.
Silver	14	µg/L	<3	<12	<4	NWQL	50	--	--	--	No data exceeded a standard.
Vanadium	14	µg/L	<6	<30	<24	NWQL	--	--	100	--	No data exceeded a standard.
Zinc	429	µg/L	<20	5,460	<20	Metro District	--	5,000	2,000	2,000	D16

¹Standards are listed as a range, so exceedances are values above or below this range.

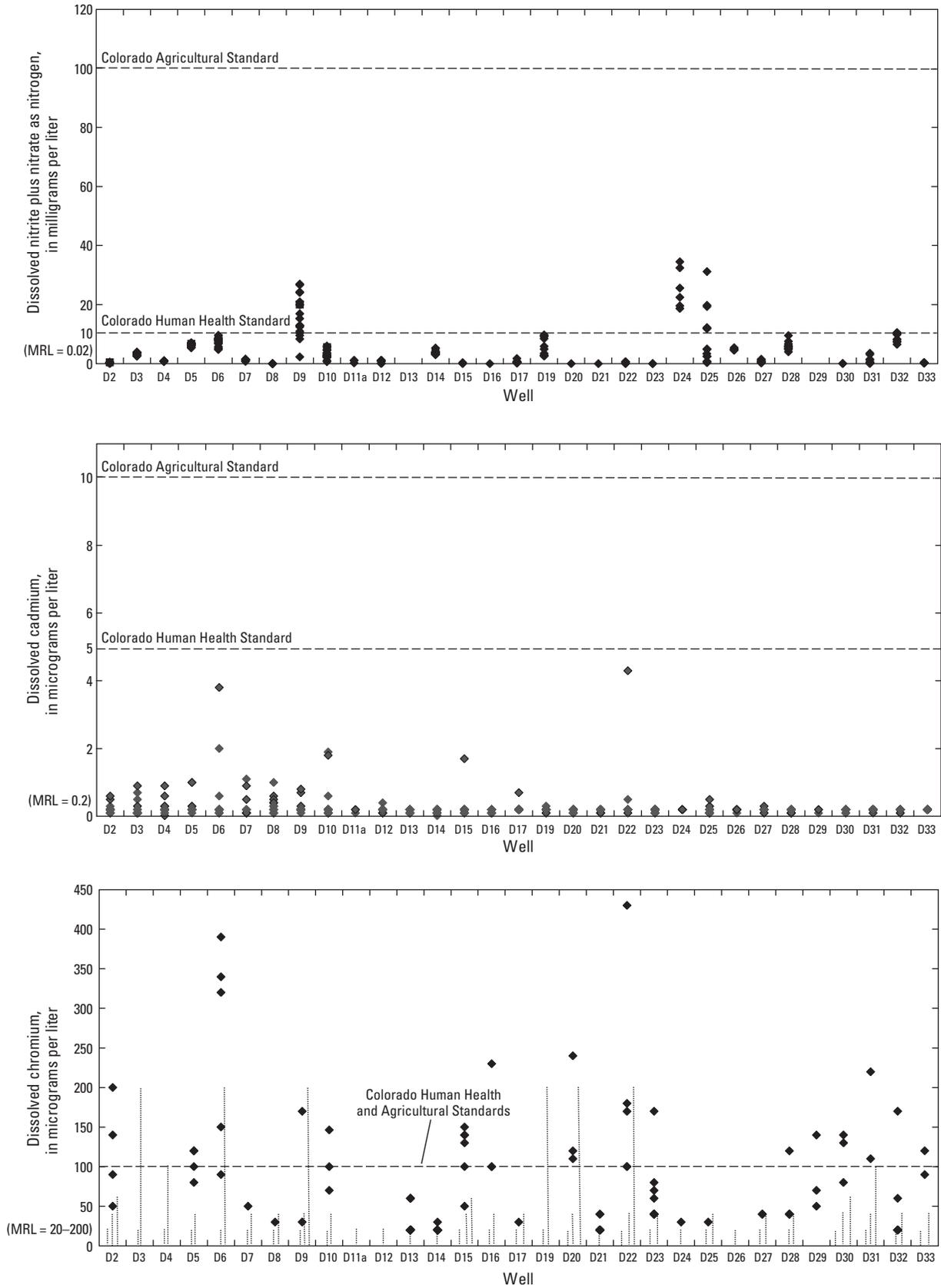


Figure 13. Distribution of groundwater-concentration data for samples collected near Deer Trail, Colorado, compared to regulatory standards for selected constituents, 1993 through 1999. [Where the minimum reporting level (MRL) is distinguishable above the axis, dotted vertical lines represent data that were reported by the laboratory as less than the MRL]

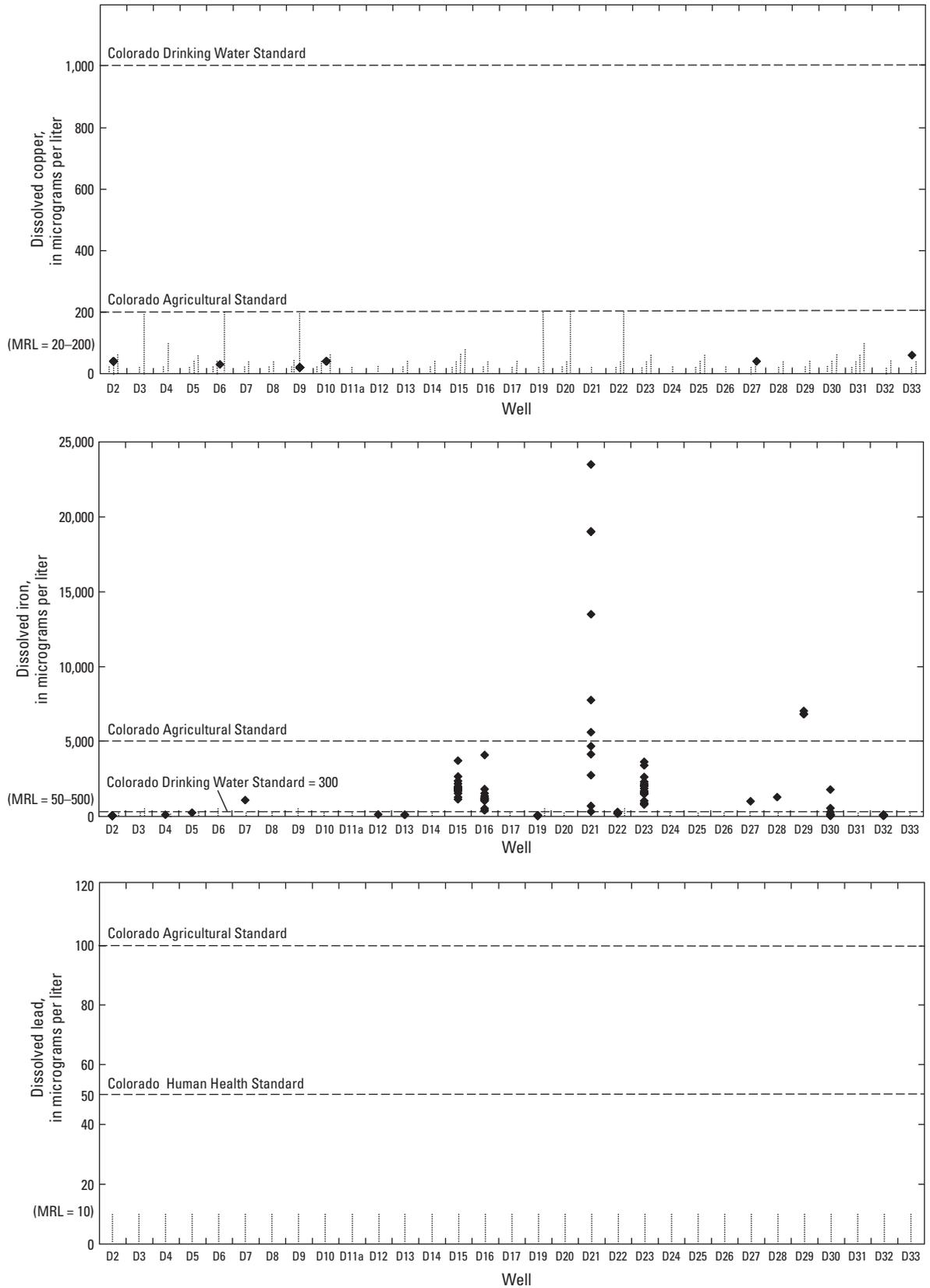


Figure 13. Distribution of groundwater-concentration data for samples collected near Deer Trail, Colorado, compared to regulatory standards for selected constituents, 1993 through 1999. [Where the minimum reporting level (MRL) is distinguishable above the axis, dotted vertical lines represent data that were reported by the laboratory as less than the MRL]—Continued

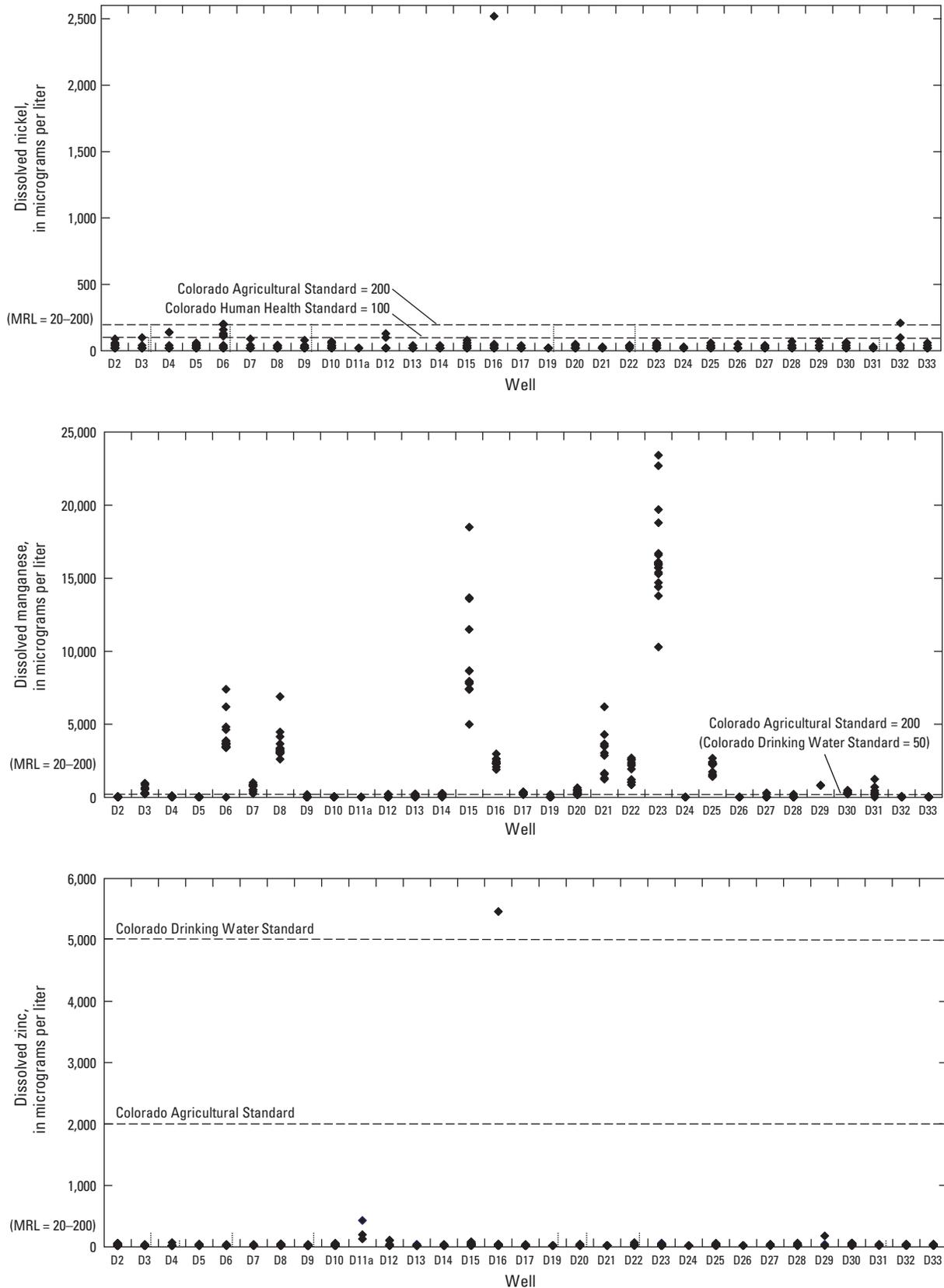


Figure 13. Distribution of groundwater-concentration data for samples collected near Deer Trail, Colorado, compared to regulatory standards for selected constituents, 1993 through 1999. [Where the minimum reporting level (MRL) is distinguishable above the axis, dotted vertical lines represent data that were reported by the laboratory as less than the MRL]—Continued

the concentration data but do not indicate biosolids effects on water quality. Therefore, all the water-quality data are included in this comparison of regulatory standards. The groundwater samples were not routinely analyzed for all regulated constituents, but at least some of the samples were analyzed for all regulated characteristics and inorganic constituents. During 1993–1999, groundwater samples from the study area exceeded various Colorado regulatory standards.

Colorado has stipulated regulatory limits for some major ions in groundwater (Colorado Department of Public Health and Environment, 1997). Groundwater samples from the study area met the drinking-water standard for chloride of 250 mg/L, except for most samples from well D6 (table 8). The maximum chloride concentration reported for the study-area samples during 1993–1999 was 515 mg/L at well D6 in March 1996. All groundwater samples from the study area that were analyzed for fluoride met the human-health and agricultural standards (table 8). However, groundwater samples from most routinely monitored wells in the study area including well D6 exceeded the drinking-water standard for sulfate of 250 mg/L (table 8). The maximum sulfate concentration reported for 1993–1999 was 14,400 mg/L at well D6 in August 1997. In addition, concentrations of dissolved solids were greater than 10,000 mg/L in all samples from wells D6 and D22 (table 5), which can limit use of water at these sites.

Most concentrations of nitrate were less than the 10 mg/L Colorado human-health standard (fig. 13). Concentrations of nitrate exceeded the standard in samples from wells D9, D24, D25, and D32 (fig. 13). Nitrate concentration exceeded this standard for all samples from well D24 and most samples from well D9 (fig. 13). Concentrations of nitrate in baseline samples from well D9 also exceeded the Colorado human health standard. All groundwater data for nitrate from study-area wells were less than the agricultural standard of 100 mg/L (fig. 13). The maximum nitrate concentration reported for 1993–1999 was 34.50 mg/L as N at well D24 in November 1997 (tables 5 and 8).

Samples were not routinely analyzed for all the regulated trace elements, and sometimes the laboratory reported data as censored at MRLs greater than the standard, in which cases it is not known if the concentration in the sample exceeded the standard. Of the trace elements that were routinely analyzed, concentrations in the groundwater usually were less than Colorado drinking-water standards (table 8). Exceptions include nickel in samples from wells D4, D6, D12, D16, and D32 and chromium, iron, and manganese concentrations in samples from many wells (fig. 13). Concentrations of trace elements in the groundwater were less than Colorado agricultural standards (table 8), except for iron concentrations in samples from wells D21 and D29; nickel concentrations in samples from wells D6, D16, and D32; and manganese concentrations in samples from wells D3, D6, D7, D8, D12, D13, D14, D15, D16, D17, D20, D21, D22, D23, D25, D27, D28, D29, D30, D31, and G3. Concentrations of aluminum, antimony, arsenic, barium, beryllium, cobalt, copper, lead, lithium, mercury, selenium, silver, and vanadium in environmental

samples collected in 1999 (table 8) and in replicate samples collected during 1994–1999 from study-area wells all were less than Colorado standards.

Concentrations in baseline groundwater samples exceeded some Colorado regulatory standards; note that these samples were collected before biosolids applications to the study area began. Concentrations of chloride in baseline samples from well D6 and concentrations of sulfate in all baseline samples (except those from well G2) exceeded Colorado drinking-water standards. Concentrations of nitrate in baseline samples from well D9 exceeded the Colorado drinking-water standard. Concentrations of iron and manganese in baseline samples from various monitoring wells in the study area also exceeded Colorado regulatory standards, sometimes by a large margin.

Effects on Water Quality

Natural factors such as geology, meteorology, and microbial activity can affect water quality. Anthropogenic factors such as biosolids applications also can affect water quality. Many other factors could affect water quality but were not considered in this limited study. Statistical comparisons generally are not applicable for this limited data set. In particular, many more water-quality samples would have had to be collected in order to apply multivariate statistical techniques to the 1993–1999 data set (D.R. Helsel, U.S. Geological Survey, oral commun., 2000). However, specialty sampling and preliminary geochemical modeling can provide information about how various factors are affecting water quality. For this analysis of effects on water quality, all the water-quality data collected for the study during 1993–1999 were included because geological, meteorological, microbiological, and flow-path effects on water quality do not stop when biosolids are applied. These natural processes can still dominate water quality in a biosolids-application area if the biosolids effects are small.

Geological Effects

Near-surface geological materials in the study area include alluvium, loess, sandstone, siltstone, and shale (fig. 10; Robson and Banta, 1995; Sharps, 1980; Yager and Arnold, 2003). Aquifer-bearing geologic materials in the study area that are within a few hundred feet of the land surface include loess, current or past alluvial deposits, sandstone, and siltstone. Lithologic information for the study area was reported by Yager and Arnold (2003) and Yager and others (2004a, table 7). Some lithologic information for wells D31 and D33 is included in table 9, but detailed lithologic information for the screened interval is not available for most of the monitoring wells. Much more detailed lithologic information for the vicinity of the study area was obtained when the monitoring wells for the USGS Expanded Monitoring Program (fig. 3) were installed.

Table 9. Chemical data for core samples collected from D31 and D33 boreholes during drilling near Deer Trail, Colorado, May 1995.

[Chemical analyses from Metro Wastewater Reclamation District laboratory; all core was loess obtained from split-spoon auger during drilling of the borehole for the monitoring well; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $\mu\text{g}/\text{g}$, micrograms per gram; (A), available metals from ammonium bicarbonate extraction; (T), total metals; (E), extractable by using sodium bicarbonate; <, less than]

Sample site (fig. 2)	Sample depth, feet below land surface	Sample date	Sample texture ¹	pH, soil paste, standard units	Specific conductance, soil paste, $\mu\text{S}/\text{cm}$	Organic matter, percent	Volatile solids, percent	Total solids, percent	Nitrogen, ammonia as N, $\mu\text{g}/\text{g}$	Nitrogen, nitrite plus nitrate as N, $\mu\text{g}/\text{g}$	Phosphorus (E), $\mu\text{g}/\text{g}$	Phosphorus (T), $\mu\text{g}/\text{g}$
D31	0–0.17	5/4/1995	Clay loam	7.6	430	1.27	5.2	81.1	5	4.99	10	231
D31	0.17–1.7	5/4/1995	Loamy sand	7.6	340	1.63	4.0	82.0	5	3.60	2	271
D31	1.7–2.4	5/4/1995	Clay loam, sand	8.0	550	1.42	3.7	81.6	4	9.90	1	297
D31	5.0–6.0	5/4/1995	Clay loam	7.9	9,430	0.31	2.7	75.8	2	1.86	1	326
D31	6.0–7.0	5/4/1995	Clay loam	7.9	7,930	0.31	2.6	74.0	3	0.80	<1	314
D31	8.0–9.0	5/4/1995	Clay loam	7.9	6,910	0.27	2.4	79.9	2	0.65	<1	323
D33	0–0.33	5/5/1995	Sandy loam	7.8	570	1.55	3.9	88.4	8	1.51	10	208
D33	0.75–2.25	5/5/1995	Loamy sand	8.0	1,020	0.43	2.6	93.7	3	0.82	3	256
D33	2.25–3.0	5/5/1995	Loamy sand	7.9	5,930	0.44	3.0	88.5	8	0.55	6	340
D33	4.5–5.0	5/5/1995	Sandy loam	8.0	2,550	0.50	2.5	93.2	10	0.98	<1	238
D33	5.0–5.5	5/5/1995	Clayey sand	8.0	7,250	0.30	3.4	87.6	5	0.67	8	392
D33	9.0–12.0	5/5/1995	Loamy sand	8.0	4,130	0.12	2.3	77.9	7	0.51	<1	301

Sample site (fig. 2)	Sample depth, feet below land surface	Antimony, $\mu\text{g}/\text{g}$	Arsenic (A), $\mu\text{g}/\text{g}$	Arsenic (T), $\mu\text{g}/\text{g}$	Beryllium (T), $\mu\text{g}/\text{g}$	Cadmium (A), $\mu\text{g}/\text{g}$	Cadmium (T), $\mu\text{g}/\text{g}$	Chromium (A), $\mu\text{g}/\text{g}$	Chromium (T), $\mu\text{g}/\text{g}$	Copper (A), $\mu\text{g}/\text{g}$	Copper (T), $\mu\text{g}/\text{g}$	Iron (A), $\mu\text{g}/\text{g}$	Iron (T), $\mu\text{g}/\text{g}$	Lead (A), $\mu\text{g}/\text{g}$
D31	0–0.17	<20	<4	1.7	<4	<0.2	<2	<0.8	12	2.7	<20	27	19,300	1.6
D31	0.17–1.7	<20	<4	1.5	<4	<0.2	<2	<0.8	10	1.0	<20	<16	13,700	1.3
D31	1.7–2.4	<20	<4	1.6	<4	<0.2	<2	<0.8	12	1.0	<20	<16	14,200	1.3
D31	5.0–6.0	<10	<4	3.0	<4	<0.2	<2	<0.8	9	1.1	<20	30	12,700	0.9
D31	6.0–7.0	<20	<4	3.0	<4	<0.2	<2	<0.8	12	1.2	<20	32	14,000	1.5
D31	8.0–9.0	<20	<4	3.0	<4	<0.2	<2	<0.8	11	0.4	<20	<16	12,400	0.8
D33	0–0.33	<20	<4	1.4	<4	<0.2	<2	<0.8	10	0.5	<20	<16	10,600	<0.8
D33	0.75–2.25	<20	<4	1.0	<4	<0.2	<2	<0.8	8	<0.4	<20	<16	10,100	<0.8
D33	2.25–3.0	<20	<4	2.3	<4	<0.2	<2	<0.8	16	<0.4	<20	<16	15,400	<0.8
D33	4.5–5.0	<20	<4	1.2	<4	<0.2	<2	<0.8	11	0.6	<20	<16	12,000	<0.8
D33	5.0–5.5	26	<4	2.2	<4	<0.2	<2	<0.8	14	0.8	<20	16	14,500	<0.8
D33	9.0–12.0	<20	<4	1.9	<4	<0.2	<2	<0.8	8	0.8	<20	<16	10,600	<0.8

Sample site (fig. 2)	Sample depth, feet below land surface	Lead (T), $\mu\text{g}/\text{g}$	Manganese (A), $\mu\text{g}/\text{g}$	Mercury (A), $\mu\text{g}/\text{g}$	Molybdenum (A), $\mu\text{g}/\text{g}$	Molybdenum (T), $\mu\text{g}/\text{g}$	Nickel (A), $\mu\text{g}/\text{g}$	Nickel (T), $\mu\text{g}/\text{g}$	Selenium (A), $\mu\text{g}/\text{g}$	Selenium (T), $\mu\text{g}/\text{g}$	Zinc (A), $\mu\text{g}/\text{g}$	Zinc (T), $\mu\text{g}/\text{g}$
D31	0–0.17	<20	5.07	<0.1	<0.4	<10	0.4	16	<4.0	0.1	1	56
D31	0.17–1.7	<20	0.99	<0.1	<0.4	<10	<0.4	10	<4.0	0.3	<0.4	48
D31	1.7–2.4	<20	1.10	<0.1	<0.4	<10	<0.4	11	<4.0	0.5	<0.4	48
D31	5.0–6.0	<20	4.24	<0.1	<0.4	<10	<0.4	<10	<4.0	<0.1	<0.4	38
D31	6.0–7.0	<20	2.35	<0.1	<0.4	<10	<0.4	<10	<4.0	<0.1	<0.4	43
D31	8.0–9.0	<20	0.60	<0.1	<0.4	<10	<0.4	<10	<4.0	<0.1	<0.4	39
D33	0–0.33	<20	1.35	<0.1	<0.4	<10	<0.4	<10	<4.0	<0.1	<0.4	39
D33	0.75–2.25	<20	<0.16	<0.1	<0.4	<10	<0.4	<10	<4.0	<0.1	<0.4	38
D33	2.25–3.0	<20	0.38	<0.1	<0.4	<10	<0.4	13	<4.0	0.1	<0.4	57
D33	4.5–5.0	<20	1.24	<0.1	<0.4	<10	<0.4	11	<4.0	0.2	<0.4	70
D33	5.0–5.5	<26	2.81	<0.1	<0.4	<10	<0.4	13	<4.0	<0.1	<0.4	53
D33	9.0–12.0	<20	1.38	<0.1	<0.4	<10	<0.4	<10	<4.0	<0.1	<0.4	45

¹From geologist's description of core.

Geology affected water quality in the study area. Major-ion and trace-element chemistry of water in the study area appears to be controlled primarily by local geology. From core obtained during well installations in 1999–2002, it was observed that geologic units mapped as sandstone in figure 8 are interbedded with thin layers of shale in the vicinity of the study area, contain iron-rich concretions, and weather chemically to produce secondary crystalline minerals and amorphous iron oxides. Chemical analysis of core samples (table 9) confirmed the presence of many of the same major and trace elements in the near-surface geologic materials of the study area that were in the groundwater. Iron concentrations in the loess samples were large (as much as 19,300 $\mu\text{g/g}$) (table 9). In some places, loess was observed to overly the alluvium from buried paleo channels; in other places, the loess occurs as terraces or as flood plains with incised alluvial systems. The alluvium was igneous (granitic sands and gravels derived from Rocky Mountain glacial outwash) or sedimentary (reworked pebbles and sands from local sandstones, siltstones, and shales). Contact with groundwater and infiltrating surface water results in dissolution, precipitation, and weathering reactions of the minerals in these rocks that change the chemical composition of the groundwater (Drever, 1988). Also, iron and manganese oxides that form naturally in the dry, oxygenated soils of the study area can sorb and later release various elements that leach from surface sources like biosolids (T.P. Wilson, U.S. Geological Survey, written commun., May 29, 2012). Localized variations in lithology, weathering, mineralogy, and residence time in the aquifers can cause the variations in groundwater major-ion and trace-element concentrations observed in the 1993–1999 data from this study area. These localized variations also explain why major-ion groundwater concentrations were not uniform within the geologic-formation boundaries shown in figure 10, but likely account for the major-ion and trace-element composition of the water in the study area.

Calcium and sulfate were major ions in the water collected from the study area (fig. 9), and the source of these ions likely was the near-surface geologic materials in the study area. Calcium content in loess samples was about 1–2 percent but as high as about 10.5 percent in loess that had gypsum crystals in contact with groundwater near well D6 (Yager and others, 2004a, table 7). Sulfur content was less than 0.05–1.5 percent in loess samples from the study area; smaller sulfur content was observed in loess samples that contained visible coal fragments (Yager and others, 2004a, table 7). Sulfur content was slightly larger (1.8 percent) in weathered shale in the vicinity of well D9. In general, sulfur content in shale is about twice that in sandstone, but calcium content is similar in sandstone and shale (Hem, 1992, p. 5). Sulfur in water of the study area during 1993–1999 was primarily in the form of sulfate (tables 5 and 10). Precipitation of calcium sulfate or calcium carbonate minerals will decrease the concentrations of calcium and sulfate that are dissolved in the water, which can account for some of the spatial variability of calcium and sulfate in groundwater of the study area. The dissolution of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) could account for much of the calcium and sulfate ions, and

dissolution of calcite (CaCO_3) could account for calcium and bicarbonate ions in the groundwater. Calcium concentrations ranged from about 50 mg/L in samples from wells D11a and D17 to about 600 mg/L in samples from well D29, and calcium concentrations fluctuated the most at well D9 (table 5). Sulfate concentrations ranged from less than 100 mg/L in samples from wells D11a, D17, and D19 to as much as 14,400 mg/L in samples from well D6, but fluctuated little over time in samples from most wells (table 5). Sulfate also is important in redox reactions as an energy source to groundwater microorganisms after oxygen and nitrate are depleted (see Microbiological Effects section later in this report).

Chloride and sodium were major ions in the water of the study area (fig. 9); at least one source of these ions likely was the near-surface geologic materials in the study area. Chloride content of geologic materials from the study area was not measured, but sedimentary rocks (such as those near the surface in the study area) can be a source of chloride in water (Hem, 1992). Sodium content of geologic materials from the study area was measured at 0.45–0.75 percent (Yager and others, 2004a). In general, chloride content is about 10 times larger in shales than sandstones, but sodium content is less than 2 times larger in shales than sandstones (Hem, 1992, p. 5). Chloride can be contributed by the weathering of chloride minerals such as halite (NaCl). Sodium can be contributed by the weathering of various silicate minerals. Chloride and sodium also can be contributed by residual salt in marine sediments such as those of the bedrock aquifer, especially in shale (Hem, 1992, p. 118). In general, concentrations of chloride and sodium were least in samples from wells D9 and D11a and most in samples from well D6.

Iron and manganese are trace elements that occur in large concentrations in water samples from some sites in the study area (figs. 8 and 13). The source of these elements likely was the near-surface geologic materials in the study area. Iron content in loess samples from the study area was 0.7–8.3 percent; the largest iron content measured in geologic materials from the study area was in samples of granitic alluvium and weathered shale (Yager and others, 2004a). The (total) iron content in loess samples from D31 and D33 ranged from 10,100–19,300 $\mu\text{g/g}$; the largest of these concentrations was measured in the top soil layer at D31 (table 9). Drever (1988) reported iron as a major constituent in both typical sandstones and typical shales, but Hem (1992, p. 5) reported that iron content of shales generally is about 2 times that of sandstones. Dissolution of pyrite (FeS_2) likely is a source of iron and a source of sulfur that becomes sulfate in water of the study area. Manganese content in loess samples from the study area was 102–2,360 PPM (mg/kg or $\mu\text{g/g}$); the largest manganese content was in loess and granitic alluvium samples collected near well D6 (Yager and others, 2004a). The (available) manganese content in loess from the geologic materials from D31 and D33 ranged from 0.38 to 5.07 $\mu\text{g/g}$ (table 9); the highest of these concentrations again was measured in the top soil layer at D31. Drever (1988) reported the manganese of typical shale to be about 17 times that of typical sandstone and almost twice that of typical granite, but Hem (1992, p. 5) reported

Table 10. Concentrations of redox-sensitive constituents and terminal electron-acceptor processes for groundwater from selected wells near Deer Trail, Colorado, July 1999.

[Samples collected July 12 through July 14, 1999; other water-quality data associated with these samples are listed in table 7; mm Hg, millimeters of mercury; mg/L, milligrams per liter; H₂, hydrogen; nmol/L, nanomoles per liter; NO₃, nitrate as nitrogen; dissolved, from filtered samples; SO₄, sulfate; µg/L, micrograms per liter; TEAP, terminal electron-accepting process; <, less than; Fe³⁺, ferric iron; O₂, oxygen; USGS, U.S. Geological Survey]

Sample site (fig. 2)	Air temperature, degrees Celsius	Barometric pressure, mm Hg	Electron acceptors				H ₂ , nmol/L	Final products		Predominant TEAP ²	Evidence for TEAP determination	Additional NO ₃ likely to be reduced at this site
			Dissolved oxygen ¹ , mg/L	NO ₃ , dissolved, mg/L	Iron, dissolved, µg/L	SO ₄ , dissolved, mg/L		Hydrogen sulfide, mg/L	Methane, mg/L			
D15	36	632	<0.1	<0.05	2,100	2,700	0.2	<0.01	<0.1	Fe ³⁺ Reduction	H ₂ Concentration	Yes
D16	38	628	0.1	<0.05	910	2,200	0.5	<0.01	<0.1	Fe ³⁺ Reduction	H ₂ Concentration	Yes
D21	38	627	0.2	<0.05	7,200	250	0.1	<0.01	<0.1	Fe ³⁺ Reduction	H ₂ and iron concentrations	Yes
D22	34	634	0.4	<0.05	200	9,000	1.1	<0.01	<0.1	SO ₄ Reduction	H ₂ Concentration	Yes
D23	32	627	0.4	<0.05	2,400	1,700	0.3	<0.01	<0.1	Fe ³⁺ Reduction	H ₂ Concentration and electron-acceptor consumption	Yes
D30	32	635	0.3	<0.05	120	3,000	1.8	<0.01	<0.1	SO ₄ Reduction	H ₂ Concentration and electron-acceptor consumption	Yes
DTX2 ³	30	635	0.8	<0.05	270	2,400	0.5	<0.01	<0.1	O ₂ and Fe ³⁺ Reduction	H ₂ Concentration	Possibly
DTX10 ⁴	36	634	0.7	<0.05	3,700	1,900	Offscale ⁵	0.011	<0.1	O ₂ and SO ₄ Reduction	H ₂ Concentration and final-product production	Possibly

¹Iodometric method using the Alsterberg-Azide modification to the Winkler titration procedure as described by U.S. Geological Survey (variously dated).

²From Chapelle and others (1995), Lovely and others (1994), and McMahon and Chapelle (2008).

³Alluvial-aquifer monitoring well from subsequent USGS monitoring program. This well is shown in figure 3 and is located about 5 miles north of well D30 in the Badger Creek drainage basin.

⁴Zone A (upper) of bedrock-aquifer monitoring well from subsequent USGS monitoring program. This well is shown in figure 3 and is located about 6 miles north of well D15 in the Muddy Creek drainage basin.

⁵H₂ in this sample was above analytical quantification, but the H₂ concentration could be affected by residual contamination from the submersible pump used to sample this well the previous day.

that manganese content of shales generally is less than 2 times larger than that of sandstones. By far, the largest iron concentrations in groundwater at the study area were measured in samples from well D21, whereas the largest manganese concentrations were measured in samples from wells D15 and D23 (table 5; fig. 13).

Other trace elements that are present in study-area water also can be contributed by geologic materials. Trace elements can be contributed to groundwater from a variety of silicate, carbonate, and sulfide minerals. Core samples collected at D31 and D33 contained detectable concentrations of arsenic, chromium, copper, iron, manganese, nickel, selenium, and zinc (table 9). Core samples collected at D31 also contained detectable concentrations of lead (table 9). A core sample collected at D33 also contained a detectable concentration of antimony (table 9). These elements typically are present in sedimentary rocks (Drever, 1988, p. 328–329; Hem, 1992, p. 5–6). Drever (1988) and Hem (1992) reported the antimony, arsenic, chromium, copper, lead, nickel, and zinc content of typical shale to be at least 2.5 times that of typical sandstone. The largest chromium concentrations in groundwater were measured in samples from wells D6 and D22 (table 5). Arsenic, copper, lead, and zinc were not routinely detected above the MRLs in groundwater samples from the study area, but arsenic, copper, and zinc were detected in the groundwater samples collected in 1999 and analyzed by using lower MRLs (table 7).

Milliequivalent ratios can indicate whether dissolution of some simple minerals likely accounts for the concentrations of those constituents detected in the groundwater (D.K. Nordstrom, U.S. Geological Survey, oral commun., March 22, 2000). Concentrations of mineral-forming ions can be graphed in units of milliequivalents per liter (meq/L) to evaluate concentration ratios. Gypsum, calcite, dolomite, and halite likely were present in the rocks of the study area. These minerals mostly are composed of three or less major ionic compounds, so the minerals can be represented simply in graphical form. Gypsum and anhydrite are composed of calcium sulfate, so a 1:1 ratio of calcium to sulfate in the groundwater indicates that gypsum (or anhydrite) dissolution likely accounts for those concentrations. Calcite and aragonite are composed of calcium carbonate, so a 1:1 ratio of calcium to bicarbonate in the groundwater indicates that calcite (or aragonite) dissolution likely accounts for those concentrations. Dolomite is composed of calcium, magnesium, and carbonate, so a 1:1 ratio of calcium plus magnesium to bicarbonate in the groundwater indicates that dolomite dissolution likely accounts for those concentrations. Halite is composed of sodium chloride, so a 1:1 ratio of sodium to chloride in the groundwater indicates that halite dissolution likely accounts for those concentrations. If concentrations of one of these major constituents is greater than that of the other mineral-forming constituent in the groundwater, than dissolution of other minerals or another source of that constituent is indicated.

The distribution of major constituents for selected wells is shown in figure 14 by mineral. Dissolution of gypsum (or anhydrite) likely accounts for most of the calcium and sulfate

concentrations in samples from wells D3, D4, D7, D9, D13, D20, D21, D23, D25, D27, D28, and D32 (fig. 14). Gypsum was present at well D6, and gypsum dissolution may account for much of the calcium in samples from well D6 but accounts for little of the sulfate. Dissolution of calcite and dolomite likely account for most of the calcium, magnesium, and bicarbonate concentrations in samples from wells D11a, D14, D17, D19, D21, D24, and D26. Dissolution of halite could account for some of the sodium and chloride in samples from wells D4, D14, and D19; dissolution of halite may account for all the chloride concentration in the study area, but additional sources of sodium (such as from dissolution of feldspar and clay minerals) are indicated from the ion plots. In samples from wells D7, D9, D23, D25, and D29, sulfate or magnesium have been contributed from an additional source, and calcium-magnesium ion exchange may be affecting water quality. The ion plots in figure 14 also indicate that dissolution of a magnesium-sulfate mineral such as epsomite or kieserite could account for most of the magnesium and sulfate concentrations in samples from wells D2, D6, D10, D17, D19, D22, D26, D29, D30, D31, and D33. In samples from wells D6 and D22, dissolution of gypsum and calcite likely were processes contributing calcium, sulfate, and bicarbonate to groundwater, but sulfate was contributed from an additional source such as the oxidation of pyrite (an iron-sulfide mineral) or coal, and magnesium was contributed from an additional source besides dolomite (such as from epsomite, biotite, or clay minerals). In samples from well D22, an additional source of calcium such as feldspars or clay minerals also is indicated. In samples from wells D5, D8, D15, and D16, the geochemistry is more complex and cannot be produced from simple dissolution of just gypsum, calcite, dolomite, halite, or epsomite. In general, the ion plots indicate predominantly gypsum dissolution on the west side of the study area and predominantly epsomite (or another magnesium-sulfate mineral) dissolution on the east side of the study area. Thus, ion plots of water-quality data for 1993–1998 indicate that mineral dissolution could account for much of the major-ion and trace-element chemistry of water (fig. 14).

Major-ion groupings and the chemical response of groundwater to precipitation are other indicators that geology affected water quality. As mentioned in the Spatial Variability section, well groupings indicated by major-ion chemistry (fig. 9) are fairly consistent with the geologic units mapped for the study area by Sharps (1980) (fig. 10). Major-ion concentrations at most wells temporarily decreased after prolonged, intense rainfall (as at wells D2, D6, D9, and D23; Yager and Arnold, 2003), but then concentrations increased again to previous levels as groundwater concentrations re-equilibrated with local geochemistry. This apparent short-term dilution effect on groundwater quality is consistent with geology providing most of the solutes to groundwater. The longer the residence time of a parcel of groundwater in contact with geologic materials, the more the dissolution, precipitation, and weathering reactions in the aquifer are likely to affect groundwater quality (Drever, 1988).

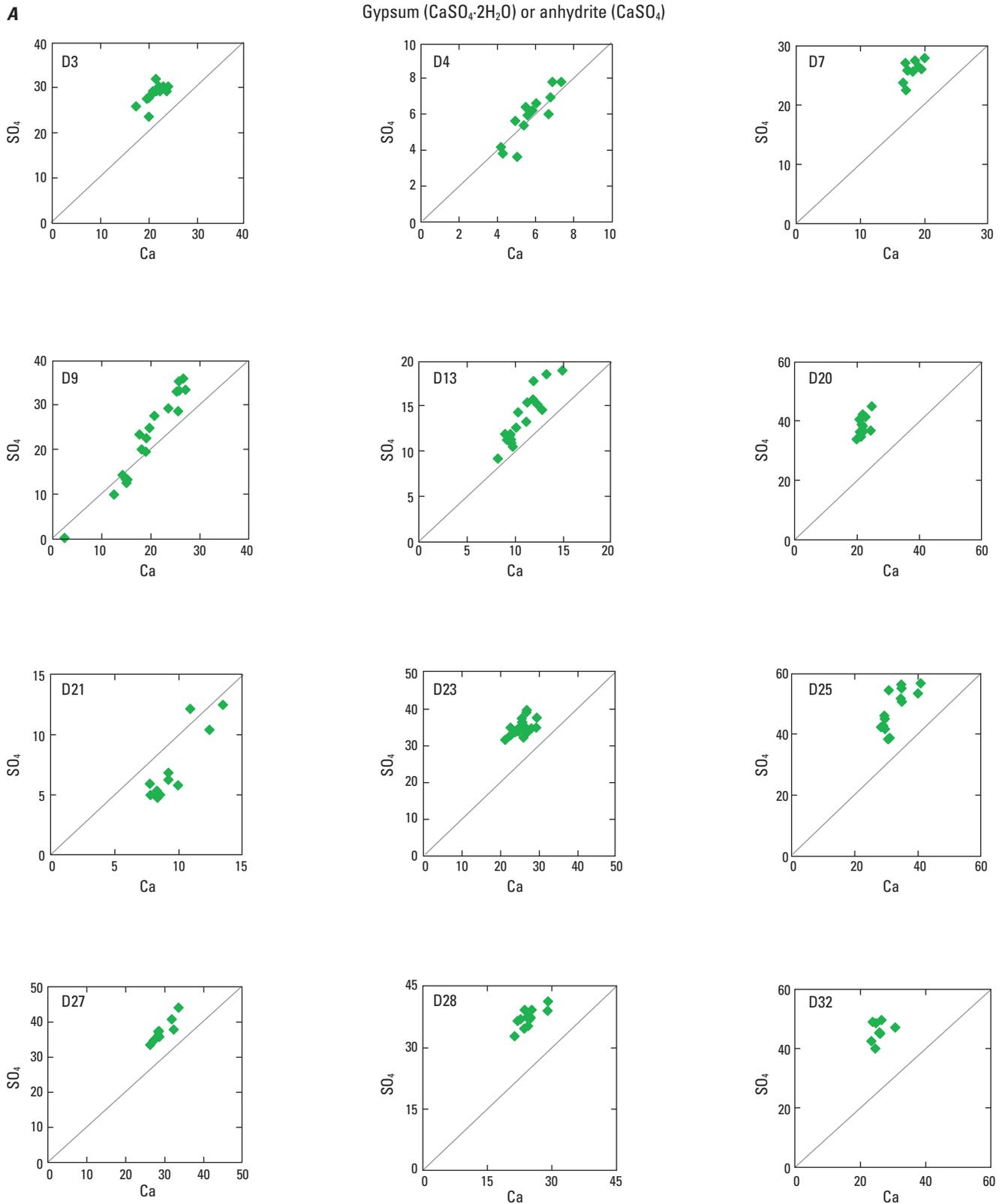


Figure 14. Ion plots showing milliequivalent ratios for (A) gypsum, (B) calcite, (C) dolomite, (D) halite, and (E) epsomite (or another magnesium-sulfate mineral) from samples collected from selected monitoring wells near Deer Trail, Colorado, 1993 through 1998. [All concentrations are shown in milliequivalents per liter; diagonal line represents 1:1 concentration ratio]

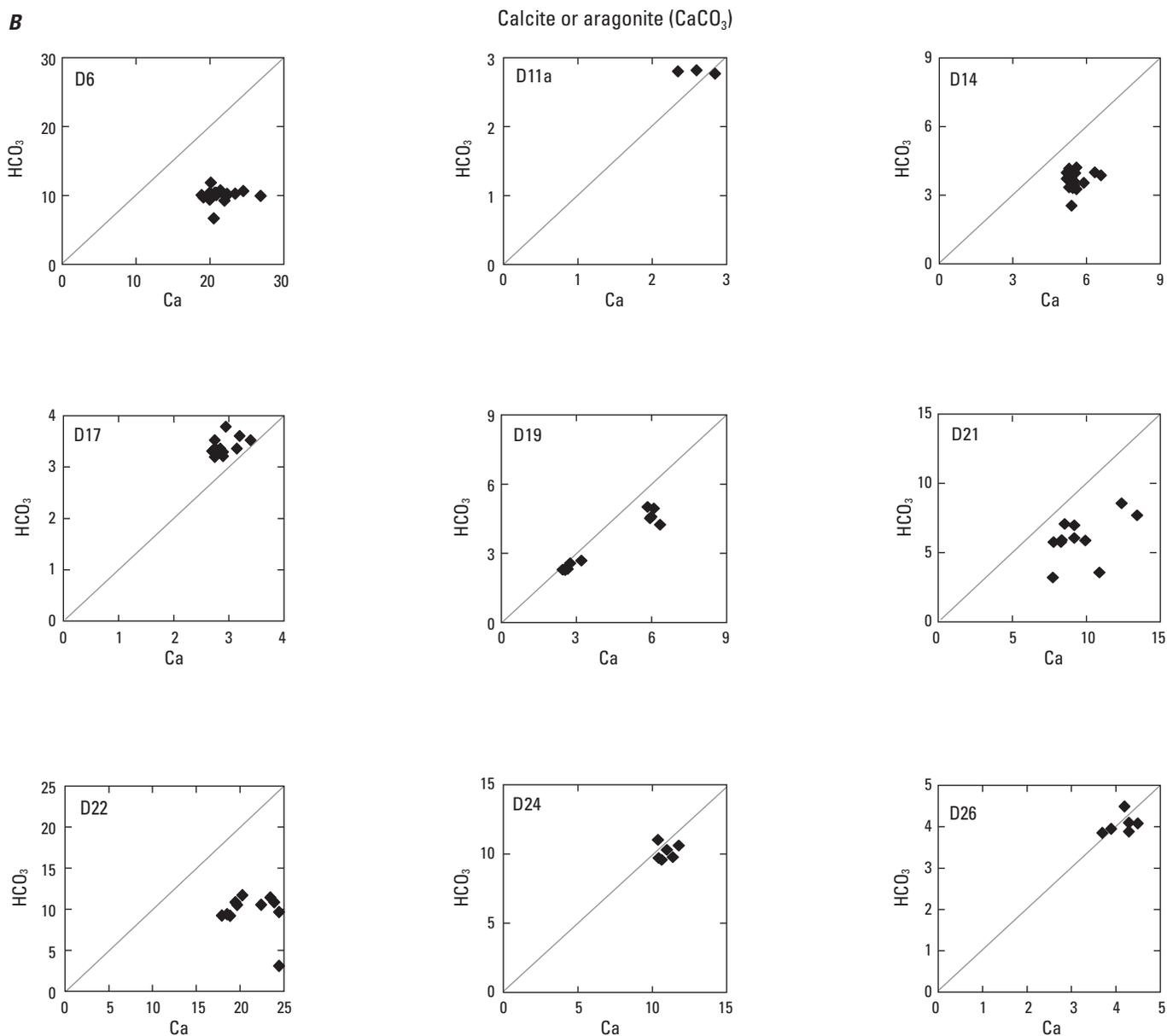


Figure 14. Ion plots showing milliequivalent ratios for (A) gypsum, (B) calcite, (C) dolomite, (D) halite, and (E) epsomite (or another magnesium-sulfate mineral) from samples collected from selected monitoring wells near Deer Trail, Colorado, 1993 through 1998. [All concentrations are shown in milliequivalents per liter; diagonal line represents 1:1 concentration ratio]—Continued

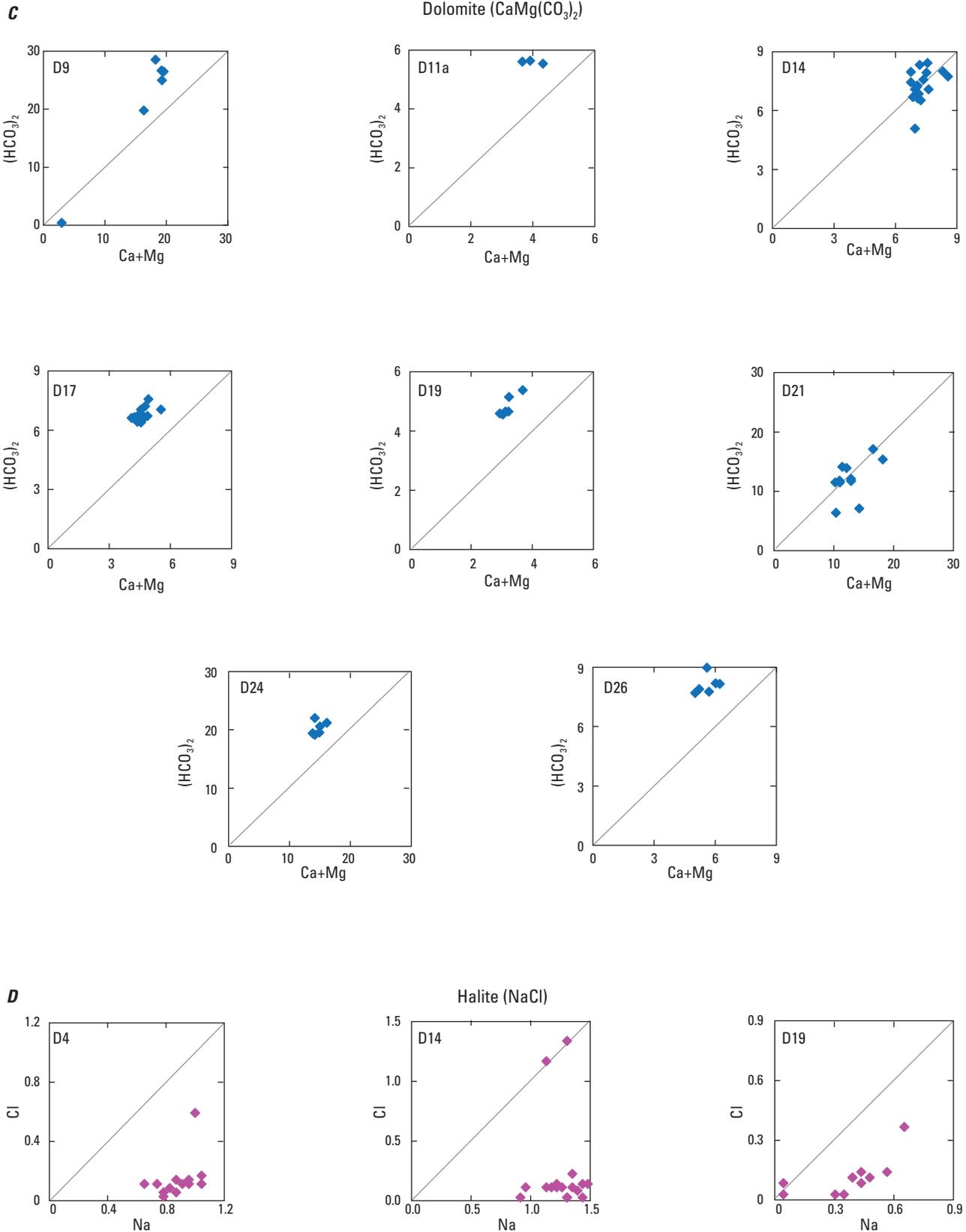


Figure 14. Ion plots showing milliequivalent ratios for (A) gypsum, (B) calcite, (C) dolomite, (D) halite, and (E) epsomite (or another magnesium-sulfate mineral) from samples collected from selected monitoring wells near Deer Trail, Colorado, 1993 through 1998. [All concentrations are shown in milliequivalents per liter; diagonal line represents 1:1 concentration ratio]—Continued

E

Epsomite ($MgSO_4 \cdot 7H_2O$) or other magnesium-sulfate mineral

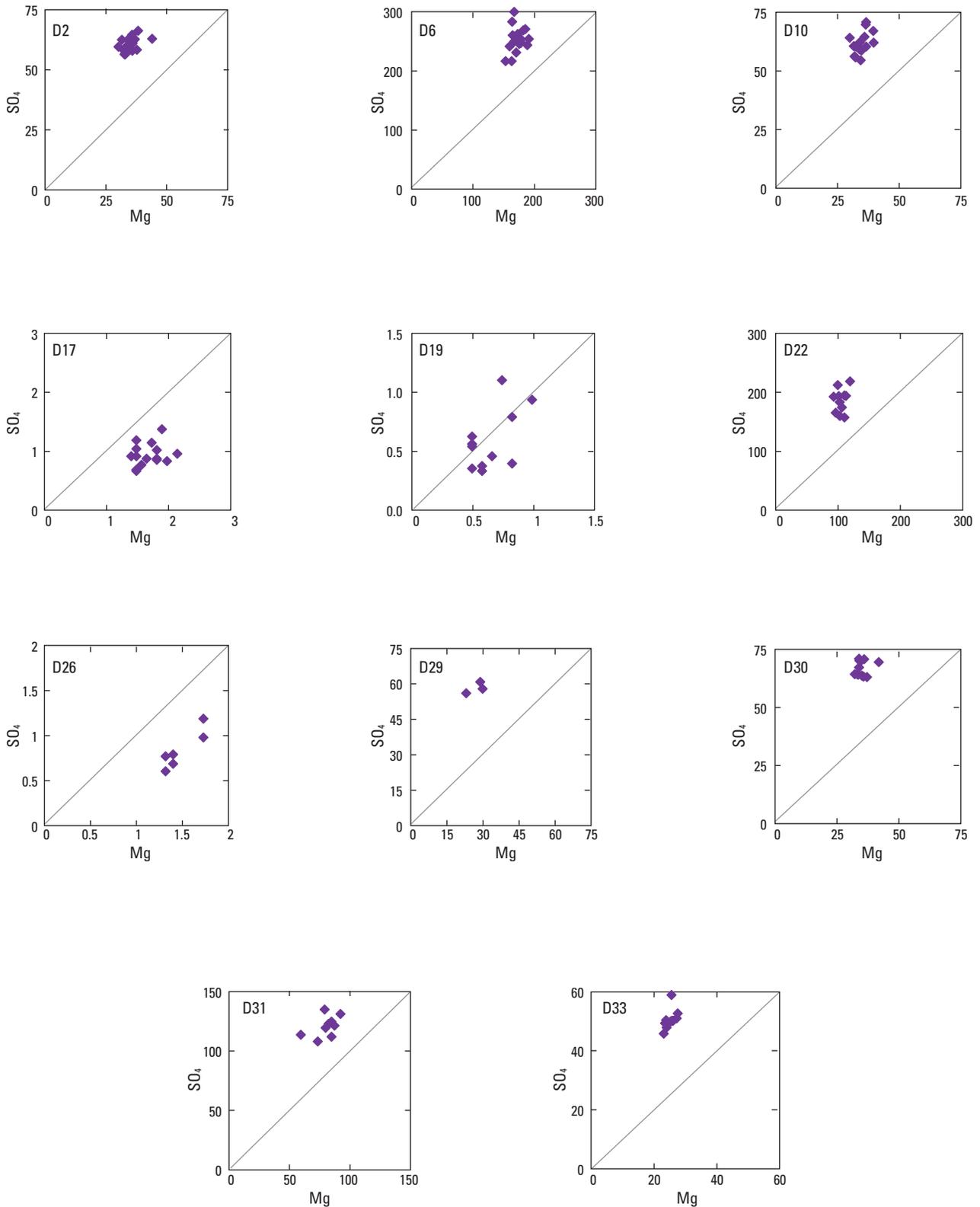


Figure 14. Ion plots showing milliequivalent ratios for (A) gypsum, (B) calcite, (C) dolomite, (D) halite, and (E) epsomite (or another magnesium-sulfate mineral) from samples collected from selected monitoring wells near Deer Trail, Colorado, 1993 through 1998. [All concentrations are shown in milliequivalents per liter; diagonal line represents 1:1 concentration ratio]—Continued

Geology also controls groundwater flow paths. Characteristics of geologic materials (bedrock and soil) such as cementation, porosity, and permeability likely determined flow paths and affected flow rates and chemistry. Characteristics of geologic materials also affect aquifer recharge and discharge locations and aquifer-mixing scenarios. The effects of flow path on water quality are discussed further in the section, Flow-Path Effects.

Meteorological Effects

Meteorology affected water quality in the study area through precipitation on surface water (wet deposition) that delivered atmospheric constituents to the water and through runoff and infiltration that transported constituents from the land surface into surface water or groundwater. The precipitation improved water quality when the chemical content of the precipitation was less concentrated than the receiving waters (dilution). The precipitation degraded water quality when the chemical content of the precipitation, runoff water, or infiltrating water was more concentrated than the receiving waters. A further effect of meteorology on water quality of the study area was the degradation of water quality by evaporation that concentrated constituents in the water during warm, dry weather.

Precipitation can affect water quality directly through wet deposition of various solutes from the atmosphere. The precipitation itself likely contained sulfate, ammonium, sodium, nitrate, chloride, and trace quantities of calcium and potassium (Nagamoto and others, 1983). Precipitation also can contain other constituents from local or regional sources. Other sources of these ions in the study area likely contributed a greater mass of these constituents to the surface and subsurface water in the study area than the direct deposition of precipitation.

Precipitation can affect water quality indirectly by mobilizing chemical constituents from the soil during runoff and infiltration. Yager and others (2004b, table 10) reported that aluminum, barium, calcium, iron, strontium, and sulfate would be the ions likely to be present in the largest concentration in the water leached from farmland soils in the vicinity of the study area that did not receive any biosolids applications (although some common anions such as bromide, chloride, fluoride, and nitrate were not analyzed). Few samples collected during 1993–1999 were analyzed for aluminum, barium, and strontium, but all water-quality samples were analyzed for calcium, iron, and sulfate. Calcium and sulfate were detected in all samples collected from the study area during 1993–1999, often in large concentrations (table 5). Iron was detected in all samples from some wells but was not detected in samples from most wells, likely because of the large MRL used by the laboratory for the 1993–1998 analyses (table 5). Barium, calcium, iron, strontium, and sulfate were detected in all samples that were collected in 1999 (table 7); aluminum was detected in only one sample collected in 1999 (table 7). These data indicate that meteorology could have affected water quality in the study area by mobilizing chemical constituents from the soil during runoff and infiltration. No information was available for the study area with regards to

chemicals that could be mobilized from precipitation on roads, buildings, vehicles, or other objects. Chemicals that could be mobilized from precipitation on biosolids are discussed in the section, Biosolids Effects.

Meteorology can affect the water quality of the study area in other ways besides precipitation providing solutes directly or transporting solutes from other sources. In some cases, warm surface temperatures coupled with low humidity and relatively small precipitation rates can result in evapotranspiration rates that exceed precipitation-infiltration rates. Pond water evaporates, and the unsaturated zone can remain too dry for wetting fronts to migrate all the way to the saturated zone (the water table). Solute concentrations can become concentrated in ponds, soil, and pore water. For example, pore-water samples were collected from the study-area unsaturated zone in 1994 after a relatively rainy spring period. Chloride concentration in the pore water ranged from about 27 to 1,200 mg/L in the 1.5-ft depth and was about 140 mg/L in the single sample collected from the 3-ft depth (table 5). Nitrate concentration in the pore water ranged from 7 to 36 mg/L in the 1.5-ft depth and was about 30 mg/L in the single sample collected from the 3-ft depth (table 5). According to calculations using the laboratory data, copper concentration in the pore water ranged from 150–6,000 µg/L in the 1.5-ft depth and was 150 µg/L in the single sample collected from the 3-ft depth (table 5); however the variation in concentration resulted mostly from the different dilution factors applied, and a similar copper concentration was reported for the blank sample. Although few unsaturated-zone data could be collected, these data indicate that surficial recharge fronts generally might have been 3-ft deep or less in the upland farmed terraces of the study area during the spring of 1994. Rainfall was not sufficient to push these chemical recharge fronts beneath the farmed fields all the way to the water table in the locations monitored. Instead, the pore-water data indicate that reservoirs of some solutes such as chloride, nitrate, and possibly copper were present in the soil near the surface and could be transported to the aquifers through a larger wetting front or through preferential flow paths. Thus, during drier periods, much of the recharge to groundwater likely happened at focused recharge areas in stream valleys, outcrop areas, or areas that had desiccation cracks.

The degree that meteorology affected the water quality of the study area was evaluated by using a variety of information. The continuously recorded precipitation data from wells D2 and D23 during 1996 through 1998 indicate that most of the precipitation was received in the study area as rainfall in summer during July–August and sometimes in spring (Yager and Arnold, 2003). The USGS observed that some precipitation events caused runoff of water to valleys that recharged streams and ponds, which may have resulted in focused recharge of groundwater at selected locations but may not have caused a noticeable groundwater-level increase at the monitoring wells. Some precipitation events caused distributed infiltration of water to the water table and thereby recharged aquifers more directly. A comparison of precipitation data with depth to water indicates that response time of water level to precipitation varied throughout the study area; sometimes

response was immediate and sometimes response was delayed (Yager and Arnold, 2003). A comparison of precipitation data with continuously recorded water-temperature and specific-conductance data from well D6 indicates a short response time of groundwater to precipitation at that site. Groundwater recharge information, therefore, can be inferred from the monitoring of precipitation, depth to groundwater, water temperature, and specific conductance (Yager and Arnold, 2003), but also can be inferred from DG-CFC data and calculations (tables 11 and 12). Still, recharge information is available for only selected wells in the study area.

The USGS recharge information indicates that groundwater likely was recharged directly by precipitation at some (but not all) locations. The DG-CFC data from 1998 indicated sites where groundwater was recharged by rainfall, such as at well D6 (table 11). Groundwater likely was recharged by precipitation at sites where water levels increased rapidly after precipitation (for example, at least some of the water from wells D2 and D23; Yager and Arnold, 2003). Water-quality data also indicated sites where groundwater was recharged by precipitation (for example, at least some of the water from wells D6, D9, and D22). At well D6 where rapid response to precipitation was discernible from the groundwater-temperature and specific-conductance data and dissolved ions were present in groundwater at large concentrations, precipitation resulted in the dilution of major ions in groundwater (Yager and Arnold, 2003). Sulfate concentrations and specific-conductance values in water samples from wells D6 and D22 generally decreased temporarily (indicating dilution) when the aquifers recharged (Yager and Arnold, 2003). Similarly, concentrations of many constituents and specific-conductance values decreased temporarily in well D9 following rainfall. This apparent short-term dilution effect on groundwater quality is consistent with minerals in the geologic materials providing most of the solutes to groundwater rather than rainfall transporting major-ion solutes from the land surface into the aquifers during recharge. Thus, geology appears to have affected water quality in the study area more than meteorology during 1993–1998.

Microbiological Effects

Microbiological effects on water quality of the study area predominantly were the microbially mediated cycling of redox-sensitive constituents. Microorganisms are common in natural environments and include bacteria and algae present in the groundwater, surface water, and the unsaturated zone. Microbial processes such as fixation, photosynthesis, respiration, and uptake affect the cycling of constituents from one form to another and can catalyze chemical reactions such as oxidation and reduction (these reactions occur simultaneously, and the combination is called redox). In oxidation reactions, chemical compounds transfer electrons, often by gaining oxygen molecules; the transformation of ammonia to nitrite to nitrate is called nitrification and is an example of oxidation. In reduction reactions, chemical compounds gain electrons, often by losing oxygen molecules. The transformation of nitrate

Table 11. Groundwater information indicated by dissolved-gas sampling at selected wells near Deer Trail, Colorado, 1998.

[The dissolved-gas data and supporting information were reported by Yager and Arnold (2003, table II.5). Sample-site locations are shown in figure 2]

Sample site	Sample date	Suggested recharge source	Apparent denitrification of groundwater	Very reducing conditions along groundwater flow path
D5	11/19/98	Pond or other groundwater	Slight	No
D5	11/19/98	Pond or other groundwater	Slight	No
D6	11/24/98	Rain	Slight	No
D6	11/24/98	Rain	Slight	No
D9	11/17/98	Pond	None	No
D10	11/19/98	Pond	Slight	No
D13	11/18/98	Pond or other groundwater	Considerable	No
D14	11/24/98	Other groundwater	Slight	No
D17	11/18/98	Pond	Slight	No
D17	11/18/98	Pond	Slight	No
D24	11/17/98	Other groundwater	None	No
D24	11/17/98	Other groundwater	None	No
D25	11/18/98	Pond	Considerable	Yes

to nitrite to nitrogen gas is called denitrification and is an example of reduction. Decomposition of microorganisms also transforms constituents; amino acids from the dead microorganisms result in ammonia. These transformations of nitrogen are part of the nitrogen cycle. Microbial processes also affect the cycling of phosphorous, sulfur, iron, manganese, and organic matter (Stevenson, 1994; Hem, 1992; McMahan and Chapelle, 2008).

Oxygen dissolved in the water affects redox reactions. Groundwater at most sites in the study area usually was oxic (contained dissolved oxygen at concentrations equal to or greater than 0.5 mg/L; McMahan and Chapelle, 2008). Dissolved-oxygen measurements for groundwater in the study area ranged from less than 0.5 mg/L to 9 mg/L (table 5); the median dissolved-oxygen value of all groundwater samples collected during 1993–1998 was 1.3 mg/L. The largest dissolved-oxygen values were measured in samples from well D9, which was a low-producing well that had oxygenated groundwater and usually pumped dry or almost dry (likely introducing additional oxygen into the sampling tubing) during sampling. Accurate dissolved-oxygen measurements of groundwater are difficult to obtain because a water sample in equilibrium in the subsurface can increase in dissolved oxygen when brought up to the land surface, and certain pumping equipment used to sample groundwater also can artificially increase dissolved oxygen in the water sample even if the well is not pumped dry. Where dissolved-oxygen values were greater than about 5 mg/L, the well-pumping mechanism might have been introducing atmospheric air into the sample (large air bubbles generally were

Table 12. Groundwater information indicated by chlorofluorocarbon sampling at selected wells near Deer Trail, Colorado, 1998.

[Apparent recharge date is an estimate for the groundwater sampled in 1998. Temp., temperature; Elev., elevation; °C, degrees Celsius; chlorofluorocarbon-sampling and age-dating methods and model from Busenberg and Plummer, 1992]

Sample site	Sample date	Estimated recharge		Apparent groundwater recharge date, as calculated by the model	Certainty of age	Apparent mixing of old and young ground water	Apparent denitrification	Apparent effects from septic or wastewater	Well samples represent water-quality effects from biosolids
		Temp. (°C)	Elev. (feet)						
D3	11/17/98	11.0	5,217	1970–1974	High	Possibly	No	Possibly	Possibly
D5	11/19/98	11.1	5,217	1975–1980	High	No	No	No	No
D6	11/24/98	15.6	5,217	1961–1969 ¹	Moderate ¹	Yes ⁴	Yes	No	Possibly
D9	11/17/98	12.0	5,163	1993–1998	Low ²	Possibly	Yes	Possibly	Possibly
D10	11/19/98	11.5	5,220	1982–1987	High	No	No	No	No
D13	11/18/98	11.0	5,264	1970–1974	High	Slight	Yes	No	No
D14	11/24/98	12.3	5,264	1970–1975	High	No	No	No	No
D17	11/18/98	11.0	5,264	1964–1968	High	Slight	No	No	No
D24	11/17/98	12.6	5,200	1989–1995	Low ²	Possibly	Yes	Possibly	Possibly
D25	11/18/98	9.9	5,160	1955–1960	Moderate ³	No	Yes	No	Possibly

¹Results indicate mixing of old groundwater, such as bedrock groundwater, with younger water. The age of the older fraction was likely older than that indicated by the model, and the age of the younger fraction was likely younger than that indicated by the model.

²Sample likely was exposed to air during pumping, which would have introduced modern levels of chlorofluorocarbons into the sample and made the sample appear more recently recharged than actual.

³Sample contained methane, which means the chlorofluorocarbon amounts likely were microbially decreased since recharge, so actual age was more recent than calculated by the model.

⁴Ratios of chlorofluorocarbons indicate that at least 50 percent of this water was young (post 1940).

visible in the pump tubing for these samples). Measurements of dissolved oxygen listed in table 10 (iodometric method) are more accurate than those listed in table 5 (amperometric method). Where groundwater was oxic, microorganisms will preferentially utilize dissolved oxygen in the groundwater (McMahon and Chapelle, 2008). Where groundwater was post oxic (suboxic or anoxic: dissolved-oxygen values were less than 0.5 mg/L), microorganisms will utilize other available electron acceptors (first nitrate, then manganese, then iron, then sulfate, then carbon dioxide from organic compounds) (McMahon and Chapelle, 2008).

Microbiological processes affecting water quality of the study area are better understood from dissolved-gas, chlorofluorocarbon, and redox sampling that were incorporated into the study in 1998–1999. Dissolved gases and chlorofluorocarbons are trace constituents that are present in air, then trapped in water when it infiltrates through the subsurface. Some dissolved gases and chlorofluorocarbons can stay unchanged in the groundwater after recharge and sometimes can be used as indicators of groundwater recharge history, flow path, and microbial conditions. Dissolved-gas and chlorofluorocarbon (DG-CFC) data collected in November 1998 for the study area were reported by Yager and Arnold (2003). The dissolved-gas and chlorofluorocarbon data indicate that denitrification was common in the study area, especially at wells D13 and D25 (tables 11 and 12). Chlorofluorocarbon data indicated that denitrification had occurred in groundwater at wells D6, D9, and D24 (table 12), yet denitrification was not sufficient to prevent nitrate concentrations from increasing during 1993–1999 at these sites because the groundwater usually was oxic. Dissolved-gas data indicated only slight denitrification in groundwater from well D6 and no denitrification in

groundwater from wells D9 and D24. Where denitrification is actively occurring, nitrate is reduced to nitrite and even to nitrogen gas; therefore, nitrate produced from additional nitrogen inputs to that site (such as from biosolids or other fertilizers) will be consumed in post-oxic groundwater.

The results from redox sampling can indicate which redox processes were active in the groundwater in 1999 and the stability of the intermediate-reaction product (hydrogen) and final products (such as sulfide and methane) in the groundwater (McMahon and Chapelle, 2008). The redox-indicator data and results are reported in table 10. Only monitoring wells that had shallow, post-oxic groundwater with larger iron concentrations in historic samples could provide useful redox information and were sampled. The theory, sampling methods, and interpretations are based on the work of Chapelle and others (1995), Lovley and others (1994), and McMahon and Chapelle (2008), who used electron-acceptor (nitrate, manganese, iron, and sulfate) consumption, intermediate-product (hydrogen) concentrations, and final-product (ferrous iron, sulfide, and methane) production to determine the predominant terminal electron-acceptor process (TEAP) in post-oxic groundwater. Listed in order of most efficient to least efficient metabolic process (and therefore in order of reaction), the TEAPs consist of oxygen reduction, nitrate reduction (denitrification), ferric-iron reduction, sulfate reduction, and carbon-dioxide reduction (methanogenesis) (McMahon and Chapelle, 2008). The predominant TEAPs were determined for the groundwater sites in the vicinity of the study area that were sampled for redox-sensitive constituents in July 1999 (table 10).

In general, the redox information indicates that oxygen was depleted (reducing groundwater conditions) at the redox-sampled wells in the study area in 1999 (table 10). The lack of

hydrogen sulfide in these groundwater samples is consistent with pyrite precipitation, which can remove sulfide from the water (Chapelle and others, 1995, p. 360); pyrite was observed in the cores of most boreholes in the vicinity of the study area. Monitoring wells in the study area that were not sampled for redox-sensitive constituents had oxic-type groundwater, which means that groundwater had sufficient dissolved-oxygen concentrations to indicate that oxygen reduction was likely the predominant TEAP. Monitoring wells in the study area that were sampled for redox-sensitive constituents had post-oxic type groundwater. Groundwater from well D21 was slightly reduced compared with that of wells having oxic-type water; any oxygen had been reduced so iron reduction was the predominant TEAP at this site. Groundwater from wells near wetland areas (wells D15, D16, D23, and D30) was further reduced compared with that of wells having oxic-type water; any oxygen and nitrate in this groundwater had been reduced, so iron reduction or sulfate reduction was the predominant TEAP at these sites (table 10). Groundwater data from well D22, which likely was completed in shale near the bottom of the Laramie-Fox Hills hydrostratigraphic unit (Yager and Arnold, 2003), indicated sulfate-reduction was the predominant TEAP at that site (oxygen and nitrate had been reduced). The two nonsequential TEAPs indicated by data from DTX2 and DTX10A (monitoring wells installed in 1999 for the USGS Expanded Monitoring Program near Deer Trail, shown in fig. 3) mean the groundwater may have been stratified, having a distinct zone of very reduced water and a zone of oxygenated water in the vicinity of those wells, so additional nitrate may not be reduced by the microorganisms. The redox information indicates that additional nitrate likely will be microbially reduced in groundwater at wells D15, D16, D21, D22, D23, and D30. In general, microbial processes in oxygen-depleted shallow groundwater (such as in much of the Muddy Creek area) have kept nitrate concentrations small and could reduce additional nitrogen inputs to the groundwater.

Pond formation can change redox conditions of the groundwater and, therefore, concentrations of redox-sensitive constituents (such as dissolved oxygen, nitrate, manganese, iron, and sulfate). Pond presence often resulted in microbial effects on water quality in the study area, such as increased nitrate and decreased iron concentrations that coincided with pond formation near wells D24, D25, D26, and D32, and substantially decreased nitrate and increased iron concentrations that coincided with (anthropogenic) pond removal at well D25. Ponds provided a source of oxygenated recharge water, and associated wetlands created reducing zones (as was mentioned regarding wells D15, D16, D23, and D30). In contrast, an anthropogenic pond near well D5 that was present in 1993 dried out gradually and was gone by 1997 with little discernible effect on water quality.

Flow-Path Effects

Some flow-path effects were evident from the water-quality data collected during 1993–1999. Flow paths determine where and when the water in the aquifer originates, what

processes affect the water, and what properties and chemistry are characteristic of the water. Flow paths primarily are determined by geology and meteorology.

A little flow-path information was available from the water-quality data listed in table 5. The variation in these data indicates that various distinct flow paths in the alluvial and bedrock groundwater were likely. Trilinear graphs of these data indicate that deep bedrock-aquifer groundwater generally was not chemically distinct from shallow bedrock-aquifer groundwater or alluvial-aquifer groundwater (fig. 9), so the deep bedrock groundwater likely shared a flow path with some of the shallow bedrock-aquifer and alluvial-aquifer groundwater. However, the water-quality data listed in table 5 do not provide much information about specific flow paths.

Flow path information was provided by hydrologic data from 1993–1999 and geohydrologic information from 1999, which were reported by Yager and Arnold (2003). Hydrologic data combined with regional geohydrologic information (such as from Robson, 1981) indicate that general groundwater flow in the study area likely was from the deeper parts of the Denver Basin outward toward the Denver Basin margins, from the bedrock aquifer toward the alluvial aquifer, from the alluvial aquifer toward the bedrock aquifer, or from the land surface downward through the unsaturated zone into the bedrock or alluvial aquifers, depending on the specific location in the study area. Water-level data from the study area indicate that a significant bedrock-aquifer flow path was from the deeper, confined part of the Denver Basin in the west toward the east, at least in the vicinity of well D11a near Muddy Creek, and that Muddy Creek alluvium may have received recharge from the Laramie-Fox Hills aquifer.

The DG-CFC sampling in the study area in 1998 provided additional flow-path information. The DG-CFC information enabled apparent groundwater recharge dates and the degree of mixing of old (pre-1940) and young (post-1940) water in the aquifer to be estimated (table 12); however, the long screens (at least 10 ft on most of the monitoring wells) can integrate water from multiple flow paths in the sample collected from each monitoring well, which increases the uncertainty of the DG-CFC results. Of the groundwater sampled in 1998 for DG-CFC, only D9 water and possibly D24 water appear to have been recharged during the 1990's (table 12). The D9 sample may have been affected by modern air if the well was pumped dry during sampling (yielding a recharge date more recent than actual), but the apparent dilution of water-quality constituents by precipitation evident from the D9 samples also indicated a recent recharge date for at least some of the D9 groundwater. Groundwater from the other wells that were sampled in 1998 appear to have been recharged during the 1950's through 1980's (table 12), which was before biosolids were applied to the study area. Ratios of the chlorofluorocarbon isotopes can indicate whether old water (pre-1940) mixed with young water at each site, as long as the isotope concentrations were in the dateable range. For the wells where DG-CFC sampling was done in 1998 (table 12), only chlorofluorocarbon data from well D6 indicated definite mixing. The ratios indicated the young fraction made up at least 50 percent

of the groundwater mixture (table 12) in the 1998 sample; the response of groundwater temperature and specific conductance at well D6 to precipitation also indicated a recent recharge date for at least some of the D6 groundwater. DG-CFC data also indicated mixed old and young groundwater at wells D3, D9, D13, D17, and D24 in 1998 (table 12). Old groundwater was likely bedrock groundwater, or at least water from deeper parts of the bedrock aquifer. Young groundwater likely was water recharged from surficial precipitation or surface water (such as ponds), but could also have been recharge from shallow parts of the bedrock aquifer. The dissolved-gas data also enabled recharge temperatures and, therefore, recharge sources (such as pond) to be estimated (table 11). More detailed information about these estimates was reported by Yager and Arnold (2003). In short, the DG-CFC data indicated that at least some of the groundwater followed a slow flow path after recharge before traveling to wells D3, D5, D6, D13, D14, D17, and D25, but at least some of the groundwater followed a rapid flow path after recharge to travel to wells D6, D9, and D24 (table 12). More wells in the study area, particularly those with short well screens, need to be sampled for DG-CFCs to further define flow paths in the study area. Resampling of some of these same wells in the future would enable confirmation of these groundwater apparent ages and flow paths, which can change over time.

Redox information from DG-CFC sampling and redox-indicator sampling also provide groundwater flow-path information for the study area. November 1998 DG-CFC data indicated that denitrification affected groundwater at numerous places in the study area, and that groundwater in the vicinity of well D25 had very reducing conditions somewhere along the groundwater flow path (possibly when water recharged through a wetland or flowed beneath a pond) (tables 11 and 12). July 1999 data for dissolved-oxygen, sulfide, methane, hydrogen, nitrate, and sulfate concentrations were compared for wells along Muddy Creek (table 10). These data indicated that groundwater likely flowed from D21 to D16 to D23 to D15 and generally became progressively reduced. Between well D21 and D16 (possibly from the tributary alluvial aquifer near well D20) and between well D23 and D15 (possibly from the tributary alluvial aquifer near well D17), more oxygenated, sulfate-rich water entered the aquifer. These data also indicated that this flow path did not necessarily include the bedrock aquifer in the vicinity of well DTX10A in 1999. The redox data did not indicate that water in the Muddy Creek alluvial aquifer (as represented by the data from well D15) recharged the bedrock aquifer in the vicinity of well DTX10A, but redox conditions in the Muddy Creek alluvial aquifer could change over the 6 mi between well D15 and well DTX10A, the bedrock well that was sampled.

During flow through an aquifer, groundwater chemically interacts with the geologic materials and likely is affected by hydrologic and microbial processes. Therefore, groundwater chemically evolves as it follows a flow path into and through an aquifer. Geochemical modeling can be a useful tool to evaluate this chemical evolution by helping to evaluate the effects of geology, land use, fertilizer treatments, and the various

aquifer processes on groundwater. Forward modeling can be used to predict water chemistry or to evaluate likely effects of chemical inputs to the geochemical aquifer system, such as from biosolids treatments (D.L. Parkhurst, U.S. Geological Survey, oral commun., March 22, 2000). Inverse modeling can be used to evaluate how groundwater at a well may have chemically evolved, including whether the groundwater evolved from rain water dissolving rock minerals, mixing between aquifers, anthropogenic chemical inputs, or from chemical reactions along the flow path (D.L. Parkhurst, U.S. Geological Survey, oral commun., March 22, 2000). Inverse modeling, in particular, could be useful in considering some geochemical questions about groundwater in the study area. For example, this modeling could provide insight into what caused the unusual water quality at well D6 and whether the bedrock aquifer was receiving water from the alluvial aquifers (flow-path information).

To use geochemical models, the appropriate data must be available. Full geochemical modeling requires detailed mineralogy, chemical analysis of the minerals, detailed chemical information for anthropogenic chemical compounds related to land use or fertilizer treatments, and accurate, detailed water-quality data for geochemical constituents (major-ion plus comprehensive trace-element analyses). However, this study was not planned to include geochemical modeling as a primary tool, so much of the data needed for detailed geochemical modeling of the study area were not available. Data for mineralogy, mineral chemistry, and anthropogenic-compound chemistry were not collected during 1993–1999, and lithologic data for specific wells were limited. Water-quality data collected for the study area did not routinely include silica, aluminum, arsenic, boron, bromine, cobalt, fluorine, lithium, selenium, and strontium. Also, the trace-element data obtained from routine analyses were not all appropriate for geochemical modeling because all or most of the data were censored below the MRL for some of these constituents.

Despite these data deficiencies, the water-quality data obtained through the NWQL analyses of selected replicate samples, data from the USGS Expanded Monitoring Program near Deer Trail (Stevens and others, 2003), and knowledge of the geology of the area enabled some limited geochemical modeling of the study area that provided useful information. Lignite, a type of coal, was mined from the Laramie Formation (Soister, 1974) and was known to be present in the vicinity of the study area as thin, discontinuous layers in the bedrock or as weathered alluvial material that may or may not be present at any specific well. Alluvium in the study area consisted of glacial loess and outwash (minerals likely included montmorillonite, quartz, feldspar, biotite, pyroxene) and weathered conglomerates, sandstones, siltstones, and shale (minerals likely included montmorillonite, quartz, feldspar, gypsum, and calcite) (B.F. Jones, U.S. Geological Survey, oral commun., March 22, 2000). Bedrock in the study area consisted of marine sandstone, siltstone, and shale (minerals likely included montmorillonite, pyrite, quartz, carbonates, and possibly aragonite) (B.F. Jones, U.S. Geological Survey, oral commun., March 22, 2000). Montmorillonite is a common

clay mineral, and quartz is a common mineral comprising sand grains. Using this assumed mineralogy with water-quality data from wells D5, D6, D10, D29, and D32, geochemical modeling was done with NETPATH (Plummer and others, 1994) to determine if groundwater from D6 could be chemically evolved from that of well D29 (bedrock groundwater), from upgradient shallow groundwater at D5, D10 or D32, from coal beds (if they were present at D6, which was not known), or from biosolids applied near D6 (modeled as organic matter, CH₂O). Results from this geochemical modeling indicated that groundwater in samples from well D6 likely was not evolved from a combination of groundwater from wells D5, D10, D29, or D32, but could have been evolved from rain water reacting with rocks and either the presence of coal or organic matter (such as biosolids). Thus, this preliminary geochemical modeling indicated that the groundwater flow path for well D6 likely did not include the bedrock aquifer water (as represented by well D29) or groundwater from the upgradient shallow wells, but could include bedrock groundwater from a different location or simply rain water that interacted with rocks and either coal or organic matter (representing biosolids) in the vicinity of the well. Collection of additional data for lithology, mineralogy, mineral chemistry, fertilizer chemistry, and water quality (including silica, strontium, boron, and uranium and using analytical methods that had lower MRLs) could be useful to further define study-area flow paths, especially for wells D2, D6, D9, D24, and D25.

Biosolids Effects

Biosolids were applied to the study area intermittently and at various application rates during 1993–1999 (table 1). Application records were not detailed with respect to the exact date of application to a specific area (such as a drainage basin or the area around a well) within each half-section (table 1; fig. 5). Applications listed in table 1 did not always encompass all the land within the listed half-section. Therefore, effects from biosolids on water quality were challenging to identify. To evaluate whether biosolids applications affected the water-quality of the study area during 1994 through 1998, post-biosolids-application data were compared with baseline data, water-quality data from the biosolids-treated area were compared with a control site, temporal patterns in selected water-quality constituents were examined for response to nearby biosolids applications, and other indicators of biosolids effects were considered.

Comparison with Baseline Data

If baseline data are collected from a study area before a treatment begins, as well as after the treatment, the data often are used to indicate treatment effects. However, the difference between groundwater baseline data and later data for the same site may not represent effects from a particular treatment during that time (such as farming with biosolids applied as a fertilizer) if water infiltrating through biosolids-treated soils has not yet recharged into the aquifer. Groundwater recharge can

take as little as hours to as long as hundreds of years, depending on geologic and hydrologic conditions at a particular site. Yager and Arnold (2003) reported groundwater recharge times ranging from a few hours to more than 50 years in the study area. Apparent recharge dates determined from DG-CFC data for groundwater sampled from selected wells in 1998 are listed in table 12.

Regardless of whether groundwater had recharged through biosolids-treated fields when it was sampled during 1994 through 1999, the baseline data collected from the study area in 1993 were adequate to indicate that sources of major ions, nutrients, trace elements, and bacteria affected groundwater and surface-water concentrations before biosolids were applied in the study area. For example, chloride, magnesium, sodium, and sulfate concentrations were relatively large in samples from well D6 before biosolids applications began (table 5). Zinc concentration was relatively large in samples from well D12 before biosolids were applied, although the zinc concentration could be related to the pump, cables, and grease that had been in this livestock well before it was used only for monitoring. In addition, fecal streptococcus bacteria were detected in baseline samples from wells D3 and D12. Fecal coliform and fecal streptococci bacteria in water originate from animal feces, as well as from human sewage (Murray and others, 2001).

Chloride, sulfate, nitrate, and manganese concentration in some baseline groundwater samples exceeded Colorado regulatory standards. Chloride in baseline samples from well D6 exceeded the Colorado drinking-water standard. Sulfate in baseline samples from all wells except G2 exceeded the Colorado drinking-water standard (tables 5 and 8). Nitrate concentrations were relatively large and exceeded the Colorado Drinking Water standard in samples from well D9, and many wells had detectable nitrate concentrations before biosolids applications began (tables 5 and 8). Manganese concentration was relatively large and exceeded the Colorado drinking-water and agricultural standards in samples from wells D3, D6, D7, D8, and D12 before biosolids applications began (tables 5 and 8).

Most chemical-constituent concentrations were similar in the baseline samples as in later post-biosolids-application samples for 1994–1998 (fig. 15). Some concentration values of chloride, sulfate, nitrate, phosphate, cadmium, iron, and manganese were larger in the post-biosolids-application groundwater samples than in the baseline samples, but the median chloride, nitrate, and orthophosphate concentrations in groundwater were less in the post-biosolids-applications samples than the median of the baseline samples when data from all the monitoring wells were pooled. The smaller median concentrations in post-biosolids-application samples do not indicate that biosolids applications improved water quality in the study area. Rather, the differences between baseline and post-biosolids-application samples likely were because not all sample sites included in the post-biosolids-application sampling were available for baseline sampling, so the baseline data did not represent the full range of water-quality concentrations found in the study area. Most of the large range

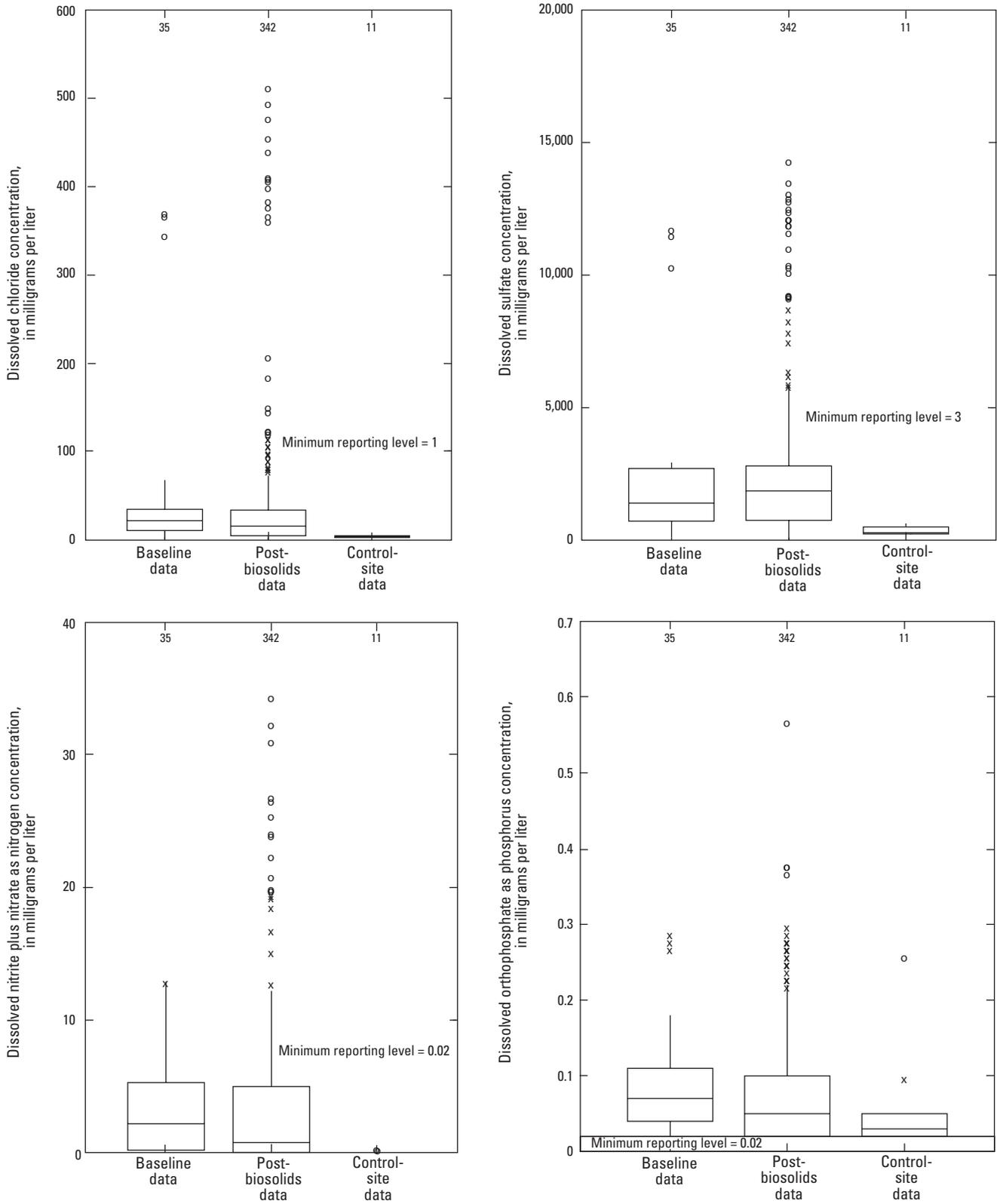


Figure 15. Comparison of baseline, post-biosolids, and control-site groundwater-quality data for selected constituents in samples from all monitoring wells near Deer Trail, Colorado, 1993 through 1998.

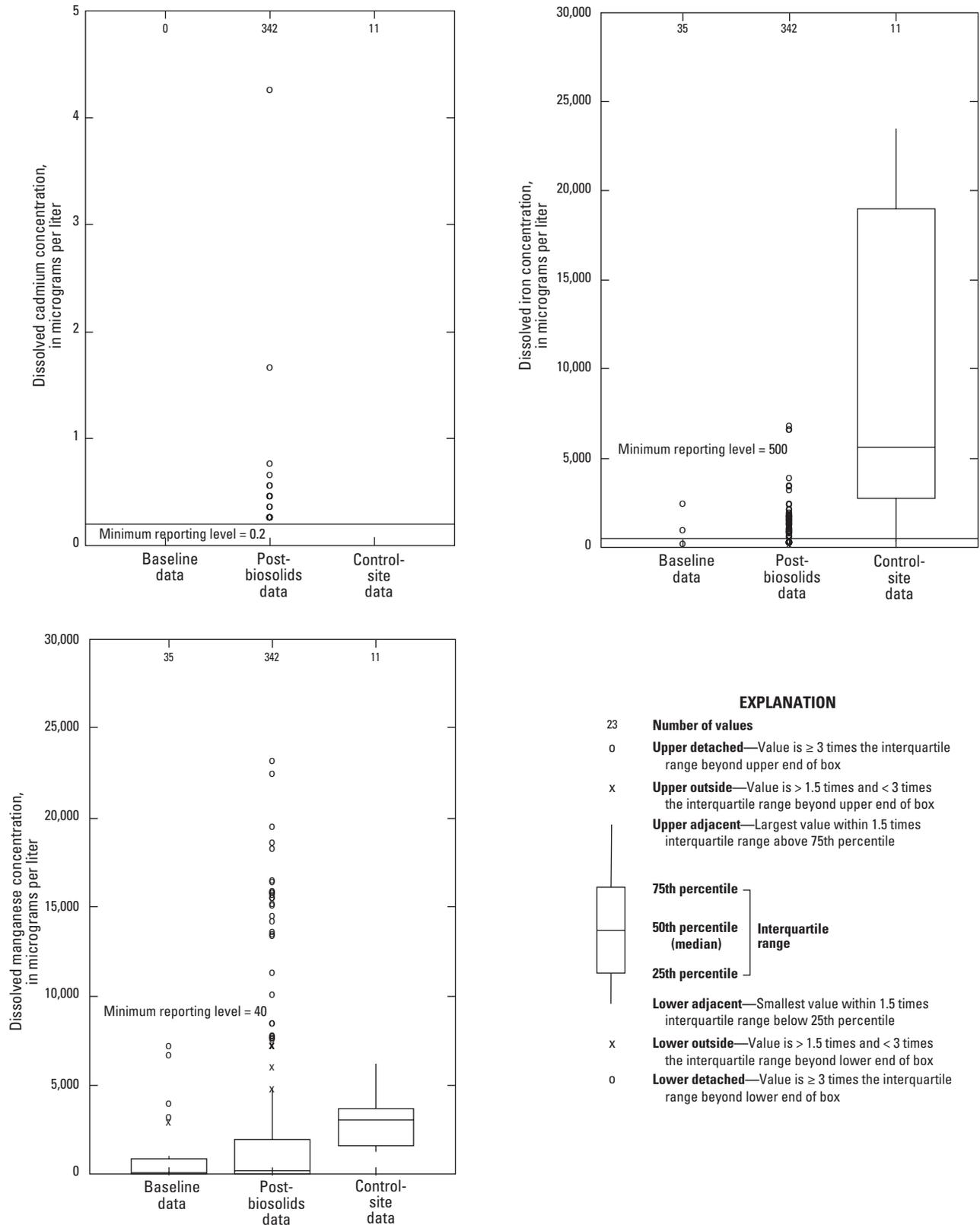


Figure 15. Comparison of baseline, post-biosolids, and control-site groundwater-quality data for selected constituents in samples from all monitoring wells near Deer Trail, Colorado, 1993 through 1998.—Continued

in concentration shown in figure 15 for both baseline and post-biosolids-application data resulted from spatial variability (compare fig. 15 with table 5, and note that water-quality variations across the study area were discussed in the Spatial Variability section). Because of the large spatial and temporal variability in water quality for both the baseline and the post-application data and the similarity in concentrations before and after biosolids application, effects from biosolids applications were not discernible from a simple comparison of baseline data with post-application data.

Yager and others (2004b) and Yager and McMahon (2012) determined that biosolids samples from the Metro District leached substantial concentrations of chloride, potassium, sodium, sulfate, ammonia, organic nitrogen, and phosphorus in addition to lesser amounts of many trace elements (especially iron, aluminum, molybdenum, and boron). However, soil from the vicinity of the study area that did not receive biosolids applications also leached major ions, nutrients, and trace elements (Yager and others, 2004b). Ions that had concentrations at least one order of magnitude (a factor of 10) larger in the biosolids leachate than in the soil leachate were considered biosolids-signature constituents to indicate collectively that aqueous media like groundwater and surface water had been affected by biosolids applications. Inorganic biosolids-signature constituents for aqueous media as refined from the various leachate experiments included primarily nitrogen, phosphorus, molybdenum, and tungsten, and to a lesser extent, antimony, cadmium, cobalt, copper, nickel, selenium, vanadium, and zinc (Yager and others, 2004b, table 10; Yager and McMahon, 2012). Of these, only nitrogen, phosphorus (orthophosphate as phosphorus), cadmium, copper, nickel, and zinc were analyzed routinely in both the baseline and post-biosolids-application water-quality samples. For the sites where baseline samples were collected (fig. 8), post-biosolids-application concentrations generally were not larger than baseline concentrations of ammonia plus organic nitrogen, phosphorus (orthophosphate as phosphorus), cadmium, copper, nickel, or zinc (table 5). Most post-biosolids-application concentrations were larger than baseline concentrations of nitrate in samples from wells D2, D3, D5, D6, D7, D9, D10 and D12. Nitrification can transform ammonia and organic nitrogen into nitrate. Therefore, the baseline data indicated that the slight increase in nitrate in shallow Muddy Creek drainage-basin groundwater and the more marked increase in nitrate in the Cottonwood Creek drainage-basin groundwater (fig. 12) could relate to biosolids applications to the study area.

In general, the comparison of baseline water-quality data with post-biosolids-applications data indicated that biosolids applications during 1993–1998 did not have a large effect on study-area water quality during 1994 through 1999; however, the baseline sampling sites were not fully representative of water quality in all parts of the study area. The baseline data indicated that biosolids effects on study-area water quality during 1994–1999 seemed to be limited to increases in nitrate concentrations. Because water affected by biosolids applications is unlikely to have recharged groundwater at all sampled locations by 1998–1999, the collection of additional

water-quality data for future comparison with baseline data would be helpful in evaluating effects of biosolids on water quality of this study area.

Comparison with Data from a Control Site

Comparison of water quality at control sites (which receive no treatment) with water quality at sites affected by a treatment can indicate effects of that treatment if the control sites are representative of the study area and sufficient time is allowed for the treatment to have an effect. To evaluate the effects on water quality of a treatment such as farming with biosolids applied as a fertilizer, control sites can be useful. Because of topographic controls (fig. 2) and the lack of shallow groundwater or any flowing surface water throughout most of the study area during 1993–1998, only one control site was available: well D21 in the southwest part of the study area. This location was both topographically and hydraulically upgradient of nearly all biosolids-application areas. Well D21 also was upgradient from most of the nearby farmed areas but downgradient from grazing land. Unfortunately, access to well D21 turned out to be intermittent so samples could not be obtained from the control site every trip.

The water quality at this control site (well D21) was not better, and in fact was in some ways worse, than the water quality at the sites in the biosolids-treatment area (table 5) during 1994–1999. Concentrations of ammonia plus organic nitrogen in samples from the control site were the largest measured in the study area (maximum was 3.6 mg/L as N in July 1995). The laboratory reported detections of nitrite in 5 of the 11 control-site samples, although nitrate was not detected in these same samples. Most of the nitrogen in the groundwater samples from the control site was in the form of ammonia, except in July of 1994 and 1998 when most of the nitrogen was organic (table 5). Nitrogen at other sites in the study area usually was in the form of nitrate, even in baseline samples (table 5). Sulfate concentrations in control-site samples were relatively small, but not as small as those from some wells in the biosolids-treatment area (D11a, D17, D19, D24, and D26). Concentrations of other major ions and some trace elements in control-site samples were similar to those in samples from wells in the biosolids-treatment area. However, concentrations of iron and manganese were much higher in the control-site samples than in samples from most of the other monitoring wells in the biosolids-treatment area (fig. 15 and table 5). Concentrations of iron in samples from well D21 were the highest measured in the study area and fluctuated more than in samples from most of the other monitoring wells (fig. 15 and table 5). Fecal coliform bacteria were not detected in samples from the control site, but fecal streptococcus bacteria were detected in one of four samples from the control site and were detected at a similar level found in many samples from the biosolids-treated area (table 6).

More information about water quality at this control site (well D21) was obtained when the well was sampled for redox-sensitive constituents during July 1999. The groundwater sample from the control site was analyzed for additional

water-quality constituents, including most of the inorganic biosolids-signature constituents (table 7). Phosphorus, cobalt, copper, molybdenum, nickel, and zinc were detected in the sample from the control site in 1999 at small concentrations (table 7). This sample also had smaller concentrations of ammonia and organic nitrogen than in 1994–1998 but still no detectable nitrate (table 7). The predominant TEAP at the control site that was indicated by the July 1999 sample was Fe^{3+} reduction; any additional nitrate in groundwater at this site was likely to be reduced (table 10). Where nitrate, Fe^{3+} , or sulfate reduction was the predominant TEAP, nitrate concentrations in the groundwater likely would remain small, even if the groundwater was located in the biosolids-treatment area.

The single control site available for this study area was of marginal use in evaluating biosolids effects on water quality for 1993–1999. The water-quality data obtained for the study area for 1993–1999 indicate that the control site was not representative of all the other groundwater locations in the study area before biosolids applications began (compare baseline data to control-site data in fig. 15), particularly with respect to physical properties and concentrations of major ions, nitrogen, iron, and manganese. Therefore, differences in groundwater physical properties and concentrations of major ions, nitrogen, iron, and manganese between the control site and the biosolids-treatment area should not be attributed to biosolids but to geological and microbiological effects on water quality. It is interesting to note that the limited data from the July 1999 groundwater sampling indicated smaller phosphorus concentrations and larger concentrations of molybdenum, cobalt, chromium, copper, and nickel in the five samples from the biosolids-treatment area compared to concentrations in samples from the control site (table 7). Larger concentrations of biosolids-signature elements like phosphorus, molybdenum, and tungsten (as well as nitrogen, antimony, cadmium, cobalt, copper, nickel, selenium, vanadium, and zinc) in groundwater from the biosolids-treatment area relative to concentrations in samples from the control site were more likely to represent effects from biosolids applications, particularly once enough time had elapsed that the groundwater had recharged after biosolids applications began. Additional samples would need to be collected and analyzed for the biosolids-signature elements to determine if concentrations were significantly larger in the biosolids-treatment area relative to concentration variability. However, the control-site data were useful to indicate yet another variation in water quality in the study area, and may be useful (especially the 1999 data) for future data comparisons to establish biosolids effects on water quality.

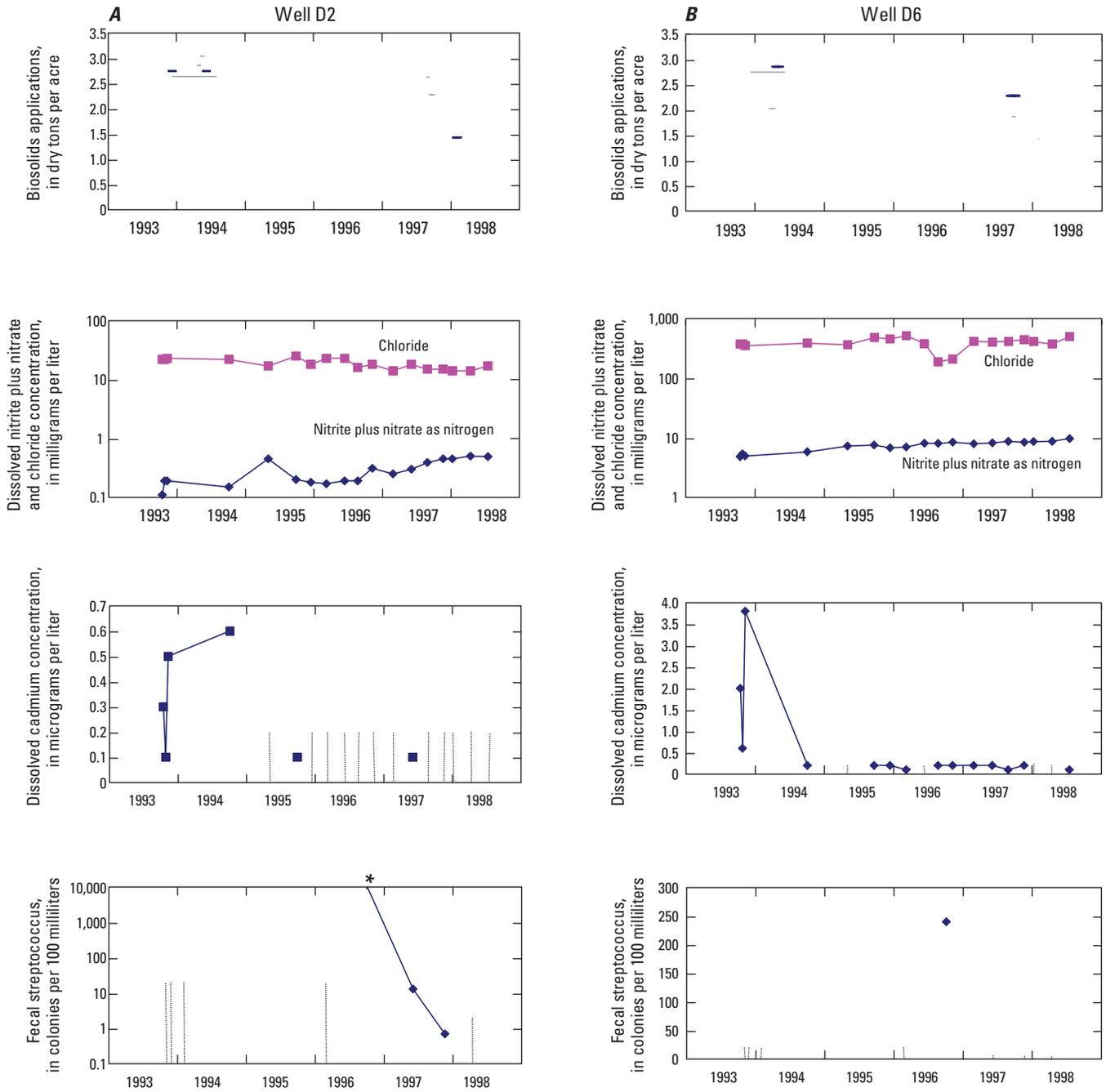
Comparison of Temporal Patterns

Temporal change in water quality often is considered an indicator of treatment effects if concentrations of constituents increase during or after the time of treatment; however, temporal patterns in water quality can have other causes than the treatment. The difference in groundwater time-series data for the study area may not represent effects from the treatment (biosolids applied as a fertilizer) if water infiltrating through

biosolids-treated soils had not yet recharged into the aquifer at the time samples were collected. Despite the uncertainty contributed by mixing along the long well screens, the DG-CFC results indicated that groundwater in at least some parts of the study area likely had not yet recharged through biosolids-treated areas when sampled during 1994–1998. Data from the study area also indicated that at least some of the groundwater in other parts of the study area had recharged through biosolids-treated areas; however, temporal patterns in water quality that are caused by biosolids applications could be obscured by larger effects from other processes or sources, such as natural geochemical or microbiological processes or historic land uses of the study area (prior to 1993). Also, differences in constituent concentration over time can result from sample collection, processing, or analysis and be unrelated to the study area or the treatment. Therefore, caution should be used in interpreting time-series data with respect to treatment effects. More evidence than an increase in a constituent over time is needed to indicate that biosolids applications have affected water quality.

Biosolids applications could increase bacteria colonies and concentrations of nutrients, major ions, and trace elements in study-area water. In particular, an increase in concentrations of the biosolids-signature elements that followed biosolids applications might be attributed to biosolids effects on water quality. A time lag between application dates and groundwater-concentration increases would be expected because of the time it takes to recharge groundwater, and this time lag could be unique and vary for each site that was sampled. Increases in concentrations of biosolids-signature constituents in study-area water samples that were caused by biosolids applications likely would be widespread and occur at some relatively consistent interval after biosolids applications. To further evaluate the effect of biosolids on water quality of the study area, concentrations of selected biosolids-signature constituents (included in table 5) and other constituents that could come from biosolids (such as fecal streptococcus bacteria; table 6) were compared to biosolids-application loads and dates (table 1). Biosolids-applications and concentrations of selected biosolids-related constituents are compared in figure 16 for selected sites that likely had at least some modern groundwater (wells D2, D6, D9, D23, and D24) and for one site that had at least some old groundwater but also had the occasional large nitrate concentration (well D25). Because copper, nickel, and zinc detections in the samples from these sites were rare, these constituents were not included in figure 16.

Biosolids were applied in the eastern part of the study area (in the vicinity of Cottonwood Creek and wells D2 and D6; DC 301 and DC 310) in December 1993 through June 1994 and in September 1997 through February 1998 (table 1; fig. 16). Nitrate concentration in samples from well D2 spiked slightly in May 1995 and then increased gradually. Nitrate concentration in samples from well D6 did not spike but did increase gradually. Chloride concentration remained fairly constant in samples from well D2, whereas chloride concentration was constant with one decrease in 1996 in samples from well D6. Cadmium concentration was largest in October 1994 but barely



EXPLANATION

- Biosolids application to the half section (destination code) that contains the well or, if well is close to a boundary between two destination codes, biosolids application to either of the two destination codes that surround the well
- Biosolids application to a more distant upgradient destination code in the same drainage basin that contains the well
- ⋮ Data that were reported by the laboratory as less than the minimum reporting level; height of dotted line corresponds to censored interval
- * Reported by laboratory as >10,000 but value may be from field or laboratory contamination

Figure 16. Comparison of selected water-quality constituents with biosolids-application data for selected sites near Deer Trail, Colorado, 1993 through 1998.

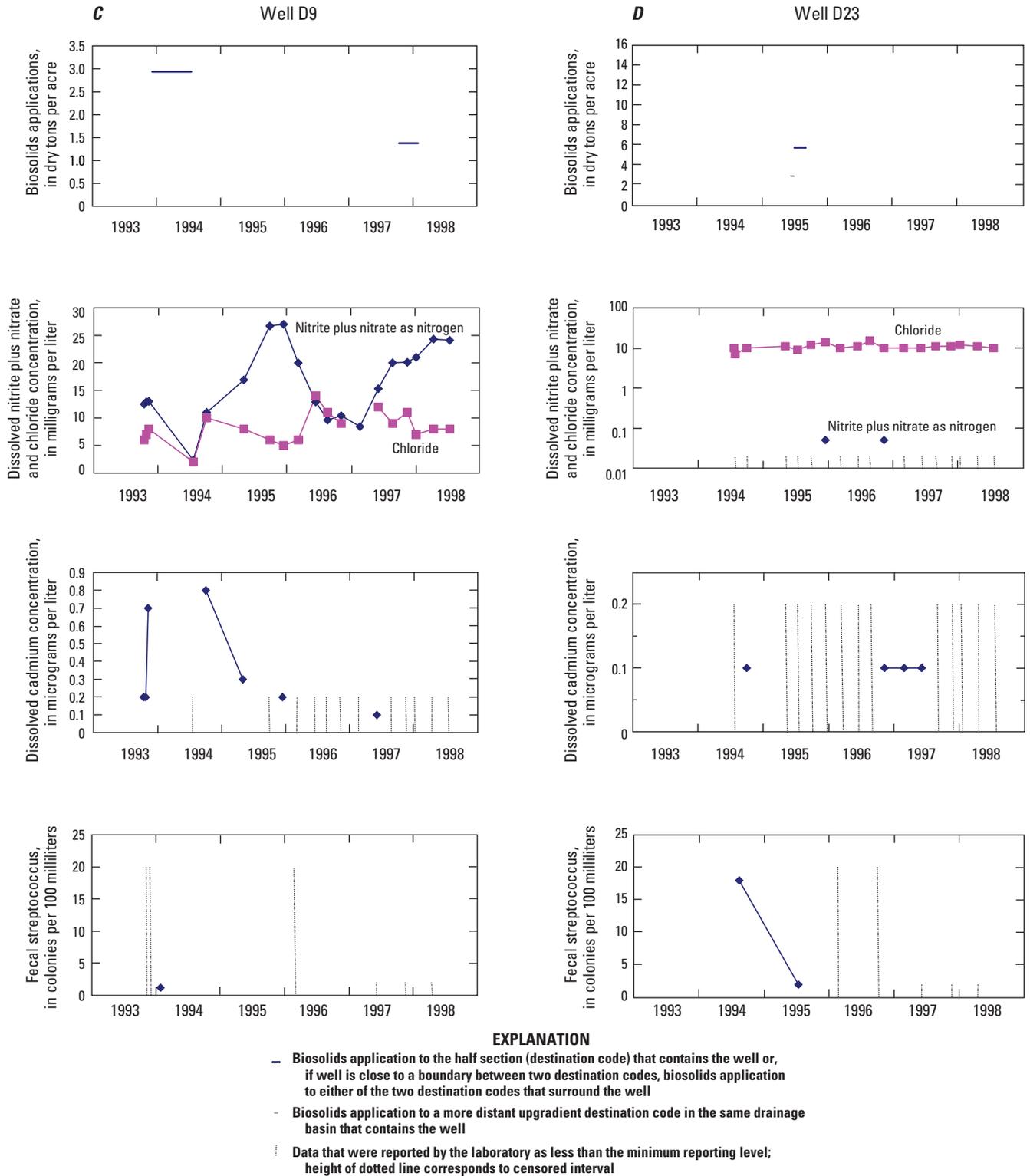


Figure 16. Comparison of selected water-quality constituents with biosolids-application data for selected sites near Deer Trail, Colorado, 1993 through 1998.—Continued

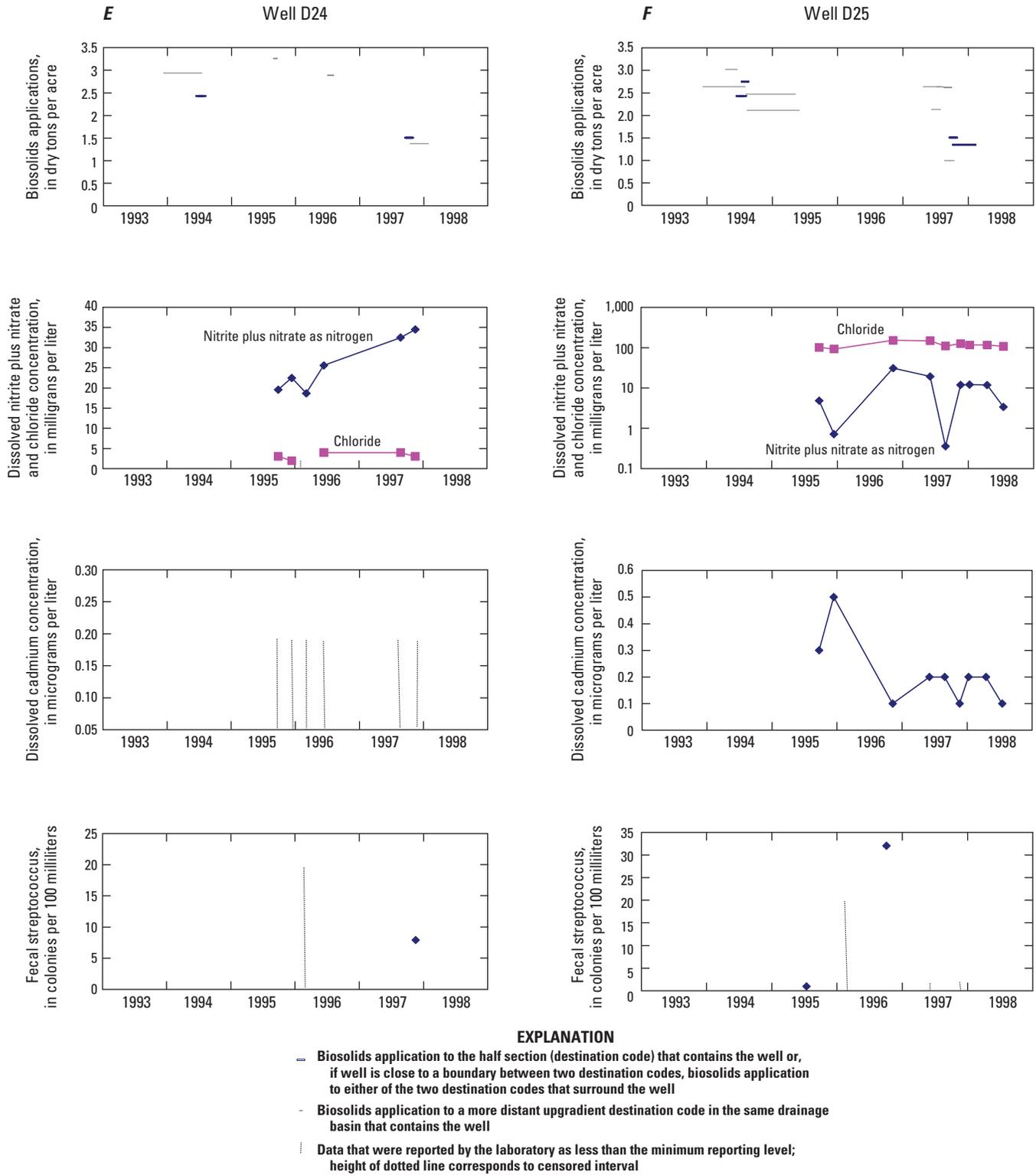


Figure 16. Comparison of selected water-quality constituents with biosolids-application data for selected sites near Deer Trail, Colorado, 1993 through 1998.—Continued

larger than baseline concentrations in samples from well D2, whereas cadmium concentration was not detected above the MRL except for baseline concentrations in samples from well D6. Fecal streptococcus bacteria were not detected in samples from well D2 until October 1996 but then were detected in the highest number cultured for study-area samples (greater than 10,000 colonies per 100 mL) before decreasing throughout 1997. Fecal streptococcus bacteria also were detected in numbers much higher than the MRL in the sample from well D6 in October 1996. Bacteria colonies were detected in other samples from some of the Cottonwood Creek drainage-basin wells and a pond, but not consistently or in increasing quantities. Phosphorus concentration spiked slightly in the September 1995 sample from well D2 but stayed near baseline concentrations in samples from well D6. Copper and nickel concentrations spiked slightly higher than baseline concentrations in the June 1997 samples from wells D2 and D6. The generally increasing concentrations of nitrate in samples from wells D2 and D6 may have resulted from biosolids applications in the area, but the rather random temporal patterns in the other water-quality data did not indicate much effect of biosolids applications on water quality during 1993–1998.

Biosolids were applied in the vicinity of well D23 (DC 326 and DC 328) only during June–August 1995 (table 1; fig. 16). The July 1995 ammonia concentration in the sample from well D23 increased slightly, but concentrations of chloride, other nutrients, cadmium, copper, nickel, and zinc stayed about the same, were not detected, or were detected at about the same concentration as the MRL. Detections of fecal streptococcus bacteria were about the same as the MRL, and the number of bacteria decreased in the July 1995 sample relative to the August 1994 sample. Therefore, the temporal data pattern for well D23 did not indicate that the biosolids application in the vicinity of well D23 affected water quality during 1994–1998.

Biosolids were applied to the north part of the study area in the vicinity of wells D9 and D24 (DC 302 and DC 304) in December 1993 through July 1994 and October 1997 through January 1998 (table 1; fig. 16). Nitrate concentrations increased in samples from well D9 within one year of biosolids application, decreased, and then began increasing again without additional biosolids application. Chloride concentration varied differently from nitrate concentration but generally increased during 1993–1998 in samples from well D9. Cadmium concentration in samples from well D9 fluctuated most in November 1993 through September 1995 samples then was fairly constant. The single fecal streptococcus bacteria detection in the January 1994 sample from well D9 (during the biosolids application period) was smaller than that of the control site and the MRL. The largest phosphorus concentration reported for samples from well D9 was for the July 1994 sample. Copper concentration in samples from well D9 was not detected above the MRL (table 5). The only concentrations of nickel detected in samples from well D9 were in March 1996, November 1997, and January 1998, which did not correspond to the dates of zinc detections (October 1994 and June 1997). In the same part of the study area, however,

nitrate concentration increased markedly in samples from well D24 following biosolids application in the area; it is not known whether nitrate concentration was increasing at this location prior to biosolids application. Chloride and cadmium concentrations in samples from well D24 remained small. Only one of the two bacteria samples from well D24 had detections of fecal streptococcus bacteria, and the count was less than the MRL. Phosphorus detections were small and erratic. Copper, nickel, and zinc generally were not detected in samples from well D24. The generally increasing concentrations of nitrate in samples from wells D9 and D24 may have resulted from biosolids applications in the area; however, the temporal patterns in the water-quality data for other constituent concentrations do not indicate much effect of biosolids applications on water quality during 1993–1998.

Biosolids were applied to the north part of the study area in the vicinity of well D25 (DC 304 and DC 305) in July 1994 and October 1997 through February 1998 (table 1; fig. 16). Biosolids were applied to areas upgradient from well D25 (DCs 303, 306, 307, and 308) in December 1993 through September 1997 (table 1; fig. 5). Nitrate concentrations spiked in samples from well D25 within 2.5 years after the initial biosolids application, decreased, and then spiked again within several months after the next biosolids application. Large chloride concentrations coincided with the largest nitrate concentrations in samples from well D25 (November 1997 and January 1998) (table 5). Cadmium was detected in all samples from well D25, but was reported at a slightly larger concentration in the December 1995 sample. Fecal streptococcus bacteria were reported above the MRL in an October 1996 sample from well D25. Phosphorus (and to a lesser extent organic nitrogen) concentrations were substantially larger in the November 1996 and June 1997 samples, the same samples that had larger concentrations of nitrate and cadmium. However, copper, nickel, and zinc were not detected above the MRL in samples from well D25. In general, the nitrate, chloride, and cadmium data from well D25 show a temporal pattern that could correspond with water-quality effects that lagged biosolids applications by about 1.5–2.5 years, although a longer period of data comparison would be needed to confirm this pattern.

In general, the comparison of temporal patterns of nitrate, chloride, cadmium, and fecal streptococcus bacteria with temporal patterns and magnitude (loading) of biosolids applications for well samples that contained at least some modern groundwater did not indicate biosolids effects on water quality. Only samples from well D25 had temporal concentration patterns in that seemed possibly related to biosolids applications.

Other Indicators

Levels of indicator bacteria can be used to evaluate sources of water-quality impairments (Gaggiani, 1991, p. 40; Murray and others, 2001). If the ratio of fecal coliform bacteria to fecal streptococcus bacteria in a sample is greater than 4.0, then humans likely are the source of the bacteria (Murray and others, 2001), although this ratio will not indicate the specific type

of human fecal matter (such as septic, pit toilets, or biosolids) that contributed the bacteria. If the bacteria ratio is below 0.6 (Murray and others, 2001) or 0.7 (Gaggiani, 1991), then other warm-blooded animals such as cattle or wildlife likely are the source of the bacteria. Few samples from the study area had detections of both fecal coliform and fecal streptococcus bacteria (table 6); however, the sample data where ratios could be calculated indicated that humans were not the source of the bacteria in groundwater or surface-water samples.

The DG-CFC data can provide additional information about biosolids effects on water quality. As was mentioned previously, DG-CFC data can indicate apparent recharge dates for groundwater. Chlorofluorocarbon-113 (CFC-113) enrichment in groundwater samples can indicate that groundwater has been affected by some type of human wastewater; however, the chlorofluorocarbon data do not indicate which type of wastewater (biosolids, septic systems, historic outhouse effluent, or other sewage sources) affected the groundwater (E. Busenberg, U.S. Geological Survey, written commun., November 18, 1999). The chlorofluorocarbon data collected from the study area indicated that groundwater at wells D3, D9, and D24 may have been affected by wastewater sources. Historic homesteads are not known in the vicinity of wells D9 and D24, so biosolids are the most likely type of wastewater to have affected the groundwater at these locations. A homestead was present near well D3, so a pit toilet, septic system, or biosolids could have affected groundwater at this location. Even if CFC-113 enrichment indicates biosolids or some other wastewater type affected the groundwater, the presence of tracer constituents, such as DG-CFCs in water samples, does not constitute contamination or even adverse effects. Note that counts of fecal streptococcus bacteria were largest in samples from well D3 in November 1993 (8 months before biosolids were applied), but concentrations of other constituents such as nutrients and trace elements were not particularly large. In contrast, the large nitrate concentrations in samples from wells D9 and D24 in addition to CFC-113 enrichment indicate that biosolids could be the source of the nitrate in samples from wells D9 and D24. Thus, the presence of tracer constituents such as DG-CFCs along with elevated concentrations of other constituents (such as nitrate) can indicate sources of the elevated-concentration constituents.

In general, biosolids applications may have affected water quality slightly in parts of the study area during 1993–1998 through increases in nitrate and possibly a few other constituents, particularly where groundwater was oxic. However, increased nitrate concentrations were not widespread throughout the study area during the 1–5 years after biosolids applications began and were much less than those reported by Gaggiani (1991) for water-quality sites at a sewage-disposal area that was about 40 mi farther west in Colorado. For most water-quality constituents, any effects from biosolids on water quality of the study area during 1993–1998 were obscured by high variation in concentrations, and the effects of biosolids applications on water quality of the study area during 1993–1999 were less than natural geological or microbiological effects.

Summary

The Metro Wastewater Reclamation District (Metro District) in Denver, Colo., applied biosolids resulting from municipal sewage treatment to farmland in eastern Colorado beginning in December 1993. The biosolids were a treated sewage product that met State and Federal regulatory criteria and were applied at agronomic loading rates as a fertilizer and soil amendment.

In mid-1993, the U.S. Geological Survey in cooperation with the Metro District began monitoring water quality at the biosolids-application area about 10 miles (mi) east of Deer Trail, Colo., to evaluate baseline water quality and the combined effects of natural processes, land uses, and biosolids applications on water quality of the biosolids-application area. The study included limited sampling of surface water and the unsaturated zone, but primarily focused on the sampling of groundwater, which was more abundant. The study area was on the eastern margin of the Denver Basin, a bowl-shaped sequence of sedimentary rocks that was formed in an ocean or near-ocean environment. The surficial geology of the study area consisted of interbedded shale, siltstone, and sandstone, with unconsolidated clay, silt, sand, and gravel. The primary water-supply aquifer in the study area was the Laramie-Fox Hills aquifer. Multiple alluvial aquifers associated with the surficial drainage network were present. Depth to groundwater below land surface at sampling locations ranged from a few feet to about 100 feet (ft). Most streams were ephemeral, so surface water predominantly was in the form of ponds. The climate was semi-arid with most of the precipitation occurring as rainfall in spring and in late summer. Land use was rangeland or cropland. The primary crop was winter wheat; farmland was not irrigated. Herbicides and other chemicals were applied to the study area for farming and weed-control purposes. Biosolids were applied as the only fertilizer and soil amendment on the Metro District properties during the study.

Baseline sampling was done in 1993 to provide information about water quality in the study area before biosolids applications began. Reconnaissance sampling was done during 1993 through 1995 to establish the spatial variability in water quality of the study area. Routine sampling was done during 1995 through 1998 to establish the temporal variation in water quality after biosolids applications began. The water-quality samples were analyzed by the Metro District laboratory for selected major ions, nutrients, and trace elements in filtered samples and bacteria (fecal coliform and fecal streptococcus bacteria) in unfiltered samples. Specialty sampling for unsaturated-zone pore water was initiated by the USGS in 1994 to determine if pore-water chemistry under biosolids-applied farmland differed from pore-water chemistry under farmland that was not applied with biosolids. Specialty sampling for dissolved gases and chlorofluorocarbons (CFCs) was done at selected monitoring wells in 1998 to infer information about water quality, flow paths, and groundwater recharge. Specialty sampling for oxidation-reduction (redox) information was done in 1999 to determine redox states in the groundwater. Other specialty monitoring included the use of automated data

recorders during 1997 and 1998 to provide detailed information about selected water-quality characteristics. Core-chemistry data from well borings in the study area also were obtained for comparison with the water-quality data.

Baseline water quality was marginal at some sites and better at other sites. Large concentrations of chloride, sulfate, nitrate, iron, and manganese were detected in some baseline samples. Sulfate concentrations in baseline samples were largest in samples from well D6. Nitrogen in baseline samples predominantly was in the form of nitrate. One-half of the sites sampled for baseline water quality had nitrate concentrations of 1 milligram per liter as nitrogen (mg-N/L) or greater, five sites had baseline nitrate concentrations greater than 3 mg-N/L, three sites had baseline nitrate concentrations in the range of 5–10 mg-N/L, and one site (well D9) had baseline nitrate concentrations greater than 10 mg-N/L. Concentrations of iron and manganese were detected above the minimum reporting level (MRL) in baseline samples from various monitoring wells in the study area. Chloride was detected in nearly all baseline samples; some concentrations were large. Phosphorus (orthophosphate as phosphorus) and cadmium were detected at small concentrations in most baseline samples. Chromium and copper were not detected in any baseline samples, but nickel and zinc were detected in baseline samples. Bacteria (fecal streptococcus) were found in baseline samples from two of the 10 sampled wells. The baseline data indicate that major-ion, nutrient, trace-element, and bacteria sources other than biosolids were present in the study area and that water in the study area was of variable quality before biosolids ever were applied.

Variability in water quality of the study area was evident from the baseline data as well as from the data collected after biosolids applications began. The hydrology of the study area likely accounts for some of the variability in water quality. Precipitation caused runoff from farmed fields, caused intermittent and ephemeral streams to flow, and fed natural and anthropogenic ponds. During dry periods, pond water evaporated and desiccation cracks formed. Groundwater recharged preferentially from ponds and through desiccation cracks and coarse-grained deposits and outcrops, not uniformly through the unsaturated zone beneath all fields.

Concentrations of major ions, nutrients, trace elements, and bacteria varied spatially in the study area. Concentrations of sulfate, nitrate, iron, and manganese varied the most. Major-ion concentrations in groundwater varied more by lithology or geologic formation than by drainage basin, biosolids treatment, site type, or well depth. Nitrate concentrations generally were largest in shallow bedrock-aquifer wells in the north part of the study area and smallest near wetland areas. Fecal coliform and fecal streptococcus bacteria were not detected in most of the samples from the study area, although fecal streptococcus bacteria were detected more frequently than fecal coliform bacteria, and pond samples generally had larger bacteria counts than nearby wells. Water-quality concentration did not correlate well with depth of sample, but smaller chloride, nitrate, and manganese concentrations were characteristic of deeper wells and the largest nitrate concentrations detected in study-area water was in pore-water samples from the 1.5-ft

depth. The pore-water data indicated that chloride, nitrate and copper reservoirs in the upper 3 ft of the unsaturated zone could eventually migrate to the saturated zone.

Temporal variability in water quality generally was larger at some sites than other sites in the study area and larger for some water-quality constituents (like nitrate, iron, manganese, and fecal streptococcus bacteria) than other constituents. Nitrate concentrations in samples from wells D6, D24, and D32 increased more markedly and more consistently than in those from other wells in the study area. In general, nitrate concentration increased in samples from most wells along lower Cottonwood Creek but was more variable in samples from wells D9, D14, D19, D25, D28, and D31. Of the limited analytes considered for this study, nitrate increased in concentration the most consistently over time.

Groundwater samples from the study area exceeded various Colorado regulatory standards. Groundwater concentrations exceeded Colorado human-health or drinking-water standards for chloride in samples from well D6; for sulfate in samples from most wells; for nitrate in samples from wells D9, D24, D25, and D32; for nickel in sample from wells D4, D6, D12, D16, and D32; and for chromium, iron, and manganese in samples from many wells. Concentrations generally were less than Colorado agricultural standards, except for iron concentrations in samples from wells D21 and D29; nickel concentrations in samples from wells D6, D16, and D32; and manganese concentrations in samples from many wells. Baseline groundwater concentrations of chloride, sulfate, nitrate, iron, and manganese in samples from some wells exceeded Colorado regulatory standards before biosolids applications to the study area began.

Geology affected water quality in the study area. Major-ion and trace-element chemistry of water in the study area appears to be controlled primarily by local geology. Sandstone units in the study area contain iron-rich concretions and weather chemically to produce secondary crystalline minerals and amorphous iron oxides. Chemical analysis of core samples confirmed the presence of many of the same major and trace elements in the near-surface geologic materials of the study area that were in the groundwater. The dissolution and precipitation of common minerals such as gypsum, calcite, dolomite, halite, magnesium-sulfate, and pyrite minerals likely controlled the calcium, chloride, magnesium, sodium, and sulfate concentrations in the groundwater from many of the monitoring wells. Major-ion and trace-element chemistry of water in the study area therefore appears to have been controlled by local geology. In addition, characteristics of bedrock and soil such as cementation, porosity, and permeability likely determined groundwater flow paths and affected groundwater flow rates and chemistry.

Meteorology affected water quality in the study area through precipitation on surface water (wet deposition) that delivered atmospheric constituents to the water and through runoff and infiltration that transported constituents from the land surface into surface water or groundwater. Other sources of ions in the study area likely contributed a greater mass of constituents to the surface and subsurface water in the study area than the direct deposition of precipitation. The data

indicate that meteorology could have affected water quality in the study area by mobilizing chemical constituents from the soil during runoff and infiltration. Warm surface temperatures coupled with low humidity and relatively small precipitation rates can result in evapotranspiration rates that exceeded precipitation-infiltration rates. Solutes can become concentrated in ponds, soil, and pore water. The pore-water data from the study area indicated that reservoirs of some solutes such as chloride, nitrate, and possibly copper were present in the soil near the surface and could be transported to the aquifers through a larger wetting front or through preferential flow paths. During drier periods, much of the recharge to groundwater likely happened at focused recharge areas in stream valleys, outcrop areas, or areas that had desiccation cracks. Geology appears to have affected water quality in the study area more than meteorology during 1993–1998.

Microbiological effects on water quality of the study area predominantly were the microbially mediated cycling of redox-sensitive constituents. Groundwater at most sites in the study area was oxidic. Groundwater at some sites in the study area was depleted in oxygen (post oxidic). Denitrification was a common process in groundwater of the study area, especially at wells D13 and D25. Chlorofluorocarbon data indicated that denitrification had occurred in groundwater at wells D6, D9, and D24, yet denitrification was not sufficient to prevent nitrate concentrations from increasing during 1993–1999 at these sites because the groundwater usually was oxidic. Where denitrification is actively occurring, nitrate is reduced to nitrite and even to nitrogen gas; therefore, nitrate produced from additional nitrogen inputs to that site (such as from biosolids or other fertilizers) will be consumed in post-oxidic groundwater. Oxygen reduction likely was the predominant terminal electron-acceptor process at sites where groundwater was oxidic. Ferric-iron reduction (wells D15, D16, D21, and D23) or sulfate reduction (wells D22 and D30) was the predominant terminal electron-acceptor process at sites where groundwater was post-oxidic. In general, microbial processes in oxygen-depleted shallow groundwater (such as in much of the Muddy Creek area) have kept nitrate concentrations small and could reduce additional nitrogen inputs to the groundwater. Pond presence often resulted in microbial effects on water quality in the study area. Ponds provided a source of oxygenated recharge water, and associated wetlands created reducing zones.

Some flow-path effects were evident from the water-quality data collected during 1993–1999. Dissolved-gas and chlorofluorocarbon data indicated mixed old and young groundwater at wells D3, D6, D9, D13, D17, and D24 in 1998. Dissolved-gas and chlorofluorocarbon data indicated that groundwater followed a slow flow path after recharge before traveling to wells D3, D5, D6, D13, D14, D17, and D25, but at least some of the groundwater followed a rapid flow path after recharge to travel to wells D6, D9, and D24. Redox data indicated that a significant flow path for the Muddy Creek alluvial aquifer was from well D21 towards well D15, and that tributary alluvial aquifers in the vicinity of wells D20 and D17 likely flowed toward and joined the Muddy Creek alluvial aquifer, but do not indicate that the Laramie-Fox Hills aquifer

6 mi north of well D15 was part of this flow path in 1999. Preliminary geochemical modeling indicated that the groundwater flow path for well D6 likely did not include the bedrock-aquifer water (as represented by well D29) or groundwater from other upgradient shallow wells, but could include bedrock groundwater from a different location or simply rain water that interacted with rocks and either coal or organic matter (representing biosolids) in the vicinity of the well.

Biosolids effects on water quality were challenging to identify. The baseline data collected from the study area in 1993 were adequate to indicate that sources of major ions, nutrients, trace elements, and bacteria affected water quality before biosolids were applied. Chloride, sulfate, nitrate, and manganese concentrations in some baseline groundwater samples exceeded Colorado regulatory standards. Most chemical-constituent concentrations were similar in the baseline samples as in later post-biosolids-application samples for 1994–1998. Because of the large spatial and temporal variability in water quality for both the baseline and the post-application data and the similarity in concentrations before and after biosolids application, effects from biosolids applications were not discernible from a simple comparison of baseline data with post-application data. Of the inorganic biosolids-signature constituents for aqueous media that were analyzed routinely in both the baseline and post-biosolids-application water-quality samples, only nitrate concentrations increased after biosolids applications began. The single control site available for this study area was of marginal use in evaluating biosolids effects on water quality for 1993–1999. The control site was not representative of all the other groundwater locations in the study area before biosolids applications began, particularly with respect to physical properties and concentrations of major ions, nitrogen, iron, and manganese. Differences in groundwater physical properties and concentrations of major ions, nitrogen, iron, and manganese between the control site and the biosolids-treatment area should not be attributed to biosolids but to geological and microbiological effects on water quality. Only samples from well D25 had temporal concentration patterns that seemed possibly related to biosolids applications. The sample data where ratios of fecal coliform bacteria to fecal streptococcus bacteria could be calculated indicated that humans were not the source of the bacteria in groundwater or surface-water samples. The chlorofluorocarbon data collected from the study area indicated that groundwater at wells D3, D9, and D24 may have been affected by wastewater sources. In general, biosolids applications may have affected water quality slightly in parts of the study area during 1993–1998 through increases in nitrate and possibly a few other constituents, particularly where groundwater was oxidic. However, increased nitrate concentrations were not widespread throughout the study area during the 1–5 years after biosolids applications began. For most water-quality constituents, any effects from biosolids on water quality of the study area during 1993–1998 were obscured by high variation in concentrations, and the effects of biosolids applications on water quality of the study area during 1993–1999 were less than natural geological or microbiological effects.

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Appendixes

Appendix 1. Information for U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1993 through 1998.

[Lithologic descriptions and diagrams of well parts were reported by Yager and Arnold (2003); diagrams of well parts and other information for monitoring wells installed in 1999 as part of the U.S. Geological Survey Expanded Monitoring Program near Deer Trail were reported by Stevens and others (2003). Latitude and longitude are in the format degrees minutes seconds referenced to North American Datum of 1983; stickup, the length of well casing above ground (fluctuates because land surface is uneven and changes height over time), and measuring point is at the top of the stickup; bmp, below measuring point on the stickup; sump, the nonperforated closed casing below the screen; U, not known; HUC, hydrologic unit code in the format 101900XX from Seaber and others (1987); altitude is in feet above North American Vertical Datum of 1988; km, kilometers; N, North; W, West; <, less than; Metro District, Metro District Wastewater Reclamation District; --, no data]

Well (fig. 2)	Latitude	Longitude	County	Date drilled	Stickup, feet above land surface	Total depth (from drillers' notes), feet bmp	Screened interval		Screen length (from drillers' notes), feet
							Top (from drillers' notes), feet bmp	Bottom (from drillers' notes), feet bmp	
D1	39 36 57.80671N	103 52 36.00105W	Arapahoe	9/7/1993	2.09	17	12	17	5
¹ D2	39 36 46.91675N	103 51 58.93608W	Arapahoe	9/7/1993	3.29	25	15	25	10
D3	39 37 20.89342N	103 54 31.35544W	Arapahoe	9/11/1993	2.83	46	36	46	10
D4	39 36 40.77561N	103 53 51.02474W	Arapahoe	9/10/1993	2.11	34	24	34	10
D5	39 36 18.96329N	103 51 55.40047W	Arapahoe	9/11/1993	3.45	30	20	30	10
² D6	39 36 32.92243N	103 51 22.41861W	Arapahoe	9/12/1993	2.65	26	16	26	10
D7	39 36 00.91012N	103 53 56.45627W	Arapahoe	9/10/1993	2.62	25	15	25	10
D8	39 36 36.96236N	103 54 21.56186W	Arapahoe	9/10/1993	2.79	20	10	20	10
D9	39 37 27.90764N	103 52 57.05224W	Arapahoe	9/12/1993	2.37	61	51	61	10
D10	39 36 07.67740N	103 51 49.94923W	Arapahoe	9/11/1993	2.40	20	10	20	10
³ D11	39 36 38N	103 53 13W	Arapahoe	9/12/1993	3.5	17	7	17	10
⁴ D11a	39 33 34N	103 54 36W	Elbert	10/23/1997	2.46	143.03	112.65	122.65	10
⁵ D12	39 37 01.56726N	103 52 18.76732W	Arapahoe	U	0.62	U	U	U	U
D13	39 34 41.52701N	103 54 37.51467W	Arapahoe	4/4/1994	1.81	17	7	17	10
D14	39 34 28.76792N	103 54 03.29046W	Arapahoe	4/4/1994	1.39	24	14	24	10
D15	39 33 58.75763N	103 54 54.24674W	Elbert	4/7/1994	1.86	25	15	25	10
D16	39 33 06N	103 54 56W	Elbert	4/7/1994	1.88	25	15	25	10
D17	39 33 34.44687N	103 54 36.41899W	Elbert	4/5/1994	1.90	22	12	22	10
D18	39 33 29N	103 55 20W	Elbert	4/16/1994	2.50	15	10	15	5
D19	39 33 16.97000N	103 54 18.09956W	Elbert	4/5/1994	1.69	30	20	30	10
D20	39 32 46N	103 54 42W	Elbert	4/6/1994	2.27	22	12	22	10
D21	39 32 09N	103 54 46W	Elbert	4/5/1994	1.71	20	10	20	10
D22	39 33 07.54597N	103 52 00.42522W	Elbert	4/8/1994	3.58	41	31	41	10
⁷ D23	39 33 42.22201N	103 55 1.14240W	Elbert	4/8/1994	2.54	15	10	15	5
D24	39 37 24.35652N	103 53 51.56324W	Arapahoe	5/10/1995	2.31	60	20	50	30
D25	39 37 02.36429N	103 54 41.77998W	Arapahoe	5/1/1995	2.23	25	15	25	10
D26	39 36 39.48726N	103 53 30.23390W	Arapahoe	5/3/1995	2.44	44	34	44	10
D27	39 36 20.63663N	103 54 09.06578W	Arapahoe	5/2/1995	2.77	26	16	26	10
D28	39 35 44.79713N	103 53 40.17959W	Arapahoe	5/2/1995	2.12	30	20	30	10
⁸ D29	39 36 32N	103 52 43W	Arapahoe	11/4/1997	2.38	183.19	147.81	157.81	10
D30	39 36 54.59463N	103 51 22.26453W	Arapahoe	5/5/1995	1.98	21	11	21	10
D31	39 36 55.75641N	103 51 38.57257W	Arapahoe	5/4/1995	1.84	26	11	21	10
D32	39 36 09.10353N	103 51 25.51780W	Arapahoe	5/9/1995	1.99	40	30	40	10
D33	39 35 56.05290N	103 51 53.08219W	Arapahoe	5/5/1995	1.73	25	10	20	10

Appendix 1. Information for U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1993 through 1998.—Continued

[Lithologic descriptions and diagrams of well parts were reported by Yager and Arnold (2003); diagrams of well parts and other information for monitoring wells installed in 1999 as part of the U.S. Geological Survey Expanded Monitoring Program near Deer Trail were reported by Stevens and others (2003). Latitude and longitude are in the format degrees minutes seconds referenced to North American Datum of 1983; stickup, the length of well casing above ground (fluctuates because land surface is uneven and changes height over time), and measuring point is at the top of the stickup; bmp, below measuring point on the stickup; sump, the nonperforated closed casing below the screen; U, not known; HUC, hydrologic unit code in the format 101900XX from Seaber and others (1987); altitude is in feet above North American Vertical Datum of 1988; km, kilometers; N, North; W, West; <, less than; Metro District, Metro District Wastewater Reclamation District; --, no data]

Well (fig. 2)	Screen opening, inches	Sump length, feet	Diameter of well casing, inches	HUC	Property owner	Calculated altitude of land surface, feet	Calculated altitude of land surface, km	Surveyed altitude of measuring point (top of stickup), feet	Effective total depth, measured 12/95–2/96, feet bmp
D1	Hand slotted	<1	2	13	Metro District	5,227.51	1.59	5,229.60	17.15
¹ D2	0.010	<1	2	13	Metro District	5,169.60	1.58	5,172.89	24.50
D3	0.010	<1	2	11	Metro District	5,188.46	1.58	5,191.29	47.28
D4	0.010	<1	2	11	Metro District	5,210.40	1.59	5,212.51	33.41
D5	0.010	<1	2	13	Metro District	5,194.84	1.58	5,198.29	29.21
² D6	0.010	<1	2	13	Metro District	5,126.13	1.56	5,128.78	25.10
D7	0.010	<1	2	11	Metro District	5,220.66	1.59	5,223.28	23.77
D8	0.010	<1	2	11	Metro District	5,186.35	1.58	5,189.14	19.15
D9	0.010	<1	2	12	Metro District	5,218.23	1.59	5,220.60	62.00
D10	0.010	<1	2	13	Metro District	5,197.39	1.58	5,199.79	19.19
³ D11	0.010	<1	2	11	Metro District	5,260	--	--	--
⁴ D11a	0.010	20.38	2	11	Metro District	5,374	1.64	5,377	--
⁵ D12	U	U	4	13	Metro District	5,193.41	1.58	5,194.03	55.48
D13	0.010	<1	2	11	Metro District	5,233.52	1.60	5,235.33	16.15
D14	0.010	<1	2	11	Metro District	5,270.74	1.61	5,272.13	24.00
D15	0.010	<1	2	11	Private ⁶	5,244.91	1.60	5,246.77	24.06
D16	0.010	<1	2	11	Private ⁶	5,277	1.61	5,279	24.06
D17	0.010	<1	2	11	Metro District	5,275.83	1.61	5,277.73	20.89
D18	0.010	<1	2	11	Private ⁶	5,295	1.61	5,298	14.90
D19	0.010	<1	2	11	Metro District	5,302.55	1.62	5,304.24	29.00
D20	0.010	<1	2	11	Private ⁶	5,280	1.61	5,282	7--
D21	0.010	<1	2	11	Private ⁶	5,317	1.62	5,319	19.12
D22	0.010	<1	2	13	Metro District	5,154.08	1.57	5,157.66	39.30
⁷ D23	0.010	<1	2	11	Private ⁶	5,250.97	1.60	5,253.51	15.00
D24	0.010	10	2	11	Metro District	5,242.69	1.60	5,245.00	59.50
D25	0.010	<1	2	11	Metro District	5,164.90	1.57	5,167.13	22.93
D26	0.010	<1	2	11	Metro District	5,230.90	1.59	5,233.34	43.50
D27	0.010	<1	2	11	Metro District	5,204.43	1.59	5,207.20	23.96
D28	0.010	<1	2	11	Metro District	5,236.99	1.60	5,239.11	28.38
⁸ D29	0.010	25.38	2	13	Metro District	5,369	1.64	5,371	--
D30	0.010	<1	2	13	Metro District	5,094.45	1.55	5,096.43	18.99
D31	0.010	5	2	13	Metro District	5,117.92	1.56	5,119.76	23.94
D32	0.010	<1	2	13	Metro District	5,186.94	1.58	5,188.93	39.00
D33	0.010	5	2	13	Metro District	5,227.35	1.59	5,229.08	24.19

¹Well had continuous-recorder instrumentation for water-level, water-temperature, and precipitation data from 1995 through 1998.

²Well had continuous-recorder instrumentation for specific conductance and water-temperature data from 1996 through 1998.

³Well was closed on 9/7/1995.

⁴Well information from geologist's notes.

⁵This well was not installed by the USGS. The well was installed by a previous land owner before 1993 and once contained a pump powered by a windmill for watering livestock.

⁶Property was owned by Metro Wastewater Reclamation District in 1993 and 1994, then transferred to a private land owner in 1995.

⁷Accuracy of depth measurement in question because well seemed to have an object immersed in the well from before October 1995.

⁸Well had continuous-recorder instrumentation for water-level, water-temperature, and precipitation data from 1994 through 1998.

Appendix 2. Chemical symbols and abbreviations used in reporting chemical data in the appendixes.

Symbol or abbreviation	Spelled-out form	Symbol or abbreviation	Spelled-out form
--	No data	Metro District	Metro Wastewater Reclamation District
(CaCO ₃)	As calcium carbonate	Mg	Magnesium
+	Plus	mg/L	Milligrams per liter
<	Less than	Mn	Manganese
>	Greater than (not fully quantified)	Mo	Molybdenum
µg/L	Micrograms per liter	MRL	Minimum reporting level, which varied based on dilution factor
µS/cm	Microsiemens per centimeter at 25 degrees Celsius	Na	Sodium
Ag	Silver	NH ₃ +Org N-N	Ammonia plus organic nitrogen as nitrogen
Al	Aluminum	NH ₃ -N	Ammonia as nitrogen
Alk	Alkalinity, as calcium carbonate, measured on a filtered sample	Ni	Nickel
ANC	Acid-neutralizing capacity, as calcium carbonate, measured on an unfiltered sample	NO ₂ +NO ₃ -N	Nitrite plus nitrate as nitrogen
As	Arsenic	NO ₂ -N	Nitrite as nitrogen in filtered sample
B	Boron	NO ₃ -N	Nitrate as nitrogen in filtered sample
Ba	Barium	°C	Degrees Celsius
Be	Beryllium	P	Phosphorus
Br	Bromide	Pb	Lead
C	Carbon	pH	pH measured in standard units
Ca	Calcium	PO ₄ -P	Orthophosphate as phosphorus
Calc	Calculated, such as from the sum of constituents	Rep	Replicate sample, usually a duplicate
Cd	Cadmium	ROE	Residue on evaporation at 180 degrees Celsius
Cl	Chloride	S	Sulfur
Co	Cobalt	Sb	Antimony
Cr	Chromium	SC	Specific conductance
Cu	Copper	Se	Selenium
diss	Dissolved (sample filtered at 0.45 micron)	Seq	Sequential
DO	Dissolved oxygen	Si	Silica
e	Estimated by laboratory	SiO ₂	Silica as silicon dioxide (SiO ₂)
F	Fluoride	SO ₄	Sulfate
Fe	Iron	Sr	Strontium
field	Measured in the field, not in the laboratory	Std	Standard
Hard	Hardness	TDS	Dissolved solids
Hg	Mercury	Tl	Thallium
K	Potassium	tot	Total (unfiltered sample)
lab	Measured in the laboratory, not in the field	U	Uranium, natural
Li	Lithium	USGS	U.S. Geological Survey
		V	Vanadium
		Zn	Zinc

Appendix 3. Physical properties and major-ion data for replicate water-quality samples collected near Deer Trail, Colorado, 1993 through 1998.

[All abbreviations listed in appendix 2; data from filtered samples except ANC, pH, and SC data; $\mu\text{S/cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; Rep, replicate; $\mu\text{g/L}$, micrograms per liter; Metro District, Metro Wastewater Reclamation District; --, no data; Seq, sequential; C1, first composite; C2, second composite; <, less than]

Sample date	Sample site	Sample type	Sample sub-type	Analyzing laboratory	ANC, lab, mg/L	Alk, lab, mg/L	Hard (CaCO ₃), mg/L	pH, lab	SC, lab, $\mu\text{S/cm}$	TDS (ROE), mg/L	Ca, mg/L	Cl, mg/L	F, mg/L	K, mg/L	Mg, mg/L	Na, mg/L	SiO ₂ , mg/L	SO ₄ , mg/L
7/20/1994	D22	Rep	None	Metro District	--	573	5,120	--	--	11,400	371	55	--	17.6	1,250	1,530	--	7,680
7/21/1994	D14	Rep	None	Metro District	--	139	350	--	--	457	107	4	--	1.9	19	31	--	159
9/30/1994	D23	Rep	None	Metro District	--	371	1,880	--	--	2,870	512	11	--	4.4	104	184	--	1,680
10/3/1994	D10	Rep	Seq	Metro District	--	357	2,920	--	--	--	518	28	--	19.5	440	313	--	3,330
10/3/1994	D10	Rep	Seq	USGS	--	--	2,900	7.2	4,760	4,980	490	24	0.60	--	400	270	24	3,100
7/12/1995	D7	Rep	None	Metro District	--	184	1,320	--	--	2,030	348	18	--	3.0	116	60	--	1,240
7/12/1995	D25	Rep	None	Metro District	--	298	2,160	--	--	3,460	581	95	--	6.0	165	157	--	2,050
9/20/1995	D31	Rep	None	Metro District	--	533	5,500	--	--	9,430	396	100	--	6.0	1,020	747	--	5,700
9/26/1995	D20	Rep	None	Metro District	--	261	1,920	--	--	2,808	428	7	--	8.0	155	148	--	1,720
12/14/1995	D15	Split	C1	Metro District	--	527	2,810	--	--	4,860	502	19	--	5.0	318	503	--	2,990
12/14/1995	D15	Split	C2	Metro District	--	526	2,540	--	--	4,890	425	19	--	3.0	316	487	--	2,760
12/14/1995	D15	Split	C2	USGS	--	--	2,400	6.9	4,980	5,060	470	17	2.0	--	300	450	17	2,900
12/14/1995	D3	Split	C1	Metro District	--	110	1,630	--	--	2,320	460	28	--	4.0	104	50	--	1,360
12/14/1995	D3	Split	C2	Metro District	--	112	1,440	--	--	2,250	434	28	--	4.0	106	54	--	1,340
12/14/1995	D3	Split	C2	USGS	--	--	1,400	7.3	2,390	2,260	400	28	1.3	--	100	62	30	1,400
3/8/1996	D5	Split	C1	Metro District	--	246	2,480	--	--	4,210	512	39	--	4.0	268	229	--	2,800
3/8/1996	D5	Split	C2	Metro District	--	218	2,500	--	--	4,220	518	40	--	4.0	300	227	--	2,720
3/8/1996	D5	Split	C2	USGS	--	--	2,400	7.3	4,150	4,090	480	30	0.50	--	300	240	20	2,600
6/14/1996	D9	Split	C1	Metro District	--	252	1,500	--	--	2,190	418	14	--	<0.1	102	37	--	1,260
6/14/1996	D9	Split	C2	Metro District	--	254	1,460	--	--	2,220	420	14	--	<0.1	102	37	--	1,240
6/14/1996	D9	Split	C2	USGS	--	--	1,600	7.3	2,340	2,240	450	9.1	1.1	--	110	45	25	1,200
8/22/1996	D17	Split	C2	Metro District	--	236	264	--	--	292	57	3	--	2.0	25	10	--	40
8/22/1996	D17	Split	C2	USGS	235	--	230	7.7	515	295	55	2.0	1.8	--	22	15	20	39
8/22/1996	D17	Split	C1	Metro District	--	232	278	--	--	302	57	3	--	2.0	26	10	--	38
11/8/1996	D25	Split	C1	Metro District	--	598	3,880	--	--	5,660	836	151	--	7.0	340	336	--	2,640
11/8/1996	D25	Split	C2	Metro District	--	591	4,000	--	--	5,680	884	151	--	7.0	348	330	--	2,960
11/8/1996	D25	Split	C2	USGS	596	--	3,300	7.2	5,480	5,580	740	160	1.3	--	340	350	35	3,000
2/26/1997	D15	Split	C1	Metro District	--	541	2,580	--	--	4,990	514	20	--	4.0	359	590	--	3,340
2/26/1997	D15	Split	C2	Metro District	--	547	2,680	--	--	5,050	474	<1	--	<0.1	334	550	--	3,150
2/26/1997	D15	Split	C2	USGS	551	--	2,400	6.9	5,010	4,790	450	46	1.8	--	310	500	15	3,100
2/26/1997	D23	Rep	None	Metro District	--	365	1,870	--	--	2,890	538	9	--	6.0	116	185	--	1,950
6/3/1997	D2	Rep	None	Metro District	--	270	3,420	--	--	4,740	482	17	--	<0.1	415	206	--	2,880
6/5/1997	D10	Split	C1	USGS	387	--	2,700	7.4	4,570	4,630	440	19	0.6	--	380	270	21	2,900
6/5/1997	D10	Split	C2	Metro District	--	404	4,210	--	--	4,790	448	20	--	15.0	393	294	--	2,680
6/5/1997	D10	Split	C2	Metro District	--	392	3,510	--	--	4,760	447	20	--	14.0	388	288	--	3,060

Appendix 3. Physical properties and major-ion data for replicate water-quality samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All abbreviations listed in appendix 2; data from filtered samples except ANC, pH, and SC data; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; mg/L, milligrams per liter; Rep, replicate; $\mu\text{g}/\text{L}$, micrograms per liter; Metro District, Metro Wastewater Reclamation District; --, no data; Seq, sequential; C1, first composite; C2, second composite; <, less than]

Sample date	Sample site	Sample type	Sample sub-type	Analyzing laboratory	ANC, lab, mg/L	Alk, lab, mg/L	Hard (CaCO ₃), mg/L	pH, lab	SC, lab, $\mu\text{S}/\text{cm}$	TDS (ROE), mg/L	Ca, mg/L	Cl, mg/L	F, mg/L	K, mg/L	Mg, mg/L	Na, mg/L	SiO ₂ , mg/L	SO ₄ , mg/L
8/27/1997	D25	Split	C2	Metro District	--	310	2,290	--	--	3,810	612	111	--	3.0	159	168	--	2,210
8/27/1997	D25	Split	C2	USGS	310	--	2,200	7.3	3,720	3,850	610	100	1	--	160	180	25	2,100
8/27/1997	D25	Split	C1	Metro District	--	321	2,300	--	--	3,820	610	110	--	<0.1	164	187	--	1,810
8/27/1997	D31	Rep	None	Metro District	--	559	4,960	--	--	8,780	424	87	--	<0.1	887	768	--	6,030
11/17/1997	D9	Rep	None	Metro District	--	227	1,660	--	--	2,900	464	12	--	4.0	143	58	--	1,590
11/19/1997	D25	Split	C1	Metro District	--	493	2,480	--	--	4,620	707	126	--	11.0	245	294	--	2,500
11/19/1997	D25	Split	C2	Metro District	--	505	2,540	--	--	4,640	798	127	--	11.0	260	318	--	2,730
11/19/1997	D25	Split	C2	USGS	502	--	2,700	7.3	4,590	4,710	700	120	1.1	--	230	280	28	2,500
1/6/1998	D9	Rep	None	Metro District	--	207	1,450	--	--	2,830	500	7	--	3.0	157	71	--	1,720
1/8/1998	D25	Split	C1	Metro District	--	478	2,760	--	--	4,550	690	116	--	<0.1	248	280	--	2,490
1/8/1998	D25	Split	C2	Metro District	--	474	2,730	--	--	4,590	699	119	--	<0.1	259	296	--	2,530
1/8/1998	D25	Split	C2	USGS	510	--	2,600	7.3	4,540	4,520	660	120	1.2	--	220	270	29	2,500
4/15/1998	D9	Rep	None	Metro District	--	226	1,800	--	--	2,890	539	7	--	<0.1	143	55	--	1,740
4/16/1998	D25	Split	C1	Metro District	--	471	2,700	--	--	4,510	820	120	--	3.0	262	300	--	2,810
4/16/1998	D25	Split	C2	Metro District	--	472	2,900	--	--	4,570	752	119	--	<0.1	246	288	--	2,500
4/16/1998	D25	Split	C2	USGS	494	--	2,500	7.3	4,550	4,530	630	110	1	--	230	280	27	2,400
7/15/1998	D30	Rep	None	Metro District	--	359	2,770	--	--	4,960	487	51	--	4.0	457	372	--	3,030
7/16/1998	D25	Split	C1	Metro District	--	366	1,980	--	--	4,160	697	109	--	<0.1	179	209	--	2,310
7/16/1998	D25	Split	C2	Metro District	--	390	2,280	--	--	4,250	719	109	--	<0.1	194	227	--	2,320
7/16/1998	D25	Split	C2	USGS	368	--	2,200	7.5	3,940	4,010	560	110	1	--	180	210	25	2,200

Appendix 4. Nutrient data for replicate water-quality samples collected near Deer Trail, Colorado, 1993 through 1998.

[All data from filtered samples unless otherwise noted; mg/L, milligrams per liter; Rep, replicate; Metro District, Metro Wastewater Reclamation District; --, no data; <, less than; Seq, sequential; C1, first composite; C2, second composite; FCA, filtered chilled acidified sample; WCA, whole-water chilled acidified sample; FCC, filtered chilled unacidified sample; other abbreviations listed in appendix 2]

Sample date	Sample site	Sample type	Sample subtype	Analyzing laboratory	NH ₃ + Org N-N, diss, mg/L	NH ₃ + Org N-N, tot, mg/L	NH ₃ -N, mg/L	NO ₂ -N, mg/L	NO ₂ + NO ₃ -N, mg/L	P, diss, mg/L	P, tot, mg/L	PO ₄ -P, mg/L
7/20/1994	D22	Rep	None	Metro District	1.2	--	<0.1	0.03	0.71	--	--	<0.02
7/21/1994	D14	Rep	None	Metro District	0.5	--	<0.1	0.04	3.78	--	--	<0.02
9/30/1994	D23	Rep	None	Metro District	1.6	--	0.9	<0.02	<0.02	--	--	0.04
10/3/1994	D10	Rep	Seq	Metro District	0.3	--	<0.1	<0.02	0.69	--	--	0.17
10/3/1994	D10	Rep	Seq	USGS	0.20	--	0.020	<0.010	0.65	0.13	--	0.15
7/12/1995	D7	Rep	None	Metro District	<0.3	--	0.1	<0.02	1.43	--	--	0.07
7/12/1995	D25	Rep	None	Metro District	0.8	--	0.1	<0.02	2.47	--	--	0.10
9/20/1995	D31	Rep	None	Metro District	0.3	--	<0.1	0.03	1.52	--	--	0.04
9/26/1995	D20	Rep	None	Metro District	<0.3	--	<0.1	<0.02	<0.02	--	--	0.21
12/14/1995	D15	Split	C1	Metro District	1.9	--	0.6	<0.02	<0.02	--	--	0.05
12/14/1995	D15	Split	C2	Metro District	1.4	--	0.6	<0.02	<0.02	--	--	<0.02
12/14/1995	D15	Split	C2	USGS	1.4	--	0.960	<0.010	<0.05	0.02	--	0.02
12/14/1995	D3	Split	C1	Metro District	<0.3	--	<0.1	<0.02	2.76	--	--	0.04
12/14/1995	D3	Split	C2	Metro District	<0.3	--	<0.1	<0.02	3.67	--	--	<0.02
12/14/1995	D3	Split	C2	USGS	<0.20	--	0.080	<0.010	3.70	0.04	--	0.02
3/8/1996	D5	Split	C1	Metro District	<0.3	--	<0.1	<0.02	6.22	--	--	0.03
3/8/1996	D5	Split	C2	Metro District	0.6	--	<0.1	<0.02	6.24	--	--	<0.02
3/8/1996	D5	Split	C2	USGS	<0.20	--	0.120	<0.010	6.00	<0.01	--	0.02
6/14/1996	D9	Split	C1	Metro District	0.5	--	<0.1	<0.02	12.9	--	--	0.06
6/14/1996	D9	Split	C2	Metro District	0.5	--	<0.1	0.02	12.8	--	--	0.06
6/14/1996	D9	Split	C2	USGS	0.40	--	0.060	<0.010	14.0	0.08	--	0.06
8/22/1996	D17	Split	C2	Metro District	0.5	--	<0.1	<0.02	0.50	--	--	0.08
8/22/1996	D17	Split	C2	USGS	<0.20	--	<0.015	0.010	0.53	0.06	--	0.09
8/22/1996	D17	Split	C1	Metro District	0.4	--	<0.1	<0.02	0.48	--	--	0.08
11/8/1996	D25	Split	C1	Metro District	1.4	--	<0.1	0.02	30.9	--	--	0.21
11/8/1996	D25	Split	C2	Metro District	1.4	--	<0.1	0.02	29.9	--	--	0.19
11/8/1996	D25	Split	C2	USGS	1.7	--	0.300	0.040	34.0	0.19	--	0.02

Appendix 4. Nutrient data for replicate water-quality samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data from filtered samples unless otherwise noted; mg/L, milligrams per liter; Rep, replicate; Metro District, Metro Wastewater Reclamation District; --, no data; <, less than; Seq, sequential; C1, first composite; C2, second composite; FCA, filtered chilled acidified sample; WCA, whole-water chilled acidified sample; FCC, filtered chilled unacidified sample; other abbreviations listed in appendix 2]

Sample date	Sample site	Sample type	Sample subtype	Analyzing laboratory	NH ₃ + Org N-N, diss, mg/L	NH ₃ + Org N-N, tot, mg/L	NH ₃ -N, mg/L	NO ₂ -N, mg/L	NO ₂ + NO ₃ -N, mg/L	P, diss, mg/L	P, tot, mg/L	PO ₄ -P, mg/L
2/26/1997	D15	Split	C1	Metro District	1.2	--	0.4	0.02	<0.02	--	--	0.05
2/26/1997	D15	Split	C2	Metro District	1.2	--	<0.1	<0.02	<0.02	--	--	0.03
2/26/1997	D15	Split	C2	USGS	1.3	--	0.890	<0.010	<0.05	<0.010	--	0.010
2/26/1997	D23	Rep	None	Metro District	1.1	--	0.7	0.02	<0.02	--	--	0.05
6/3/1997	D2	Rep	None	Metro District	<0.3	--	<0.1	<0.02	0.30	--	--	0.04
6/5/1997	D10	Split	C1	USGS	<0.20	--	0.015	<0.010	3.60	0.14	--	0.16
6/5/1997	D10	Split	C2	Metro District	<0.3	--	<0.1	<0.02	3.67	--	--	0.17
6/5/1997	D10	Split	C2	Metro District	0.4	--	<0.1	<0.02	3.68	--	--	0.16
8/27/1997	D25	Split	C2	Metro District	0.6	--	<0.1	<0.02	0.40	--	--	0.08
8/27/1997	D25	Split	C2	USGS	0.42	--	0.110	0.014	0.31	0.081	--	0.099
8/27/1997	D25	Split	C1	Metro District	0.6	--	<0.1	<0.02	0.28	--	--	0.07
8/27/1997	D31	Rep	None	Metro District	0.8	--	<0.1	<0.02	0.08	--	--	<0.02
11/17/1997	D9	Rep	None	Metro District	<0.3	--	<0.1	<0.02	20.0	--	--	0.08
11/19/1997	D25	Split	C1	Metro District	1.2	--	<0.1	<0.02	11.8	--	--	0.12
11/19/1997	D25	Split	C2	Metro District	1.2	--	<0.1	<0.02	10.5	--	--	0.12
11/19/1997	D25	Split	C2	USGS	1.1	--	0.100	0.015	13.0	0.12	--	0.17
1/6/1998	D9	Rep	None	Metro District	<0.3	--	<0.1	<0.02	21.4	--	--	0.05
1/8/1998	D25	Split	C1	Metro District	1.1	--	<0.1	<0.02	12.1	--	--	0.12
1/8/1998	D25	Split	C2	Metro District	1.0	--	<0.1	<0.02	12.5	--	--	0.12
1/8/1998	D25	Split	C2	USGS	1.0	--	0.064	0.011	13.0	0.096	--	0.15
4/15/1998	D9	Rep	None	Metro District	0.5	--	<0.1	<0.02	24.2	--	--	<0.02
4/16/1998	D25	Split	C1	Metro District	0.9	--	<0.1	<0.02	12.1	--	--	0.11
4/16/1998	D25	Split	C2	Metro District	1.1	--	<0.1	<0.02	12.3	--	--	0.11
4/16/1998	D25	Split	C2 FCA, WCA	USGS	1.3	1.2	0.160	0.013	13.0	0.16	0.15	0.16
4/16/1998	D25	Split	C2 FCC	USGS	1.1	--	0.065	--	13.0	0.15	--	--
7/15/1998	D30	Rep	None	Metro District	0.7	--	<0.1	<0.02	<0.02	--	--	0.04
7/16/1998	D25	Split	C1	Metro District	1.0	--	<0.1	<0.02	3.42	--	--	0.12
7/16/1998	D25	Split	C2	Metro District	1.0	--	<0.1	<0.02	3.80	--	--	0.09
7/16/1998	D25	Split	C2 FCA, WCA	USGS	0.62	0.60	0.066	0.016	3.70	0.13	0.12	0.11
7/16/1998	D25	Split	C2 FCC	USGS	0.60	--	0.068	--	3.70	0.081	--	--

Appendix 5. Trace-element data for replicate water-quality samples collected near Deer Trail, Colorado, 1993 through 1998.

[All data from filtered samples; µg/L, micrograms per liter; Rep, replicate; Metro District, Metro Wastewater Reclamation District; --, no data; <, less than; Seq, sequential; C1, first composite; C2, second composite; other abbreviations listed in appendix 2]

Sample date	Sample site	Sample type	Sample sub-type	Analyzing laboratory	Ag, µg/L	Ba, µg/L	Be, µg/L	Cd, µg/L	Cr, µg/L	Co, µg/L	Cu, µg/L	Fe, µg/L	Li, µg/L	Mn, µg/L	Mo, µg/L	Ni, µg/L	Pb, µg/L	V, µg/L	Zn, µg/L
7/20/1994	D22	Rep	None	Metro District	--	--	--	<0.2	180	--	<40	<100	--	1,220	--	<40	<10	--	<40
7/21/1994	D14	Rep	None	Metro District	--	--	--	<0.2	20	--	<100	<250	--	250	--	<100	<10	--	<100
9/30/1994	D23	Rep	None	Metro District	--	--	--	<0.2	<20	--	<20	990	--	16,050	--	<20	<10	--	<20
10/3/1994	D10	Rep	Seq	Metro District	--	--	--	0.1	<100	--	<100	<250	--	<100	--	<100	<10	--	<100
10/3/1994	D10	Rep	Seq	USGS	<4	14	<2	<4	<20	<12	<40	<12	220	<4	<40	<40	<40	<24	<12
7/12/1995	D7	Rep	None	Metro District	--	--	--	0.1	<20	--	<20	<50	--	550	--	<20	<10	--	<20
7/12/1995	D25	Rep	None	Metro District	--	--	--	0.1	<20	--	<20	<50	--	2,300	--	<20	<10	--	<20
9/20/1995	D31	Rep	None	Metro District	--	--	--	<0.2	<100	--	<100	<250	--	420	--	<100	<10	--	<100
9/26/1995	D20	Rep	None	Metro District	--	--	--	0.1	<20	--	<20	<50	--	250	--	<20	<10	--	<20
12/14/1995	D15	Split	C1	Metro District	--	--	--	0.1	<20	--	<20	1,840	--	7,810	--	20	<10	--	<20
12/14/1995	D15	Split	C2	Metro District	--	--	--	<0.2	<20	--	<20	1,810	--	7,940	--	30	<10	--	<20
12/14/1995	D15	Split	C2	USGS	<3	13	<2	6.0	<20	<9	<30	2,000	140	7,400	30	30	<30	<18	16
12/14/1995	D3	Split	C1	Metro District	--	--	--	0.1	<20	--	<20	<50	--	550	--	40	<10	--	<20
12/14/1995	D3	Split	C2	Metro District	--	--	--	0.1	<20	--	<20	<50	--	280	--	20	<10	--	<20
12/14/1995	D3	Split	C2	USGS	3	11	<2	6.0	<15	<9	<30	<9	150	300	40	40	<30	<18	<9
3/8/1996	D5	Split	C1	Metro District	--	--	--	<0.2	<40	--	<40	<100	--	<40	--	<40	<10	--	<40
3/8/1996	D5	Split	C2	Metro District	--	--	--	<0.2	<40	--	<40	<100	--	<40	--	<40	<10	--	<40
3/8/1996	D5	Split	C2	USGS	<3	9	<2	<3.0	<20	<9	<30	26	160	3	<30	<30	110	<18	<9
6/14/1996	D9	Split	C1	Metro District	--	--	--	0.1	<20	--	<20	<50	--	<20	--	<20	<10	--	<20
6/14/1996	D9	Split	C2	Metro District	--	--	--	<0.2	<20	--	<20	230	--	<20	--	<20	<10	--	<20
6/14/1996	D9	Split	C2	USGS	<3	14	<2	4.0	<20	<9	<30	<120	85	<6	<30	<30	50	<18	<9
8/22/1996	D17	Split	C2	Metro District	--	--	--	<0.2	<20	--	<20	<50	--	220	--	<20	<10	--	<20
8/22/1996	D17	Split	C2	USGS	2	57	<0.5	<1.0	<5	<3	<10	<3	29	210	<10	10	20	<6	12
8/22/1996	D17	Split	C1	Metro District	--	--	--	<0.2	<20	--	<20	<50	--	200	--	<20	<10	--	<20
11/8/1996	D25	Split	C1	Metro District	--	--	--	0.2	<20	--	<20	<50	--	1,340	--	<20	<10	--	<20
11/8/1996	D25	Split	C2	Metro District	--	--	--	0.3	<20	--	<20	<50	--	1,520	--	<20	<10	--	<20
11/8/1996	D25	Split	C2	USGS	<4	21	<2	<4	<20	<10	<40	<12	120	1,600	<40	<40	<40	<24	23

Appendix 5. Trace-element data for replicate water-quality samples collected near Deer Trail, Colorado, 1993 through 1998.—Continued

[All data from filtered samples; µg/L, micrograms per liter; Rep, replicate; Metro District, Metro Wastewater Reclamation District; --, no data; <, less than; Seq, sequential; C1, first composite; C2, second composite; other abbreviations listed in appendix 2]

Sample date	Sample site	Sample type	Sample sub-type	Analyzing laboratory	Ag, µg/L	Ba, µg/L	Be, µg/L	Cd, µg/L	Cr, µg/L	Co, µg/L	Cu, µg/L	Fe, µg/L	Li, µg/L	Mn, µg/L	Mo, µg/L	Ni, µg/L	Pb, µg/L	V, µg/L	Zn, µg/L
2/26/1997	D15	Split	C1	Metro District	--	--	--	0.1	<20	--	<20	1,440	--	7,700	--	<20	<10	--	<20
2/26/1997	D15	Split	C2	Metro District	--	--	--	0.1	<20	--	<20	1,340	--	7,880	--	<20	<10	--	<20
2/26/1997	D15	Split	C2	USGS	<3	13	<2	<3	<20	10	<30	1,400	140	7,200	<30	<30	<30	<18	<9
2/26/1997	D23	Rep	None	Metro District	--	--	--	<0.2	<20	--	<20	1,640	--	15,700	--	<20	<10	--	<20
6/3/1997	D2	Rep	None	Metro District	--	--	--	<0.2	90	--	<60	<150	--	<60	--	30	<10	--	50
6/5/1997	D10	Split	C1	USGS	<4	9	<2	<4	<20	<12	<40	<12	180	<4	<40	<40	<40	<24	<12
6/5/1997	D10	Split	C2	Metro District	--	--	--	0.1	110	--	50	<150	--	<60	--	<60	<10	--	50
6/5/1997	D10	Split	C2	Metro District	--	--	--	0.1	110	--	70	<150	--	<60	--	100	<10	--	20
8/27/1997	D25	Split	C2	Metro District	--	--	--	0.2	60	--	<40	<100	--	2,380	--	<40	<10	--	<40
8/27/1997	D25	Split	C2	USGS	<3	15	<1.5	<3	<15	<9	<30	<9	73	2,300	<30	<30	50	<18	<9
8/27/1997	D25	Split	C1	Metro District	--	--	--	0.2	40	--	<40	<100	--	2,380	--	<40	<10	--	<40
8/27/1997	D31	Rep	None	Metro District	--	--	--	<0.2	340	--	<100	<250	--	200	--	<100	<10	--	<100
11/17/1997	D9	Rep	None	Metro District	--	--	--	<0.2	<20	--	<20	<50	--	<20	--	20	<10	--	<20
11/19/1997	D25	Split	C1	Metro District	--	--	--	0.1	<20	--	<20	<50	--	2,840	--	<20	<10	--	<20
11/19/1997	D25	Split	C2	Metro District	--	--	--	0.1	<20	--	<20	<50	--	2,900	--	<20	<10	--	<20
11/19/1997	D25	Split	C2	USGS	<4	21	<2	<4	<20	<12	<40	<12	100	2,700	<40	<40	<40	<24	<12
1/6/1998	D9	Rep	None	Metro District	--	--	--	<0.2	<20	--	<20	<50	--	<20	--	<20	<10	--	<20
1/8/1998	D25	Split	C1	Metro District	--	--	--	0.2	<20	--	<20	<50	--	2,290	--	<20	<10	--	<20
1/8/1998	D25	Split	C2	Metro District	--	--	--	0.3	<20	--	<20	<50	--	2,330	--	<20	<10	--	<20
1/8/1998	D25	Split	C2	USGS	<12	18	<3	<24	<42	<36	<30	<30	99	2,100	<180	<120	<300	<30	<60
4/15/1998	D9	Rep	None	Metro District	--	--	--	0.1	<40	--	<40	<100	--	<40	--	<40	<10	--	<40
4/16/1998	D25	Split	C1	Metro District	--	--	--	0.2	<40	--	<40	<100	--	2,190	--	<40	<10	--	<40
4/16/1998	D25	Split	C2	Metro District	--	--	--	0.2	<40	--	<40	<100	--	2,240	--	<40	<10	--	<40
4/16/1998	D25	Split	C2	USGS	<12	17	<3	<24	<42	<36	<30	<30	99	2,300	--	<120	<300	<30	--
7/15/1998	D30	Rep	None	Metro District	--	--	--	<0.2	80	--	<40	290	--	250	--	<40	<10	--	<40
7/16/1998	D25	Split	C1	Metro District	--	--	--	0.2	60	--	<40	<100	--	2,520	--	<40	<10	--	<40
7/16/1998	D25	Split	C2	Metro District	--	--	--	0.2	80	--	<40	<100	--	2,300	--	<40	<10	--	<40
7/16/1998	D25	Split	C2	USGS	<12	16	<3	<24	<42	<36	<30	<30	86	2,300	<180	<120	<300	<30	<60

Appendix 6. Codes used in reporting information and chemical data (appendix 7) for blank water-quality samples collected near Deer Trail, Colorado, 1993 through 1999.

[USGS, U.S. Geological Survey]

Sampling type	
2	Groundwater inorganic-sampling blank
3	Pore water (unsaturated zone) inorganic-sampling blank
Type of blank	
FB	Field blank
EB	Equipment blank
Sub-type	
A	Acids only
F	All field plus lab conditions, including equipment
E	All equipment or specific equipment
Site	
CD	USGS laboratory in Denver, Colorado
L	Lowry former sewage-sludge disposal site near Denver, Colorado
D#	Deer Trail project well site
Ambient condition	
D	Dusty
R	Road dust and exhaust
B	Biosolids recently applied
P	Pesticides recently applied
W	Windy
N	Unremarked
C	Cattle nearby
L	Normal laboratory
Sample matrix	
DI	Deionized water from USGS water systems in Denver
TAP	Municipal tap water
IBW	Certified Inorganic Blank Water from USGS laboratory in Ocala, Florida
ST	Sterile buffered water (for bacteria-sample blanks)
Matrix source	
C	Plastic carboy, reused each trip
J	Plastic 1-gallon jug from Ocala laboratory, used one time only
L	USGS laboratory spigot
BJ	Blue plastic 5-gallon jug, reused each trip
U	Undocumented USGS deionized-water source
Filter	
P	0.45 micron cellulose nitrate disposable filter in reused plate stand
C	0.45 micron cellulose nitrate disposable filter factory-sealed in plastic capsule
N	None used
U	Not documented
D	0.45 micron nylon-disc filter for syringe
Pump	
G1	Submersible pump (Grundfos) attached to polyethylene hose, used 1993–1996
GP	Assorted project-owned peristaltic pumps (Geopump)
G2	Submersible pump (Grundfos) attached to teflon-lined polyethylene hose, used 1996–1998
G3	Submersible pump (Grundfos) with independent, quick-connected polyethylene hose sections, used 1998–2001
G4	Submersible pump (Grundfos) attached to teflon-lined polyethylene hose, used 1998–1999
G5	USGS Arsenal project's submersible pump (Grundfos) attached to polyethylene hose, used January 1998, only
G6	Submersible pump (Grundfos) attached to teflon-lined polyethylene hose, used 1999–2003
B1	Polyvinyl chloride (PVC) bailer, 4 feet long, with rusty metal fasteners and old, reused nylon rope
B2	Disposable polyethylene bailer with nylon rope and clean stainless-steel fastener
B3	Brass bailer tied to old polyester-cotton rope, used for bacteria sampling only
B4	Autoclaved, polyethylene disposable bailer, clean stainless-steel fastener, and teflon-coated cable
N	None used
U	Not documented

Appendix 6. Codes used in reporting information and chemical data (appendix 7) for blank water-quality samples collected near Deer Trail, Colorado, 1993 through 1999.—Continued

[USGS, U.S. Geological Survey]

Tubing	
A	Dedicated to unique site or use
B	Reused, cleaned between sites with deionized water only
U	Not documented
C	Reused, cleaned between sites with 5-percent hydrochloric acid
D	Disposed of after each use
E	Reused, cleaned between sites with laboratory-grade nonphosphate detergent and deionized water
F	New
N	None used
Sampling (team) equipment	
0	No “parts per billion” preparation, equipment, or packing
1	Team 1 “parts per billion” preparation, equipment, and packing
2	Team 2 “parts per billion” preparation, equipment, and packing
Sample method	
K	USGS Western Region Field Manual
B	Bailed into a rinsed pail when pump malfunctioned
PPB	USGS “Parts per Billion” method (Horowitz and others, 1994; U.S. Geological Survey, variously dated)
S	Source transfer, not a regular sampling method
F	Other USGS project sampling method (not PPB)
J	Pore-water method (Tindall and Vencill, 1995, p. 47)
Analyzing lab	
Metro District	Metro Wastewater Reclamation District Laboratory in Denver, Colorado
NWQL	USGS National Water Quality Laboratory in Denver, Colorado

Appendix 7. Information and chemical data for blank water-quality samples collected near Deer Trail, Colorado, 1993 through 1999.

[Codes are explained in appendix 6; other abbreviations are listed in appendix 2; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; all data from filtered samples unless otherwise indicated; <, less than; --, no data]

Sampling type	Blank number	Sample date	Type of blank	Sample sub-type	Sample site	Ambient condition	Sample matrix	Matrix source	Filter	Pump	Tubing	Sampling (team) equipment	Sample method	Analyzing laboratory	Alk, lab, mg/L	Hard (CaCO ₃), mg/L	pH, lab	SC, lab, µS/cm
2	1	7/20/1994	FB	F	D9	R	DI	BJ	P	G1	U	0	K	Metro District	2	<10	--	--
2	2	10/3/1994	FB	F	D5	B	DI	BJ	N	N	N	0	K	Metro District	0	<10	--	--
2	3	10/3/1994	FB	F	D5	B	DI	BJ	P	GP	E	0	K	Metro District	0	<10	--	--
2	4	10/4/1994	FB	E	D2	W	DI	BJ	N	N	N	0	K	Metro District	0	<10	--	--
2	5	10/4/1994	FB	E	D2	W	TAP	BJ	N	N	N	0	K	Metro District	62	114	--	--
2	6	7/12/1995	FB	F	D25	R	DI	BJ	U	U	U	0	K	Metro District	0	<10	--	--
2	7	9/27/1995	FB	F	D2	W	DI	C	P	GP	E	0	K	Metro District	0	<10	--	--
2	8	9/28/1995	FB	F	D9	R	DI	C	N	B1	N	0	B	Metro District	0	<10	--	--
2	9	12/14/1995	FB	F	D16	W	IBW	J	C	GP	A	1	PPB	Metro District	0	<10	--	--
2	10	12/15/1995	EB	E	CD	L	IBW	J	C	G1	E	2	PPB	Metro District	0	<10	--	--
2	11	3/8/1996	FB	F	D33	W	IBW	J	C	GP	A	2	F	Metro District	8	<10	--	--
2	12	3/11/1996	EB	E	CD	L	IBW	J	C	G1	A	2	F	NWQL	--	0	--	--
2	13	6/10/1996	EB	E	CD	L	IBW	J	C	G2	F	2	F	NWQL	--	1	--	--
2	14	6/12/1996	FB	F	D2	N	IBW	J	C	GP	F	2	F	Metro District	5	<10	--	--
2	15	6/14/1996	FB	F	D9	R	IBW	J	C	B2	F	1	B	Metro District	4	<10	--	--
2	16	6/14/1996	FB	A	D9	R	DI	C	N	N	N	1	S	Metro District	7	<10	--	--
2	17	8/21/1996	FB	F	D30	N	IBW	J	C	GP	A	2	F	Metro District	0	<10	--	--
2	18	8/22/1996	FB	F	D20	W	IBW	J	C	GP	A	1	PPB	Metro District	0	<10	--	--
2	19	8/23/1996	EB	E	CD	L	DI	C	N	N	A	1	S	NWQL	--	--	5.6	0.800
2	20	8/23/1996	EB	E	CD	L	IBW	J	N	N	N	1	S	NWQL	--	--	5.6	1
2	21	8/28/1996	FB	F	L	W	IBW	J	C	GP	C	1	PPB	Metro District	0	<10	--	--
2	22	8/29/1996	EB	E	CD	L	IBW	J	C	G2	A	2	F	NWQL	--	0	5.8	1
2	23	8/29/1996	EB	A	CD	L	IBW	J	N	N	N	2	PPB	NWQL	--	--	--	--
2	24	11/8/1996	FB	F	D25	R	IBW	J	C	GP	A	1	PPB	Metro District	0	<10	--	--
2	25	11/8/1996	FB	F	D5	W	IBW	J	C	GP	A	2	F	Metro District	0	<10	--	--
2	26	2/25/1997	FB	F	D30	N	IBW	J	C	GP	A	2	F	Metro District	0	<10	--	--
2	27	2/26/1997	FB	F	D15	W	IBW	J	C	GP	A	1	PPB	Metro District	0	<10	--	--
2	28	6/4/1997	FB	F	D17	W	IBW	J	C	GP	A	1	PPB	Metro District	8	<10	--	--
2	29	6/5/1997	EB	E	CD	L	IBW	J	C	G2	A	2	F	NWQL	--	0	6.1	1.2
2	30	8/27/1997	FB	F	D25	R	IBW	J	C	GP	A	1	PPB	Metro District	0	<10	--	--
2	31	8/26/1997	FB	F	D33	N	IBW	J	C	GP	A	2	F	Metro District	0	<10	--	--
2	32	8/29/1997	FB	F	L	N	IBW	J	C	GP	C	1	PPB	Metro District	0	<10	--	--
2	33	11/19/1997	FB	F	D2	W	IBW	J	C	GP	A	2	F	Metro District	0	<10	--	--
2	34	11/20/1997	FB	F	D15	N	IBW	J	C	GP	A	1	PPB	Metro District	0	<10	--	--
2	35	11/21/1997	EB	E	CD	L	IBW	J	C	G2	A	2	PPB	NWQL	--	0	5.5	1.5
2	36	12/4/1997	EB	E	CD	L	DI	C	C	GP	A	1	PPB	NWQL	--	--	5.7	1.5
2	37	1/8/1998	FB	F	D25	R	IBW	J	C	GP	A	1	PPB	Metro District	11	<10	--	--
2	38	1/8/1998	FB	F	D23	N	IBW	J	C	GP	A	2	PPB	Metro District	5	<10	--	--
2	39	1/15/1998	EB	E	CD	L	IBW	J	C	G5	A	2	PPB	NWQL	--	0	5.9	1.4
2	40	3/27/1998	EB	E	CD	L	DI	L	C	G4	F	2	PPB	NWQL	--	0	5.7	1.0
2	41	4/16/1998	FB	F	D25	R	IBW	J	C	GP	A	1	PPB	Metro District	0	<10	--	--
2	42	4/16/1998	FB	F	D23	N	IBW	J	C	GP	A	2	PPB	Metro District	0	<10	--	--
2	43	7/15/1998	FB	F	D5	W	IBW	J	C	GP	A	1	PPB	Metro District	0	<10	--	--
2	44	7/16/1998	FB	F	D6	W	IBW	J	C	GP	A	2	PPB	Metro District	0	<10	--	--
2	45	7/17/1998	EB	E	CD	L	DI	BJ	N	N	N	2	S	NWQL	--	--	5.65	1.6
2	46	7/21/1998	EB	E	CD	L	DI	C	N	N	A	1	S	NWQL	--	--	5.50	1.2
2	47	7/21/1998	EB	E	CD	L	DI	C	N	N	A	2	S	NWQL	--	--	5.58	1.2
2	48	7/13/1999	FB	F	D23	W	IBW	J	C	GP	A	1	PPB	NWQL	1.9	--	7.7	2
3	49	4/22/1994	EB	E	CD	N	DI	U	D	N	N	0	J	Metro District	--	--	--	--

Appendix 7. Information and chemical data for blank water-quality samples collected near Deer Trail, Colorado, 1993 through 1999.—Continued

[Codes are explained in appendix 6; other abbreviations are listed in appendix 2; mg/L, milligrams per liter; $\mu\text{S}/\text{cm}$, microsiemens per centimeter at 25 degrees Celsius; $\mu\text{g}/\text{L}$, micrograms per liter; all data from filtered samples unless otherwise indicated; <, less than; --, no data]

Sampling type	Blank number	Sample date	TDS (Calc), mg/L	TDS (ROE), mg/L	Br, mg/L	Ca, mg/L	Cl, mg/L	F, mg/L	K, mg/L	Mg, mg/L	Na, mg/L	SiO ₂ , mg/L	SO ₄ , mg/L	NH ₃ + Org N-N, diss, mg/L	NH ₃ + Org N-N, tot, mg/L
2	1	7/20/1994	--	<10	--	<5	<1	--	0.1	<5	<5	--	<3	0.3	--
2	2	10/3/1994	--	<10	--	<2	<1	--	<0.1	<2	<2	--	<3	<0.3	--
2	3	10/3/1994	--	<10	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	4	10/4/1994	--	53	--	<1	<1	--	0.2	<1	<1	--	<3	<0.3	--
2	5	10/4/1994	--	209	--	32	24	--	2.1	7	19	--	55	0.5	--
2	6	7/12/1995	--	<10	--	<1	<1	--	<0.1	<1	<1	--	7	<0.3	--
2	7	9/27/1995	--	<10	--	<1	<1	--	<0.1	<1	<1	--	10	<0.3	--
2	8	9/28/1995	--	<10	--	<1	<1	--	<0.1	<1	<1	--	9	<0.3	--
2	9	12/14/1995	--	<10	--	<1	<1	--	<0.1	<1	<1	--	4	<0.3	--
2	10	12/15/1995	--	<10	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	11	3/8/1996	--	<10	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	12	3/11/1996	--	--	--	0.05	--	--	--	0.008	<0.03	<0.02	--	--	--
2	13	6/10/1996	--	--	--	0.34	--	--	--	0.01	0.05	0.04	--	--	--
2	14	6/12/1996	--	<10	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	15	6/14/1996	--	<10	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	16	6/14/1996	--	<10	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	17	8/21/1996	--	<10	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	18	8/22/1996	--	<10	--	<1	<1	--	<0.1	<1	<1	--	4	<0.3	--
2	19	8/23/1996	--	--	<0.010	<0.002	<0.01	<0.01	--	<0.001	<0.03	<0.020	<0.01	--	--
2	20	8/23/1996	--	--	<0.010	<0.002	<0.01	<0.01	--	<0.001	<0.03	<0.020	<0.01	--	--
2	21	8/28/1996	--	<10	--	<1	<1	--	<0.1	<1	<1	--	4	0.7	--
2	22	8/29/1996	--	--	<0.010	0.04	<0.01	<0.01	--	0.004	<0.03	0.025	0.04	--	--
2	23	8/29/1996	--	--	--	<0.002	--	--	--	<0.001	<0.03	<0.020	--	--	--
2	24	11/8/1996	--	66	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	25	11/8/1996	--	36	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	26	2/25/1997	--	11	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	27	2/26/1997	--	37	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	28	6/4/1997	--	<10	--	<1	1	--	<0.1	<1	<1	--	<3	<0.3	--
2	29	6/5/1997	--	--	<0.01	0.076	<0.01	<0.01	--	0.009	<0.025	<0.020	<0.01	<0.20	--
2	30	8/27/1997	--	<10	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	31	8/26/1997	--	14	--	<1	<1	--	<0.1	<1	<1	--	4	<0.3	--
2	32	8/29/1997	--	3	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	33	11/19/1997	--	<10	--	<1	1	--	<0.1	1	1	--	<3	<0.3	--
2	34	11/20/1997	--	<10	--	<1	1	--	<0.1	<1	<1	--	<3	<0.3	--
2	35	11/21/1997	--	--	<0.01	0.047	0.02	<0.01	--	0.007	<0.025	0.047	0.03	<0.10	--
2	36	12/4/1997	--	--	<0.01	0.002	<0.01	<0.01	--	<0.001	<0.025	<0.020	<0.01	<0.10	--
2	37	1/8/1998	--	<10	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	38	1/8/1998	--	<10	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	39	1/15/1998	--	--	<0.01	0.044	0.02	<0.01	--	0.002	<0.025	<0.020	<0.01	<0.10	--
2	40	3/27/1998	--	--	<0.01	0.010	<0.01	<0.01	--	0.001	<0.025	<0.020	<0.01	<0.10	--
2	41	4/16/1998	--	63	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	42	4/16/1998	--	<10	--	<1	<1	--	<0.1	<1	<1	--	<3	<0.3	--
2	43	7/15/1998	--	<10	--	<1	<1	--	<0.1	<1	<1	--	<3	0.3	--
2	44	7/16/1998	--	<10	--	<1	<1	--	<0.1	<1	<1	--	<3	0.4	--
2	45	7/17/1998	--	--	<0.01	<0.002	0.39	0.02	--	<0.001	<0.025	<0.020	<0.1	<0.10	--
2	46	7/21/1998	--	--	<0.01	<0.002	<0.01	0.03	--	<0.001	<0.025	<0.020	3.3	<0.10	--
2	47	7/21/1998	--	--	<0.01	<0.002	0.26	0.03	--	<0.001	<0.025	<0.020	11	<0.10	--
2	48	7/13/1999	<10	<10	<0.01	00.01	<0.1	<0.1	<0.1	0.01	e0.04	<0.05	<0.1	<0.1	<0.1
3	49	4/22/1994	--	--	--	<1	<1	--	<1	<1	<1	--	<3	<0.3	--

Appendix 7. Information and chemical data for blank water-quality samples collected near Deer Trail, Colorado, 1993 through 1999.—Continued

[Codes are explained in appendix 6; other abbreviations are listed in appendix 2; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; all data from filtered samples unless otherwise indicated; <, less than; --, no data]

Sampling type	Blank number	Sampling date	NH ₃ -N, mg/L	NO ₂ -N, mg/L	NO ₂ +NO ₃ -N, mg/L	NO ₃ -N, mg/L	P, diss, mg/L	P, tot, mg/L	PO ₄ -P, mg/L	Ag, µg/L	Al, µg/L	B, µg/L	Ba, µg/L	Be, µg/L	Cd, µg/L	Co, µg/L
2	1	7/20/1994	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	2	10/3/1994	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	3	10/3/1994	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	4	10/4/1994	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	0.1	--
2	5	10/4/1994	<0.1	<0.02	0.12	--	--	--	<0.02	--	--	--	--	--	0.1	--
2	6	7/12/1995	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	7	9/27/1995	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	8	9/28/1995	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	9	12/14/1995	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	10	12/15/1995	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	11	3/8/1996	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	12	3/11/1996	<0.002	0.002	<0.005	--	--	--	0.001	<0.2	3.68	6.50	0.340	<0.2	<0.3	0.260
2	13	6/10/1996	<0.002	<0.001	<0.005	--	--	--	0.001	<0.2	0.580	5.63	0.580	<0.2	<0.3	<0.200
2	14	6/12/1996	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	15	6/14/1996	<0.1	<0.02	0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	16	6/14/1996	<0.1	<0.02	0.03	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	17	8/21/1996	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	18	8/22/1996	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	19	8/23/1996	<0.002	<0.001	<0.005	<0.010	--	--	<0.001	<0.2	<0.300	<2	<0.200	<0.2	<0.3	<0.200
2	20	8/23/1996	<0.002	<0.001	<0.005	0.010	--	--	<0.002	<0.2	<0.300	<2	<0.200	<0.2	<0.3	<0.200
2	21	8/28/1996	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	22	8/29/1996	<0.002	<0.001	<0.005	<0.010	--	--	<0.001	<0.2	0.360	4.67	<0.200	<0.2	<0.3	<0.200
2	23	8/29/1996	<0.002	<0.001	<0.005	--	--	--	<0.001	<0.2	<0.300	<2.00	<0.200	<0.2	<0.3	<0.200
2	24	11/8/1996	<0.1	<0.02	0.05	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	25	11/8/1996	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	26	2/25/1997	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	27	2/26/1997	<0.1	0.02	<0.02	--	--	--	0.04	--	--	--	--	--	<0.2	--
2	28	6/4/1997	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	29	6/5/1997	0.02	--	<0.050	<0.01	0.01	--	<0.01	<0.20	0.66	4.43	<0.20	<0.20	<0.30	<0.20
2	30	8/27/1997	<0.1	<0.02	0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	31	8/26/1997	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	32	8/29/1997	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	33	11/19/1997	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	34	11/20/1997	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	35	11/21/1997	<0.02	0.001	<0.050	<0.01	<0.01	--	0.001	<0.20	<0.30	<2	<0.20	<0.20	<0.30	0.38
2	36	12/4/1997	<0.02	0.001	<0.050	<0.01	<0.01	--	<0.001	<0.20	<0.30	3.08	<0.20	<0.20	<0.30	<0.20
2	37	1/8/1998	<0.1	<0.02	0.04	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	38	1/8/1998	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	0.1	--
2	39	1/15/1998	<0.02	0.001	<0.050	<0.01	<0.010	--	<0.001	<0.20	<0.30	<2	<0.20	<0.20	<0.30	<0.20
2	40	3/27/1998	<0.002	<0.001	<0.005	<0.01	0.02	--	<0.01	<0.20	<0.30	<2	<0.20	<0.20	<0.30	<0.20
2	41	4/16/1998	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	42	4/16/1998	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	43	7/15/1998	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	44	7/16/1998	<0.1	<0.02	<0.02	--	--	--	<0.02	--	--	--	--	--	<0.2	--
2	45	7/17/1998	<0.002	<0.001	<0.005	0.01	<0.01	--	<0.001	<0.20	<0.30	<2	<0.20	<0.20	<0.30	<0.20
2	46	7/21/1998	<0.02	--	<0.050	0.01	<0.01	--	<0.01	<0.20	<0.30	2.49	<0.20	<0.20	<0.30	<0.20
2	47	7/21/1998	0.02	--	<0.050	0.01	<0.01	--	<0.01	<0.20	<0.30	<2	<0.20	<0.20	<0.30	<0.20
2	48	7/13/1999	<0.02	--	<0.050	--	<0.05	>0.05	--	<1	<1	<16	<1	<1	<1	<1
3	49	4/22/1994	<0.1	<0.02	0.03	--	--	--	<0.02	--	--	--	--	--	<0.2	--

Appendix 7. Information and chemical data for blank water-quality samples collected near Deer Trail, Colorado, 1993 through 1999.—Continued

[Codes are explained in appendix 6; other abbreviations are listed in appendix 2; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; all data from filtered samples unless otherwise indicated; <, less than; --, no data]

Sampling type	Blank number	Sample date	Cr, µg/L	Cu, µg/L	Fe, µg/L	Mn, µg/L	Mo, µg/L	Ni, µg/L	Pb, µg/L	Sb, µg/L	Sr, µg/L	Tl, µg/L	U, µg/L	Zn, µg/L
2	1	7/20/1994	<100	<100	<250	<100	--	<100	<10	--	--	--	--	<100
2	2	10/3/1994	<40	<40	<100	<40	--	<40	<10	--	--	--	--	<40
2	3	10/3/1994	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	4	10/4/1994	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	5	10/4/1994	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	6	7/12/1995	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	7	9/27/1995	<20	<20	<50	<20	--	30	<10	--	--	--	--	<20
2	8	9/28/1995	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	9	12/14/1995	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	10	12/15/1995	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	11	3/8/1996	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	12	3/11/1996	<0.200	0.570	<3	0.770	1	0.820	<0.3	<0.200	0.2	<0.100	<0.20	7
2	13	6/10/1996	<0.200	3	<3	2	<0.200	1	<0.300	<0.200	0.520	<0.100	<0.20	3
2	14	6/12/1996	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	15	6/14/1996	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	16	6/14/1996	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	17	8/21/1996	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	18	8/22/1996	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	19	8/23/1996	<0.200	<0.200	<3	<0.100	<0.200	<0.500	<0.300	<0.200	<0.100	<0.100	<0.20	<0.500
2	20	8/23/1996	<0.200	<0.200	<3	<0.100	<0.200	<0.500	<0.300	<0.200	<0.100	<0.100	<0.20	<0.500
2	21	8/28/1996	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	22	8/29/1996	<0.200	2	<3	0.460	<0.200	<0.500	<0.300	<0.200	0.150	<0.100	<0.20	2
2	23	8/29/1996	<0.200	<0.200	<3	<0.100	<0.200	<0.500	<0.300	<0.200	<0.100	<0.100	<0.20	<0.500
2	24	11/8/1996	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	25	11/8/1996	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	26	2/25/1997	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	27	2/26/1997	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	28	6/4/1997	<20	<20	50	<20	--	<20	<10	--	--	--	--	<20
2	29	6/5/1997	<0.20	1.50	<3	0.56	<0.20	0.53	<0.30	<0.20	0.24	<0.10	<0.20	1.36
2	30	8/27/1997	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	31	8/26/1997	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	32	8/29/1997	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	33	11/19/1997	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	34	11/20/1997	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	35	11/21/1997	<0.20	0.55	<3	0.24	<0.20	<0.50	<0.30	<0.20	0.24	<0.10	<0.20	<0.50
2	36	12/4/1997	<0.20	<0.20	<3	<0.10	<0.20	<0.50	<0.30	<0.20	<0.10	<0.10	<0.20	<0.50
2	37	1/8/1998	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	38	1/8/1998	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	39	1/15/1998	<0.20	0.91	<3	<0.10	<0.20	<0.50	<0.30	<0.20	0.10	<0.10	<0.20	1.13
2	40	3/27/1998	<0.20	0.40	<3	0.22	<0.20	<0.50	<0.30	<0.20	<0.10	<0.10	<0.20	<0.50
2	41	4/16/1998	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	42	4/16/1998	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	43	7/15/1998	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	44	7/16/1998	<20	<20	<50	<20	--	<20	<10	--	--	--	--	<20
2	45	7/17/1998	<0.2	<0.20	<3	<0.10	<0.20	<0.50	<0.30	<0.20	<0.10	<0.10	<0.20	<0.50
2	46	7/21/1998	<0.20	<0.20	<3	<0.10	<0.20	<0.50	<0.30	<0.20	<0.10	<0.10	<0.20	<0.50
2	47	7/21/1998	<0.20	<0.20	<3	<0.10	<0.20	<0.50	<0.30	<0.20	<0.10	<0.10	<0.20	<0.50
2	48	7/13/1999	<1.0	<1	<10	<1	<1	<1	<1	<1	<1	--	<1	<1.0
3	49	4/22/1994	<20	40	<50	<20	--	<20	<10	--	--	--	--	<20

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
Ag	µg/L	Jan-94	T127	2.4	2.73	2.71	GFAA	GFAA
Ag	µg/L	Jan-95	T131	0.8	1.23	1.26	GFAA	ICP-MS
Ag	µg/L	Jan-95	T133	6.1	7.87	7.44	GFAA	ICP-MS
Ag	µg/L	Jul-95	T135	--	10.33	9.81	na	GFAA
Ag	µg/L	Aug-96	T139	3.4	2.13	2.26	GFAA	GFAA
Ag	µg/L	Aug-96	T141	8.2	6.00	5.91	GFAA	GFAA
Ag	µg/L	Jan-97	T143	--	19.6	19.8	na	ICP-MS
Ag	µg/L	Jan-97	T145	--	7.55	7.55	na	ICP-MS
Ag	µg/L	Aug-97	T147	9.8	7.36	7.60	GFAA	ICP-MS
Ag	µg/L	Aug-97	T149	--	<1	--	na	ICP-MS
Ag	µg/L	Feb-98	T151	15.0	11.6	11.1	GFAA	ICP-MS
Ag	µg/L	Jul-98	T153	--	6.23	6.24	na	GFAA
Ag	µg/L	Dec-98	T155	--	<1	--	na	GFAA
Ag	µg/L	Aug-99	T157	15.4	15.3	14.5	na	ICP-MS
Al	µg/L	Feb-93	T121	<100	80	85.5	--	--
Al	µg/L	Aug-93	T123	--	6.71	10.0	na	ICP/MS
Al	µg/L	Aug-93	T125	--	20.5	24.0	na	ICP
Al	µg/L	Jan-94	T127	<100	79.4	85.0	ICP	ICP
Al	µg/L	Aug-94	T129	<100	45.8	50.0	ICP	ICP
Al	µg/L	Jan-95	T131	210	125	132	ICP	ICP
Al	µg/L	Jan-95	T133	160	52.2	52.1	ICP	ICP
Al	µg/L	Jul-95	T135	--	11.4	10.5	na	ICP-MS
Al	µg/L	Feb-96	T137	--	31	30.5	na	ICP
Al	µg/L	Aug-96	T139	--	20.7	22.4	na	ICP-MS
Al	µg/L	Aug-96	T141	--	69.0	75.4	na	ICP-MS
Al	µg/L	Jan-97	T143	--	19.1	22.1	na	ICP-MS
Al	µg/L	Jan-97	T145	--	60.1	67.6	na	ICP-MS
Al	µg/L	Aug-97	T147	--	12.0	14.0	na	ICP-MS
Al	µg/L	Aug-97	T149	--	32.5	35.5	na	ICP-MS
Al	µg/L	Feb-98	T151	--	6.30	--	na	ICP-MS
Al	µg/L	Jul-98	T153	--	32.5	35.0	na	ICP-MS
Al	µg/L	Dec-98	T155	--	63.5	66.2	na	ICP-MS
Al	µg/L	Aug-99	GWT5	--	12.3	14.1	na	ICP-MS
Al	µg/L	Aug-99	T157	--	56.8	55.5	na	ICP-MS
Alk, lab	mg/L	Jan-94	M128	168	171	168	Titrate: electrometric	Titrate: electrometric
Alk, lab	mg/L	Aug-94	M130	65	59.9	60	Titrate: electrometric	Titrate: electrometric
Alk, lab	mg/L	Jan-95	M132	93	1.2	94.0	Titrate: electrometric	Titrate: electrometric
Alk, lab	mg/L	Jul-95	M134	--	64.6	62.9	na	Titrate: electrometric
Alk, lab	mg/L	Feb-96	M136	141	155	152	Titrate: electrometric	Titrate: electrometric
Alk, lab	mg/L	Apr-96	M138	48	42.5	41.1	Titrate: electrometric	Titrate: electrometric
Alk, lab	mg/L	Jan-97	M140	--	115	114	na	Titrate: electrometric
Alk, lab	mg/L	Aug-97	M142	179	182	180	Titrate: electrometric	Titrate: electrometric
Alk, lab	mg/L	Feb-98	GWM2	264	257	253	Titrate: electrometric	Titrate: electrometric
Alk, lab	mg/L	Feb-98	M144	90	89.9	88.8	Titrate: electrometric	Titrate: electrometric
Alk, lab	mg/L	Jul-98	M146	--	57.8	56.7	na	Titrate: electrometric
Alk, lab	mg/L	Aug-99	GWM4	214	210	216	na	Titrate: electrometric
Alk, lab	mg/L	Aug-99	M150	29	20.3	26.4	na	Titrate: electrometric
As	µg/L	Feb-93	T121	--	9.2	--	na	AA: hydride
As	µg/L	Aug-93	T123	23	20.3	20.2	GFAA	AA: hydride
As	µg/L	Aug-93	T125	10	11.08	10.2	GFAA	AA: hydride
As	µg/L	Jan-94	T127	<10	4.40	4.40	GFAA	GFAA
As	µg/L	Aug-94	T129	<10	<1	0.55	GFAA	GFAA
As	µg/L	Jan-95	T131	49	57.4	56.6	GFAA	GFAA
As	µg/L	Jan-95	T133	30	27.0	27.1	GFAA	GFAA

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
As	µg/L	Jul-95	T135	--	10.0	10.0	na	GFAA
As	µg/L	Feb-96	T137	--	<1	0.6	na	GFAA
As	µg/L	Aug-96	T139	--	5.47	5.55	na	GFAA
As	µg/L	Aug-96	T141	10	7.50	7.50	GFAA	GFAA
As	µg/L	Jan-97	T143	--	16.2	15.2	na	GFAA
As	µg/L	Jan-97	T145	--	9.90	9.88	na	GFAA
As	µg/L	Aug-97	T147	--	2.20	2.39	na	GFAA
As	µg/L	Aug-97	T149	--	<1	1.0	na	GFAA
As	µg/L	Feb-98	T151	--	1.60	1.01	na	GFAA
As	µg/L	Jul-98	T153	--	<1	0.50	na	GFAA
As	µg/L	Dec-98	T155	35	31.9	32.9	GFAA	GFAA
As	µg/L	Aug-99	GWT5	22.0	22.8	21.9	GFAA	GFAA
As	µg/L	Aug-99	T157	23	27.6	25.4	GFAA	GFAA
B	µg/L	Feb-93	T121	--	93	90	na	DCP
B	µg/L	Aug-93	M126	--	8.44	9.6	na	ICP
B	µg/L	Aug-93	T123	--	9.75	11.3	na	ICP
B	µg/L	Aug-93	T125	--	19.21	19.4	na	ICP
B	µg/L	Jan-94	M128	--	297	285	na	ICP
B	µg/L	Jan-94	T127	--	42.7	42.8	na	ICP
B	µg/L	Aug-94	M130	--	7.66	8.87	na	ICP
B	µg/L	Aug-94	T129	--	8.9	11.6	na	ICP
B	µg/L	Jan-95	M132	--	30.7	30.4	na	ICP
B	µg/L	Jan-95	T131	--	143	141	na	ICP
B	µg/L	Jan-95	T133	--	300	297	na	ICP
B	µg/L	Jul-95	M134	--	35.1	33.7	na	ICP
B	µg/L	Jul-95	T135	--	13.3	13.1	na	ICP
B	µg/L	Feb-96	M136	--	202	200	na	DCP
B	µg/L	Feb-96	T137	--	<10	15.6	na	DCP
B	µg/L	Apr-96	M138	--	5	10	na	ICP
B	µg/L	Aug-96	T139	--	36	36	na	DCP
B	µg/L	Aug-96	T141	--	30	29	na	ICP
B	µg/L	Jan-97	M140	--	43.6	41.6	na	ICP
B	µg/L	Jan-97	T143	--	34.9	35.0	na	ICP
B	µg/L	Jan-97	T145	--	45.7	45.6	na	ICP
B	µg/L	Aug-97	M142	--	114	121	na	ICP
B	µg/L	Aug-97	T147	--	50.4	50.0	na	ICP
B	µg/L	Aug-97	T149	--	124	128	na	ICP
B	µg/L	Feb-98	GWM2	--	235	238	na	ICP
B	µg/L	Feb-98	M144	--	45.7	46.1	na	ICP
B	µg/L	Feb-98	T151	--	36.4	36.3	na	ICP
B	µg/L	Jul-98	M146	--	14.2	13.9	na	ICP
B	µg/L	Jul-98	T153	--	97.1	99.4	na	ICP
B	µg/L	Dec-98	T155	--	94.7	94.0	na	ICP
B	µg/L	Aug-99	GWM4	--	95.2	95.2	na	ICP
B	µg/L	Aug-99	GWT5	--	98.2	98.6	na	ICP
B	µg/L	Aug-99	T157	--	70.8	70.4	na	ICP
Ba	µg/L	Feb-93	T121	--	46.28	46.3	na	ICP
Ba	µg/L	Aug-93	T123	--	7.25	7.65	na	ICP
Ba	µg/L	Aug-93	T125	--	16.3	16.9	na	ICP
Ba	µg/L	Jan-94	T127	--	19.7	20.6	na	ICP
Ba	µg/L	Aug-94	T129	--	33.0	34.0	na	ICP
Ba	µg/L	Jan-95	T131	--	495	507	na	ICP-MS
Ba	µg/L	Jan-95	T133	--	151	148	na	ICP-MS
Ba	µg/L	Jul-95	T135	--	70.6	67.8	na	ICP

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
Ba	µg/L	Feb-96	T137	--	65.18	65.0	na	ICP
Ba	µg/L	Aug-96	T139	--	44.0	44.0	na	ICP-MS
Ba	µg/L	Aug-96	T141	--	32.3	33.0	na	ICP-MS
Ba	µg/L	Jan-97	T143	--	82.2	81.9	na	ICP-MS
Ba	µg/L	Jan-97	T145	--	36.8	37.1	na	ICP-MS
Ba	µg/L	Aug-97	T147	--	73.4	73.0	na	ICP-MS
Ba	µg/L	Aug-97	T149	--	42.1	42.5	na	ICP-MS
Ba	µg/L	Feb-98	T151	--	40.8	40.7	na	ICP-MS
Be	µg/L	Jan-95	T131	<20	12.3	12.2	ICP	ICP
Be	µg/L	Jan-95	T133	<20	34.9	35.0	ICP	ICP
Be	µg/L	Jul-95	T135	--	57.2	59.0	na	ICP
Be	µg/L	Feb-96	T137	--	5.24	5.2	na	ICP-MS
Be	µg/L	Aug-96	T139	--	9.9	10.1	na	ICP
Be	µg/L	Aug-96	T141	--	8.40	8.60	na	ICP
Be	µg/L	Jan-97	T143	--	8.13	8.50	na	ICP-MS
Be	µg/L	Jan-97	T145	--	8.94	9.04	na	ICP-MS
Be	µg/L	Aug-97	T147	--	15.9	16.0	na	ICP-MS
Be	µg/L	Feb-98	T151	--	25.5	25.6	na	ICP-MS
Be	µg/L	Dec-98	T155	--	<1	--	na	ICP
Be	µg/L	Aug-99	T157	--	13.0	13.0	na	ICP
Ca	mg/L	Feb-93	T121	5	5.18	5.13	ICP	ICP
Ca	mg/L	Aug-93	M126	8	7.50	7.62	ICP	ICP
Ca	mg/L	Aug-93	T123	9	9.06	9.10	ICP	ICP
Ca	mg/L	Aug-93	T125	9	9.36	9.34	ICP	ICP
Ca	mg/L	Jan-94	M128	84	83.9	78.9	ICP	ICP
Ca	mg/L	Jan-94	T127	10	8.79	8.80	ICP	ICP
Ca	mg/L	Feb-94	P21	--	0.45	0.45	na	ICP
Ca	mg/L	Aug-94	M130	21	21.5	21.2	ICP	ICP
Ca	mg/L	Aug-94	P22	--	0.730	0.725	na	ICP
Ca	mg/L	Aug-94	T129	21	21.3	21.1	ICP	ICP
Ca	mg/L	Jan-95	M132	36	38.5	38.0	ICP	ICP
Ca	mg/L	Jan-95	P23	--	1.16	1.13	na	ICP
Ca	mg/L	Jan-95	T131	31	30.9	30.6	ICP	ICP
Ca	mg/L	Jan-95	T133	7	7.04	7.04	ICP	ICP
Ca	mg/L	Jul-95	M134	--	45.6	43.8	na	ICP
Ca	mg/L	Jul-95	P24	--	0.330	0.325	na	ICP
Ca	mg/L	Jul-95	T135	--	10.8	10.4	na	ICP
Ca	mg/L	Feb-96	M136	64	62.6	62.8	ICP	ICP
Ca	mg/L	Feb-96	P25	--	1.67	1.67	na	ICP
Ca	mg/L	Feb-96	T137	38	37.9	38.1	ICP	ICP
Ca	mg/L	Apr-96	M138	13	12.6	13.3	ICP	ICP
Ca	mg/L	Jun-96	P26	--	0.46	0.450	na	ICP
Ca	mg/L	Aug-96	T139	50	50.5	50.3	ICP	ICP
Ca	mg/L	Aug-96	T141	19	19.0	19.1	ICP	ICP
Ca	mg/L	Jan-97	M140	--	56.3	60.7	na	ICP
Ca	mg/L	Jan-97	P27	--	2.50	2.53	na	ICP
Ca	mg/L	Jan-97	T143	--	52.5	53.7	na	ICP
Ca	mg/L	Jan-97	T145	--	29.0	30.7	na	ICP
Ca	mg/L	Aug-97	M142	69	65.4	67.6	ICP	ICP
Ca	mg/L	Aug-97	P28	--	1.68	1.64	na	ICP
Ca	mg/L	Aug-97	T147	41	40.5	41.1	ICP	ICP
Ca	mg/L	Aug-97	T149	42	42.0	42.3	ICP	ICP
Ca	mg/L	Feb-98	GWM2	--	68.5	68.4	na	ICP
Ca	mg/L	Feb-98	M144	--	75.0	74.0	na	ICP

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
Ca	mg/L	Feb-98	P29	--	1.81	1.84	na	ICP
Ca	mg/L	Feb-98	T151	--	37.9	37.9	na	ICP
Ca	mg/L	Jul-98	M146	--	26.8	26.3	na	ICP
Ca	mg/L	Jul-98	P30	--	0.13	0.13	na	ICP
Ca	mg/L	Jul-98	T153	--	27.6	27.5	na	ICP
Ca	mg/L	Dec-98	M148	--	5.85	5.90	na	ICP
Ca	mg/L	Dec-98	T155	49	42.3	42.0	ICP	ICP
Ca	mg/L	Aug-99	GWM4	--	51.2	50.1	na	ICP
Ca	mg/L	Aug-99	GWT5	--	50.7	50.8	na	ICP
Ca	mg/L	Aug-99	M150	7	6.68	6.82	na	ICP
Ca	mg/L	Aug-99	P32	--	1.39	1.40	na	ICP
Ca	mg/L	Aug-99	T157	6	6.12	6.19	na	ICP
Cd	µg/L	Feb-93	T121	7.1	7.3	7.17	GFAA	GFAA
Cd	µg/L	Aug-93	T123	7.8	5.9	5.86	GFAA	GFAA
Cd	µg/L	Aug-93	T125	11.6	7.20	7.20	GFAA	GFAA
Cd	µg/L	Jan-94	T127	8.6	8.56	8.34	GFAA	GFAA
Cd	µg/L	Aug-94	T129	0.3	0.32	0.34	GFAA	GFAA
Cd	µg/L	Jan-95	T131	5.9	6.40	6.10	GFAA	GFAA
Cd	µg/L	Jan-95	T133	23.0	22.5	23.0	GFAA	GFAA
Cd	µg/L	Jul-95	T135	--	49.1	50.5	na	ICP-MS
Cd	µg/L	Feb-96	T137	--	6.36	6.80	na	ICP-MS
Cd	µg/L	Aug-96	T139	7.8	7.40	7.50	GFAA	ICP-MS
Cd	µg/L	Aug-96	T141	8.1	8.00	8.20	GFAA	ICP-MS
Cd	µg/L	Jan-97	T143	--	20.07	19.1	na	GFAA
Cd	µg/L	Jan-97	T145	--	9.79	9.33	na	GFAA
Cd	µg/L	Aug-97	T147	17.0	15.4	15.9	GFAA	ICP-MS
Cd	µg/L	Aug-97	T149	2.2	2.30	2.18	GFAA	GFAA
Cd	µg/L	Feb-98	T151	26.8	26.6	26.8	GFAA	ICP-MS
Cd	µg/L	Jul-98	T153	--	16.0	16.0	na	ICP-MS
Cd	µg/L	Dec-98	T155	6.5	11.0	11.4	GFAA	ICP-MS
Cd	µg/L	Aug-99	T157	7.2	6.00	5.80	na	ICP-MS
Cl	mg/L	Aug-93	M126	25	20.2	20.7	Colorimetry	Colorimetry
Cl	mg/L	Jan-94	M128	98	93.8	98.2	Colorimetry	IC
Cl	mg/L	Feb-94	P21	--	4.11	3.90	na	IC
Cl	mg/L	Aug-94	M130	26	21.6	21.4	Colorimetry	IC
Cl	mg/L	Aug-94	P22	--	2.96	2.92	na	IC
Cl	mg/L	Jan-95	M132	56	55.9	55.7	Colorimetry	IC
Cl	mg/L	Jan-95	P23	--	0.280	0.310	na	IC
Cl	mg/L	Jul-95	M134	--	64.6	65.0	na	IC
Cl	mg/L	Jul-95	P24	--	1.19	1.20	na	IC
Cl	mg/L	Feb-96	M136	89	93.23	92.0	Colorimetry	IC
Cl	mg/L	Feb-96	P25	--	1.27	1.30	na	IC
Cl	mg/L	Apr-96	M138	42	33.1	33.4	Colorimetry	IC
Cl	mg/L	Jun-96	P26	--	7.93	7.79	na	IC
Cl	mg/L	Jan-97	M140	--	24.7	25.8	na	IC
Cl	mg/L	Jan-97	P27	--	1.20	1.20	na	IC
Cl	mg/L	Aug-97	M142	133	135	132	Colorimetry	IC
Cl	mg/L	Aug-97	P28	--	3.33	3.30	na	IC
Cl	mg/L	Feb-98	GWM2	47	47.2	48.9	Colorimetry	IC
Cl	mg/L	Feb-98	M144	77	76.2	77.0	Colorimetry	IC
Cl	mg/L	Feb-98	P29	--	0.15	0.20	na	IC
Cl	mg/L	Jul-98	M146	--	44	46.1	na	IC
Cl	mg/L	Jul-98	P30	--	0.18	0.23	na	IC
Cl	mg/L	Dec-98	M148	46	44.6	46.0	Colorimetry	IC

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
Cl	mg/L	Aug-99	GWM4	--	53.7	49.4	na	IC
Cl	mg/L	Aug-99	M150	18	19.5	17.0	na	IC
Cl	mg/L	Aug-99	P32	--	1.66	1.64	na	IC
Co	µg/L	Jan-94	T127	--	11.3	11.6	na	GFAA
Co	µg/L	Aug-94	T129	--	0.12	0.74	na	ICP-MS
Co	µg/L	Jan-95	T131	--	24.6	24.6	na	ICP-MS
Co	µg/L	Jan-95	T133	--	19.9	20.0	na	ICP-MS
Co	µg/L	Jul-95	T135	--	39.6	40.0	na	ICP-MS
Co	µg/L	Aug-96	T139	--	6.3	6.7	na	ICP-MS
Co	µg/L	Aug-96	T141	--	6.10	6.50	na	ICP-MS
Co	µg/L	Jan-97	T143	--	17.4	17.0	na	GFAA
Co	µg/L	Jan-97	T145	--	10.0	10.0	na	ICP-MS
Co	µg/L	Aug-97	T147	--	<1	--	na	ICP-MS
Co	µg/L	Aug-97	T149	--	<1	--	na	GFAA
Co	µg/L	Feb-98	T151	--	<1	--	na	GFAA
Co	µg/L	Dec-98	T155	--	26.3	27.0	na	ICP-MS
Co	µg/L	Aug-99	GWT5	--	10.5	10.0	na	GFAA
Co	µg/L	Aug-99	T157	--	4.23	4.03	na	ICP-MS
Cr	µg/L	Jan-94	T127	<20	10.5	11.5	ICP	ICP
Cr	µg/L	Aug-94	T129	--	0.60	0.68	na	ICP-MS
Cr	µg/L	Jan-95	T131	<20	17.3	18.6	ICP	GFAA
Cr	µg/L	Jan-95	T133	40	36.2	38.0	ICP	GFAA
Cr	µg/L	Jul-95	T135	--	80.9	79.0	na	ICP
Cr	µg/L	Feb-96	T137	20	20.5	19.4	ICP	GFAA
Cr	µg/L	Aug-96	T139	--	7.50	7.75	na	ICP-MS
Cr	µg/L	Aug-96	T141	--	14.0	15.4	na	ICP-MS
Cr	µg/L	Jan-97	T143	--	35.5	37.0	na	ICP-MS
Cr	µg/L	Jan-97	T145	--	15.5	15.3	na	GFAA
Cr	µg/L	Aug-97	T147	<20	11.4	12.8	ICP	ICP-MS
Cr	µg/L	Aug-97	T149	50	46.7	48.8	ICP	ICP-MS
Cr	µg/L	Feb-98	T151	--	29.8	30.1	na	ICP-MS
Cr	µg/L	Jul-98	T153	--	14.9	14.9	na	GFAA
Cr	µg/L	Dec-98	T155	--	9.27	8.49	na	ICP-MS
Cr	µg/L	Aug-99	T157	40	32.4	31.3	na	ICP-MS
Cu	µg/L	Jan-94	T127	41	42.7	42.0	GFAA	GFAA
Cu	µg/L	Aug-94	T129	2	2.7	2.7	GFAA	GFAA
Cu	µg/L	Jan-95	T131	18	20.2	20.2	GFAA	GFAA
Cu	µg/L	Jan-95	T133	82	84.4	85.3	GFAA	ICP
Cu	µg/L	Jul-95	T135	--	61.9	62.0	na	ICP-MS
Cu	µg/L	Feb-96	T137	2	2.14	1.9	GFAA	ICP-MS
Cu	µg/L	Aug-96	T139	13	12.8	13.0	GFAA	ICP-MS
Cu	µg/L	Aug-96	T141	19	18.5	18.0	GFAA	GFAA
Cu	µg/L	Jan-97	T143	--	22.3	22.2	na	GFAA
Cu	µg/L	Jan-97	T145	--	11.1	11.0	na	GFAA
Cu	µg/L	Aug-97	T147	10	11.0	11.4	GFAA	ICP-MS
Cu	µg/L	Aug-97	T149	7	7.60	8.00	GFAA	ICP-MS
Cu	µg/L	Feb-98	T151	32	32.7	33.0	GFAA	ICP-MS
Cu	µg/L	Jul-98	T153	--	23.7	24.0	na	ICP-MS
Cu	µg/L	Dec-98	T155	36	37.9	38.0	GFAA	ICP-MS
Cu	µg/L	Aug-99	GWT5	2	2.35	2.51	GFAA	ICP-MS
Cu	µg/L	Aug-99	T157	25	25.2	24.8	GFAA	ICP-MS
TDS (ROE)	mg/L	Jan-94	M128	718	684	689	Gravimetric	Gravimetric
TDS (ROE)	mg/L	Aug-94	M130	199	193	200	Gravimetric	Gravimetric
TDS (ROE)	mg/L	Jan-95	M132	271	264	277	Gravimetric	Gravimetric

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
TDS (ROE)	mg/L	Jul-95	M134	--	369	370	na	Gravimetric
TDS (ROE)	mg/L	Feb-96	M136	551	571	568	Gravimetric	Gravimetric
TDS (ROE)	mg/L	Apr-96	M138	144	150	151	Gravimetric	Gravimetric
TDS (ROE)	mg/L	Jan-97	M140	--	370	382	na	Gravimetric
TDS (ROE)	mg/L	Aug-97	M142	755	748	746	Gravimetric	Gravimetric
TDS (ROE)	mg/L	Feb-98	GWM2	580	621	602	Gravimetric	Gravimetric
TDS (ROE)	mg/L	Feb-98	M144	530	554	546	Gravimetric	Gravimetric
TDS (ROE)	mg/L	Jul-98	M146	--	248	242	na	Gravimetric
TDS (ROE)	mg/L	Dec-98	M148	521	150	154	Gravimetric	Gravimetric
TDS (ROE)	mg/L	Aug-99	GWM4	--	436	425	na	Gravimetric
F	mg/L	Jan-94	M128	--	1.14	1.18	na	IC
F	mg/L	Feb-94	P21	--	0.14	0.03	na	IC
F	mg/L	Aug-94	M130	1.3	1.37	1.23	Ion selective electrode	Ion selective electrode
F	mg/L	Aug-94	P22	--	0.05	0.028	na	IC
F	mg/L	Jan-95	M132	0.5	0.510	0.480	Ion selective electrode	Ion selective electrode
F	mg/L	Jan-95	P23	--	0.120	0.120	na	Ion selective electrode
F	mg/L	Jul-95	M134	--	0.620	0.561	na	Ion selective electrode
F	mg/L	Jul-95	P24	--	0.120	0.110	na	IC
F	mg/L	Feb-96	M136	--	1.05	1.04	na	Ion selective electrode
F	mg/L	Feb-96	P25	--	0.16	0.139	na	IC
F	mg/L	Apr-96	M138	--	0.770	0.720	na	Ion selective electrode
F	mg/L	Jun-96	P26	--	0.05	0.040	na	Ion selective electrode
F	mg/L	Jan-97	M140	--	0.560	0.530	na	Ion selective electrode
F	mg/L	Jan-97	P27	--	<0.1	0.100	na	Ion selective electrode
F	mg/L	Aug-97	M142	--	0.500	0.460	na	Ion selective electrode
F	mg/L	Aug-97	P28	--	<0.1	0.06	na	Ion selective electrode
F	mg/L	Feb-98	GWM2	--	1.22	1.18	na	Ion selective electrode
F	mg/L	Feb-98	M144	--	0.21	0.23	na	Ion selective electrode
F	mg/L	Feb-98	P29	--	0.07	0.056	na	Ion selective electrode
F	mg/L	Jul-98	M146	--	1.06	1.07	na	Ion selective electrode
F	mg/L	Jul-98	P30	--	0.230	0.206	na	Ion selective electrode
F	mg/L	Dec-98	M148	--	1.60	2.12	na	Ion selective electrode
F	mg/L	Aug-99	GWM4	1.3	1.57	1.55	Ion selective electrode	Ion selective electrode
F	mg/L	Aug-99	M150	0.9	1.04	1.00	Ion selective electrode	Ion selective electrode
F	mg/L	Aug-99	P32	--	0.220	0.216	na	IC
Fe	µg/L	Jan-94	T127	130	131	135	ICP	ICP
Fe	µg/L	Aug-94	T129	<50	5.1	10.4	ICP	ICP
Fe	µg/L	Jan-95	T131	80	88.6	90.7	ICP	ICP
Fe	µg/L	Jan-95	T133	<50	31.0	34.1	ICP	ICP
Fe	µg/L	Jul-95	T135	--	235	228	na	ICP
Fe	µg/L	Feb-96	T137	65	69.3	71	ICP	ICP
Fe	µg/L	Aug-96	T139	--	4.7	7.5	na	ICP
Fe	µg/L	Aug-96	T141	--	<3	4.3	na	ICP
Fe	µg/L	Jan-97	T143	--	211	222	na	ICP
Fe	µg/L	Jan-97	T145	--	96	101	na	ICP
Fe	µg/L	Aug-97	T147	60	<10	8.4	ICP	ICP
Fe	µg/L	Aug-97	T149	80	67.7	70.0	ICP	ICP
Fe	µg/L	Feb-98	T151	--	7.5	10.0	na	ICP
Fe	µg/L	Jul-98	T153	--	74.7	75.0	na	ICP
Fe	µg/L	Dec-98	T155	--	84.8	88.0	na	ICP
Fe	µg/L	Aug-99	GWT5	--	8.7	12.0	na	ICP
Fe	µg/L	Aug-99	T157	80	73.0	76.0	Other	ICP
K	mg/L	Jan-94	M128	9.7	9.43	9.44	ICP	AA: direct, air
K	mg/L	Jan-94	T127	1.2	1.19	1.07	ICP	AA: direct, air

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
K	mg/L	Feb-94	P21	--	0.09	0.088	na	AA: direct, air
K	mg/L	Aug-94	M130	3	2.88	3.00	ICP	AA: direct, air
K	mg/L	Aug-94	P22	--	0.23	0.203	na	AA: direct, air
K	mg/L	Aug-94	T129	3	2.92	3.00	ICP	AA: direct, air
K	mg/L	Jan-95	M132	2.0	1.73	2.00	ICP	AA: direct, air
K	mg/L	Jan-95	P23	--	0.49	0.483	na	AA: direct, air
K	mg/L	Jan-95	T131	2.4	2.25	2.39	ICP	AA: direct, air
K	mg/L	Jan-95	T133	1.0	0.87	1.00	ICP	AA: direct, air
K	mg/L	Jul-95	M134	--	2.39	2.40	na	AA: direct, air
K	mg/L	Jul-95	P24	--	0.12	0.118	na	AA: direct, air
K	mg/L	Jul-95	T135	--	0.90	0.96	na	AA: direct, air
K	mg/L	Feb-96	M136	7	6.69	6.53	ICP	AA: direct, air
K	mg/L	Feb-96	P25	--	0.52	0.55	na	AA: direct, air
K	mg/L	Feb-96	T137	1	1.2	1.19	ICP	AA: direct, air
K	mg/L	Apr-96	M138	1	1.82	1.82	ICP	AA: direct, air
K	mg/L	Jun-96	P26	--	0.15	0.146	na	AA: direct, air
K	mg/L	Aug-96	T139	2	2.71	2.73	ICP	AA: direct, air
K	mg/L	Aug-96	T141	2	2.34	2.32	ICP	AA: direct, air
K	mg/L	Jan-97	M140	--	2.57	2.58	na	AA: direct, air
K	mg/L	Jan-97	P27	--	0.33	0.336	na	AA: direct, air
K	mg/L	Jan-97	T143	--	2.55	2.50	na	AA: direct, air
K	mg/L	Jan-97	T145	--	2.17	2.13	na	AA: direct, air
K	mg/L	Aug-97	M142	6	5.60	5.72	ICP	AA: direct, air
K	mg/L	Aug-97	P28	--	0.14	0.14	na	AA: direct, air
K	mg/L	Aug-97	T147	3	3.48	3.52	ICP	AA: direct, air
K	mg/L	Aug-97	T149	2	1.88	2.00	ICP	AA: direct, air
K	mg/L	Feb-98	GWM2	--	4.44	4.46	na	AA: direct sir
K	mg/L	Feb-98	M144	--	3.56	3.60	na	AA: direct, air
K	mg/L	Feb-98	P29	--	0.37	0.37	na	AA: direct, air
K	mg/L	Feb-98	T151	--	1.87	1.95	na	AA: direct, air
K	mg/L	Jul-98	M146	--	2.69	2.93	na	AA: direct, air
K	mg/L	Jul-98	P30	--	0.14	0.140	na	AA: direct, air
K	mg/L	Jul-98	T153	--	1.54	1.60	na	AA: direct, air
K	mg/L	Dec-98	M148	--	9.6	10.1	na	AA: direct, air
K	mg/L	Dec-98	T155	--	5.36	5.64	na	AA: direct, air
K	mg/L	Aug-99	GWM4	--	1.77	1.84	na	AA: direct, nitrous oxide
K	mg/L	Aug-99	GWT5	--	1.78	1.85	na	AA: direct, nitrous oxide
K	mg/L	Aug-99	M150	--	1.09	1.12	na	AA: direct, nitrous oxide
K	mg/L	Aug-99	P32	--	0.36	0.399	na	AA: direct, nitrous oxide
K	mg/L	Aug-99	T157	2.00	2.47	2.51	ICP	AA: direct, nitrous oxide
Li	µg/L	Jan-94	T127	--	24.0	24.0	na	ICP
Li	µg/L	Aug-94	T129	--	17.0	18.0	na	ICP
Li	µg/L	Jan-95	T131	--	19.2	17.0	na	ICP
Li	µg/L	Jan-95	T133	--	52.4	51.0	na	ICP
Li	µg/L	Jul-95	T135	--	73.6	73.7	na	ICP
Li	µg/L	Feb-96	T137	--	8.67	8.70	na	ICP
Li	µg/L	Aug-96	T139	--	19.3	18.7	na	ICP
Li	µg/L	Aug-96	T141	--	22.0	21.4	na	ICP
Li	µg/L	Jan-97	T143	--	16.6	18.0	na	ICP

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
Li	µg/L	Jan-97	T145	--	25.5	27.3	na	ICP
Li	µg/L	Aug-97	T147	--	17.3	18.0	na	ICP
Li	µg/L	Aug-97	T149	--	43.5	44.2	na	ICP
Li	µg/L	Feb-98	T151	--	28.8	27.6	na	ICP
Li	µg/L	Jul-98	T153	--	54.6	53.4	na	ICP
Li	µg/L	Dec-98	T155	--	34.9	33.2	na	ICP
Li	µg/L	Aug-99	GWT5	--	37.1	37.6	na	ICP
Li	µg/L	Aug-99	T157	--	31.9	32.4	na	ICP
Mg	mg/L	Jan-94	M128	18.3	17.1	17.4	ICP	ICP
Mg	mg/L	Jan-94	T127	2.1	2.16	2.00	ICP	ICP
Mg	mg/L	Feb-94	P21	--	0.06	0.055	na	AA: direct, air
Mg	mg/L	Aug-94	M130	6.0	5.81	5.90	ICP	ICP
Mg	mg/L	Aug-94	P22	--	0.099	0.098	na	ICP
Mg	mg/L	Aug-94	T129	6.0	5.92	5.83	ICP	AA: direct, air
Mg	mg/L	Jan-95	M132	8.5	8.35	8.49	ICP	ICP
Mg	mg/L	Jan-95	P23	--	0.310	0.317	na	ICP
Mg	mg/L	Jan-95	T131	8.1	7.79	8.00	ICP	ICP
Mg	mg/L	Jan-95	T133	6.0	5.69	5.82	ICP	ICP
Mg	mg/L	Jul-95	M134	--	9.66	9.75	na	AA: direct, air
Mg	mg/L	Jul-95	P24	--	0.05	0.055	na	ICP
Mg	mg/L	Jul-95	T135	--	2.02	2.00	na	AA: direct, air
Mg	mg/L	Feb-96	M136	15.7	14.92	15.3	ICP	ICP
Mg	mg/L	Feb-96	P25	--	0.35	0.35	na	ICP
Mg	mg/L	Feb-96	T137	10.5	10.0	10.1	ICP	AA: direct, air
Mg	mg/L	Apr-96	M138	3.8	3.62	3.70	ICP	AA: direct, air
Mg	mg/L	Jun-96	P26	--	0.06	0.060	na	ICP
Mg	mg/L	Aug-96	T139	10.1	9.78	10.00	ICP	AA: direct, air
Mg	mg/L	Aug-96	T141	5.6	5.26	5.48	ICP	AA: direct, air
Mg	mg/L	Jan-97	M140	--	17.4	18.0	na	ICP
Mg	mg/L	Jan-97	P27	--	0.450	0.401	na	ICP
Mg	mg/L	Jan-97	T143	--	10.1	10.4	na	ICP
Mg	mg/L	Jan-97	T145	--	8.17	8.68	na	ICP
Mg	mg/L	Aug-97	M142	28.2	24.4	25.3	ICP	ICP
Mg	mg/L	Aug-97	P28	--	0.87	0.883	na	ICP
Mg	mg/L	Aug-97	T147	9.1	8.04	8.20	ICP	ICP
Mg	mg/L	Aug-97	T149	14.6	13.1	13.1	ICP	ICP
Mg	mg/L	Feb-98	GWM2	--	13.7	14.	na	ICP
Mg	mg/L	Feb-98	M144	--	17.2	17.0	na	ICP
Mg	mg/L	Feb-98	P29	--	0.59	0.57	na	ICP
Mg	mg/L	Feb-98	T151	--	17.5	17.5	na	ICP
Mg	mg/L	Jul-98	M146	--	7.01	7.01	na	ICP
Mg	mg/L	Jul-98	P30	--	0.023	0.027	na	ICP
Mg	mg/L	Jul-98	T153	--	8.59	8.72	na	ICP
Mg	mg/L	Dec-98	M148	--	1.22	1.22	na	ICP
Mg	mg/L	Dec-98	T155	13.4	11.1	11.1	ICP	ICP
Mg	mg/L	Aug-99	GWM4	--	18.4	18.8	na	ICP
Mg	mg/L	Aug-99	GWT5	--	18.4	18.8	na	ICP
Mg	mg/L	Aug-99	M150	1.6	1.43	1.43	na	ICP
Mg	mg/L	Aug-99	P32	--	0.37	0.378	na	ICP
Mg	mg/L	Aug-99	T157	1.2	1.03	1.03	na	ICP
Mn	µg/L	Jan-94	T127	<20	4.8	5.43	ICP	ICP-MS
Mn	µg/L	Aug-94	T129	20	24.2	25.2	ICP	ICP
Mn	µg/L	Jan-95	T131	40	36.3	37.8	ICP	ICP-MS
Mn	µg/L	Jan-95	T133	12	116	121	ICP	ICP-MS

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
Mn	µg/L	Jul-95	T135	--	432	423	na	AA: direct, air
Mn	µg/L	Feb-96	T137	100	89.37	98	ICP	ICP-MS
Mn	µg/L	Aug-96	T139	--	2.2	2.4	na	ICP-MS
Mn	µg/L	Aug-96	T141	--	19.7	20.0	na	ICP-MS
Mn	µg/L	Jan-97	T143	--	17.8	18.2	na	ICP-MS
Mn	µg/L	Jan-97	T145	--	20.3	20.9	na	ICP-MS
Mn	µg/L	Aug-97	T147	<30	15.9	17.2	ICP	ICP-MS
Mn	µg/L	Aug-97	T149	<30	11.2	11.8	ICP	ICP
Mn	µg/L	Feb-98	T151	--	12.8	13.0	na	ICP-MS
Mn	µg/L	Jul-98	T153	--	72.5	74.5	na	ICP-MS
Mn	µg/L	Dec-98	T155	--	48.0	50.9	na	ICP-MS
Mo	µg/L	Jan-94	T127	--	0.46	1.25	na	ICP-MS
Mo	µg/L	Aug-94	T129	<30	19.2	20.3	ICP	ICP-MS
Mo	µg/L	Jan-95	T131	130	114	112	ICP	GFAA
Mo	µg/L	Jan-95	T133	40	46.8	46.0	ICP	GFAA
Mo	µg/L	Jul-95	T135	--	66.7	63.0	na	ICP-MS
Mo	µg/L	Feb-96	T137	--	8.9	8.9	na	GFAA
Mo	µg/L	Aug-96	T139	--	14.7	14.9	na	ICP-MS
Mo	µg/L	Aug-96	T141	--	2.2	2.1	na	ICP-MS
Mo	µg/L	Jan-97	T143	--	34.4	36.1	na	GFAA
Mo	µg/L	Jan-97	T145	--	8.67	9.23	na	GFAA
Mo	µg/L	Aug-97	T147	<30	10.9	11.8	ICP	GFAA
Mo	µg/L	Aug-97	T149	<30	1.14	1.25	ICP	ICP-MS
Mo	µg/L	Feb-98	T151	--	29.2	29.0	na	ICP-MS
Mo	µg/L	Jul-98	T153	--	155	154	na	ICP-MS
Mo	µg/L	Dec-98	T155	--	25.2	25.2	na	ICP-MS
Mo	µg/L	Aug-99	GWT5	--	9.76	9.27	na	ICP-MS
Mo	µg/L	Aug-99	T157	--	9.5	13.0	na	ICP-MS
Na	mg/L	Jan-94	M128	128	121	126	ICP	ICP
Na	mg/L	Jan-94	T127	71	71.1	65.1	ICP	AA: direct, air
Na	mg/L	Feb-94	P21	--	0.13	0.117	na	AA: direct, air
Na	mg/L	Aug-94	M130	36	34.6	35.8	ICP	AA: direct, air
Na	mg/L	Aug-94	P22	--	1.78	1.70	na	ICP
Na	mg/L	Aug-94	T129	35	35.0	35.5	ICP	AA: direct, air
Na	mg/L	Jan-95	M132	52	48.1	47.9	ICP	AA: direct, air
Na	mg/L	Jan-95	P23	--	0.500	0.500	na	AA: direct, air
Na	mg/L	Jan-95	T131	22	21.4	21.4	ICP	AA: direct, air
Na	mg/L	Jan-95	T133	30	29.5	29.4	ICP	AA: direct, air
Na	mg/L	Jul-95	M134	--	60.4	60.7	na	AA: direct, air
Na	mg/L	Jul-95	P24	--	0.27	0.246	na	AA: direct, air
Na	mg/L	Jul-95	T135	--	30.4	30.8	na	AA: direct, air
Na	mg/L	Feb-96	M136	118	107.6	108	ICP	AA: direct, air
Na	mg/L	Feb-96	P25	--	1.24	1.28	na	AA: direct, air
Na	mg/L	Feb-96	T137	22	20.7	22	ICP	AA: direct, air
Na	mg/L	Apr-96	M138	28	31.4	31.6	ICP	AA: direct, air
Na	mg/L	Jun-96	P26	--	4.49	4.40	na	ICP
Na	mg/L	Aug-96	T139	88	91.1	90.9	ICP	AA: direct, air
Na	mg/L	Aug-96	T141	30	32.5	33.0	ICP	ICP
Na	mg/L	Jan-97	M140	--	38.2	39.0	na	ICP
Na	mg/L	Jan-97	P27	--	1.34	1.34	na	ICP
Na	mg/L	Jan-97	T143	--	33.6	34.0	na	ICP
Na	mg/L	Jan-97	T145	--	40.2	41.2	na	ICP
Na	mg/L	Aug-97	M142	149	150	153	ICP	ICP
Na	mg/L	Aug-97	P28	--	3.30	3.25	na	ICP

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
Na	mg/L	Aug-97	T147	54	53.7	52.6	ICP	ICP
Na	mg/L	Aug-97	T149	45	43.0	42.8	ICP	ICP
Na	mg/L	Feb-98	GWM2	--	116	117	na	ICP
Na	mg/L	Feb-98	M144	--	78.8	77.7	na	ICP
Na	mg/L	Feb-98	P29	--	0.68	0.66	na	ICP
Na	mg/L	Feb-98	T151	--	55.4	55.0	na	ICP
Na	mg/L	Jul-98	M146	--	44.6	45.0	na	ICP
Na	mg/L	Jul-98	P30	--	0.32	0.34	na	ICP
Na	mg/L	Jul-98	T153	--	28.6	28.7	na	ICP
Na	mg/L	Dec-98	M148	31	32.5	31.5	ICP	ICP
Na	mg/L	Dec-98	T155	28	28.6	28.4	ICP	ICP
Na	mg/L	Aug-99	GWM4	--	77.8	79.0	na	ICP
Na	mg/L	Aug-99	GWT5	--	82.6	84.0	na	ICP
Na	mg/L	Aug-99	M150	17	17.9	17.5	ICP	ICP
Na	mg/L	Aug-99	P32	--	1.72	1.75	na	ICP
Na	mg/L	Aug-99	T157	58	59.7	60.7	ICP	ICP
NH ₃ -N	mg/L	Jan-94	N41n	1.3	--	1.22	Colorimetry: phenate	na
NH ₃ -N	mg/L	Jan-94	N41p	--	1.22	1.22	na	Colorimetry: phenate
NH ₃ -N	mg/L	Feb-94	N40p	--	0.040	0.035	na	Colorimetry: phenate
NH ₃ -N	mg/L	Aug-94	N42n	<0.2	--	0.25	Colorimetry: phenate	na
NH ₃ -N	mg/L	Aug-94	N42p	--	0.19	0.20	na	Colorimetry: phenate
NH ₃ -N	mg/L	Jan-95	N43	<0.2	0.110	0.11	Colorimetry: phenate	Colorimetry: phenate
NH ₃ -N	mg/L	Jan-95	N44	0.9	0.760	0.900	Colorimetry: phenate	Colorimetry: phenate
NH ₃ -N	mg/L	Jul-95	N45	--	0.05	0.060	na	Colorimetry: phenate
NH ₃ -N	mg/L	Jul-95	N46	1.0	1.08	1.04	Colorimetry: phenate	Colorimetry: phenate
NH ₃ -N	mg/L	Feb-96	N47	--	--	0.165	na	na
NH ₃ -N	mg/L	Feb-96	N48	0.6	--	0.698	Colorimetry: phenate	na
NH ₃ -N	mg/L	Aug-96	N49	--	0.18	0.155	na	Colorimetry: phenate
NH ₃ -N	mg/L	Aug-96	N50	--	1.04	0.82	na	Colorimetry: phenate
NH ₃ -N	mg/L	Jan-97	N51	--	0.03	0.07	na	Colorimetry: phenate
NH ₃ -N	mg/L	Jan-97	N52	--	1.36	1.33	na	Colorimetry: phenate
NH ₃ -N	mg/L	Aug-97	N53	3.1	3.70	3.50	Colorimetry: phenate	Colorimetry: phenate
NH ₃ -N	mg/L	Aug-97	N54	1.1	1.01	1.00	Colorimetry: phenate	Colorimetry: phenate
NH ₃ -N	mg/L	Feb-98	N55	0.2	0.21	0.240	Colorimetry: phenate	Colorimetry: phenate
NH ₃ -N	mg/L	Feb-98	N56	0.5	0.47	0.498	Colorimetry: phenate	Colorimetry: phenate
NH ₃ -N	mg/L	Jul-98	N57	0.4	0.199	0.210	Colorimetry: phenate	Colorimetry: phenate
NH ₃ -N	mg/L	Jul-98	N58	0.3	0.640	0.620	Colorimetry: phenate	Colorimetry: phenate
NH ₃ -N	mg/L	Dec-98	N59	--	0.36	0.327	na	Colorimetry: phenate
NH ₃ -N	mg/L	Dec-98	N60	0.5	0.64	0.578	Colorimetry: phenate	Colorimetry: phenate
NH ₃ -N	mg/L	Aug-99	N61	--	0.03	0.040	na	Colorimetry: phenate
NH ₃ -N	mg/L	Aug-99	N62	0.8	1.04	1.01	Colorimetry: indophenol	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Jan-94	N40p	--	0.07	0.270	na	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Jan-94	N41n	1.6	--	1.76	Colorimetry: phenate	na
NH ₃ + Org N-N	mg/L	Jan-94	N41p	--	1.67	1.86	na	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Aug-94	N42n	2.0	--	1.70	Colorimetry: phenate	na
NH ₃ + Org N-N	mg/L	Aug-94	N42p	--	1.70	--	na	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Jan-95	N43	<0.3	0.270	0.23	Colorimetry: phenate	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Jan-95	N44	1.0	1.21	1.24	Colorimetry: phenate	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Jul-95	N45	--	<0.2	0.300	na	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Jul-95	N46	2.4	1.68	1.81	Colorimetry: phenate	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Feb-96	N47	0.6	--	0.48	Colorimetry: phenate	na
NH ₃ + Org N-N	mg/L	Feb-96	N48	1.6	--	1.29	Colorimetry: phenate	na
NH ₃ + Org N-N	mg/L	Aug-96	N49	--	0.38	0.33	na	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Aug-96	N50	--	1.43	1.39	na	Colorimetry: phenate

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
NH ₃ + Org N-N	mg/L	Jan-97	N51	--	0.22	0.29	na	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Jan-97	N52	--	2.16	2.37	na	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Aug-97	N53	3.8	4.20	3.95	Colorimetry: phenate	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Aug-97	N54	0.8	1.30	1.26	Colorimetry: phenate	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Feb-98	N55	<0.3	0.27	0.300	Colorimetry: phenate	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Feb-98	N56	0.6	0.66	0.750	Colorimetry: phenate	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Jul-98	N57	0.5	0.186	0.285	Colorimetry: phenate	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Jul-98	N58	0.9	0.855	0.910	Colorimetry: phenate	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Dec-98	N59	--	0.37	0.390	na	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Dec-98	N60	--	0.88	0.878	na	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Aug-99	N61	--	0.07	0.096	na	Colorimetry: phenate
NH ₃ + Org N-N	mg/L	Aug-99	N62	1.2	1.14	1.15	Colorimetry: indophenol	Colorimetry: phenate
Ni	µg/L	Jan-94	T127	<20	9.40	9.00	ICP	GFAA
Ni	µg/L	Aug-94	T129	<20	1.6	1.7	ICP	GFAA
Ni	µg/L	Jan-95	T131	60	58.4	56.3	ICP	ICP
Ni	µg/L	Jan-95	T133	30	26.7	27.2	ICP	ICP-MS
Ni	µg/L	Jul-95	T135	--	65.1	65.6	na	ICP-MS
Ni	µg/L	Feb-96	T137	30	15.4	15	ICP	GFAA
Ni	µg/L	Aug-96	T139	--	14.0	13.1	na	GFAA
Ni	µg/L	Aug-96	T141	--	17.9	17.0	na	ICP-MS
Ni	µg/L	Jan-97	T143	--	71.1	71.0	na	ICP-MS
Ni	µg/L	Jan-97	T145	--	10.9	11.0	na	GFAA
Ni	µg/L	Aug-97	T147	<20	13.0	13.6	ICP	ICP-MS
Ni	µg/L	Aug-97	T149	30	33.1	31.2	ICP	GFAA
Ni	µg/L	Feb-98	T151	--	10.0	10.0	na	ICP-MS
Ni	µg/L	Jul-98	T153	--	31.2	32.2	na	ICP-MS
Ni	µg/L	Dec-98	T155	--	8.22	8.30	na	ICP-MS
Ni	µg/L	Aug-99	GWT5	--	4.03	4.45	na	ICP-MS
Ni	µg/L	Aug-99	T157	--	30.0	30.0	na	AA: direct, air
NO ₂ + NO ₃ -N	mg/L	Jan-94	N41n	1.27	--	1.25	Colorimetry: Cd diazo	na
NO ₂ + NO ₃ -N	mg/L	Jan-94	N41p	--	1.25	1.25	na	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Feb-94	N40n	0.11	--	0.110	Colorimetry: Cd diazo	na
NO ₂ + NO ₃ -N	mg/L	Feb-94	N40p	--	0.116	0.119	na	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Feb-94	N41p	--	1.25	1.25	na	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Aug-94	N42n	1.98	--	1.93	Colorimetry: Cd diazo	na
NO ₂ + NO ₃ -N	mg/L	Aug-94	N42p	--	1.94	1.92	na	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Jan-95	N43	0.14	0.150	0.15	Colorimetry: Cd diazo	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Jan-95	N44	0.78	0.780	0.800	Colorimetry: Cd diazo	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Jul-95	N45	0.29	0.21	0.29	Colorimetry: Cd diazo	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Jul-95	N46	1.28	1.18	1.23	Colorimetry: Cd diazo	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Feb-96	N47	0.25	--	0.24	Colorimetry: Cd diazo	na
NO ₂ + NO ₃ -N	mg/L	Feb-96	N48	0.78	--	0.78	Colorimetry: Cd diazo	na
NO ₂ + NO ₃ -N	mg/L	Aug-96	N49	0.21	0.21	0.18	Colorimetry: Cd diazo	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Aug-96	N50	--	0.85	0.810	na	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Jan-97	N51	--	<0.005	0.01	na	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Jan-97	N52	--	1.70	1.72	na	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Aug-97	N53	2.62	2.81	2.57	Colorimetry: Cd diazo	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Aug-97	N54	1.14	1.21	1.17	Colorimetry: Cd diazo	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Feb-98	N55	0.38	0.46	0.443	Colorimetry: Cd diazo	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Feb-98	N56	0.76	0.73	0.747	Colorimetry: Cd diazo	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Jul-98	N57	0.21	0.20	0.220	Colorimetry: Cd diazo	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Jul-98	N58	1.01	0.94	1.01	Colorimetry: Cd diazo	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Dec-98	N59	0.36	0.39	0.370	Colorimetry: Cd diazo	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Dec-98	N60	0.92	0.86	0.91	Colorimetry: Cd diazo	Colorimetry: Cd diazo

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
NO ₂ + NO ₃ -N	mg/L	Aug-99	N61	--	0.02	0.036	na	Colorimetry: Cd diazo
NO ₂ + NO ₃ -N	mg/L	Aug-99	N62	1.01	0.910	0.917	na	Colorimetry: Cd diazo
P	mg/L	Jan-94	M128	1.41	1.41	1.39	Colorimetry:	Colorimetry:
P	mg/L	Jan-94	N41n	1.65	--	1.63	phosphomolybdate	phosphomolybdate
P	mg/L	Jan-94	N41p	--	1.66	1.64	Colorimetry:	na
P	mg/L	Jan-94	N40p	--	0.06	0.062	na	Colorimetry:
P	mg/L	Aug-94	M130	<0.2	0.006	0.085	Colorimetry:	phosphomolybdate
P	mg/L	Aug-94	N42n	1.13	--	1.15	phosphomolybdate	Colorimetry:
P	mg/L	Aug-94	N42p	--	1.15	1.15	Colorimetry:	phosphomolybdate
P	mg/L	Jan-95	M132	0.03	0.06	0.03	na	Colorimetry:
P	mg/L	Jan-95	N43	0.14	0.120	0.13	phosphomolybdate	Colorimetry:
P	mg/L	Jan-95	N44	0.92	0.900	0.920	Colorimetry:	phosphomolybdate
P	mg/L	Jul-95	N45	0.13	0.130	0.139	phosphomolybdate	Colorimetry:
P	mg/L	Jul-95	N46	--	1.20	1.23	Colorimetry:	phosphomolybdate
P	mg/L	Feb-96	M136	--	0.83	0.885	na	Colorimetry:
P	mg/L	Feb-96	N47	0.17	--	0.223	Colorimetry:	phosphomolybdate
P	mg/L	Feb-96	N48	0.73	--	0.794	Colorimetry:	na
P	mg/L	Apr-96	M138	0.67	0.22	0.240	phosphomolybdate	Colorimetry:
P	mg/L	Aug-96	N49	0.29	0.21	0.17	Colorimetry:	phosphomolybdate
P	mg/L	Aug-96	N50	--	1.03	0.903	phosphomolybdate	Colorimetry:
P	mg/L	Jan-97	M140	--	0.030	0.032	na	phosphomolybdate
P	mg/L	Jan-97	N51	--	0.03	0.04	na	Colorimetry:
P	mg/L	Jan-97	N52	--	1.55	1.60	na	phosphomolybdate
P	mg/L	Aug-97	M142	<0.02	0.01	0.02	Colorimetry:	phosphomolybdate
P	mg/L	Aug-97	N53	2.26	2.47	2.32	Colorimetry:	Colorimetry:
P	mg/L	Aug-97	N54	1.67	1.89	1.78	phosphomolybdate	phosphomolybdate
P	mg/L	Feb-98	GWM2	0.16	0.18	0.20	Colorimetry:	Colorimetry:
							molybdate blue	phosphomolybdate

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
P	mg/L	Feb-98	M144	0.03	0.02	0.030	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
P	mg/L	Feb-98	N55	0.56	0.56	0.602	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
P	mg/L	Feb-98	N56	0.66	0.69	0.715	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
P	mg/L	Jul-98	N57	0.23	0.216	0.201	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
P	mg/L	Jul-98	N58	0.77	0.787	0.766	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
P	mg/L	Dec-98	M148	0.48	--	0.495	Colorimetry: phosphomolybdate	na
P	mg/L	Dec-98	N59	0.39	0.41	0.412	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
P	mg/L	Dec-98	N60	0.75	0.81	0.770	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
P	mg/L	Aug-99	M150	--	<0.004	--	na	Colorimetry: phosphomolybdate
P	mg/L	Aug-99	N61	--	0.04	0.040	na	Colorimetry: phosphomolybdate
P	mg/L	Aug-99	N62	0.82	0.85	0.805	na	Colorimetry: phosphomolybdate
Pb	µg/L	Jan-94	T127	<10	3.60	3.25	GFAA	GFAA
Pb	µg/L	Aug-94	T129	<10	0.03	1.00	ICP	ICP-MS
Pb	µg/L	Jan-95	T131	18	19.0	18.1	GFAA	GFAA
Pb	µg/L	Jan-95	T133	27	27.3	27.8	GFAA	ICP-MS
Pb	µg/L	Jul-95	T135	--	100	103	na	ICP-MS
Pb	µg/L	Feb-96	T137	--	6.13	6.3	na	ICP-MS
Pb	µg/L	Aug-96	T139	--	4.20	4.47	na	ICP-MS
Pb	µg/L	Aug-96	T141	--	5.7	5.7	na	ICP-MS
Pb	µg/L	Jan-97	T143	--	83.6	83.4	na	ICP-MS
Pb	µg/L	Jan-97	T145	--	12.6	12.7	na	GFAA
Pb	µg/L	Aug-97	T147	<10	14.0	13.8	GFAA	GFAA
Pb	µg/L	Aug-97	T149	<10	8.60	8.84	GFAA	ICP-MS
Pb	µg/L	Feb-98	T151	16	20	19.75	GFAA	GFAA
Pb	µg/L	Jul-98	T153	--	46.4	46.2	na	ICP-MS
Pb	µg/L	Dec-98	T155	15	18.1	18.8	GFAA	ICP-MS
Pb	µg/L	Aug-99	T157	--	4.40	6.90	na	GFAA
pH, lab	standard unit	Jan-94	M128	8.2	8.14	8.29	Electrometric electrode	Electrometric electrode
pH, lab	standard unit	Feb-94	P21	--	4.07	4.06	na	Electrometric electrode
pH, lab	standard unit	Aug-94	M130	8.0	7.88	8.02	Electrometric electrode	Electrometric electrode
pH, lab	standard unit	Aug-94	P22	--	7.27	5.81	na	Electrometric electrode
pH, lab	standard unit	Jan-95	M132	7.7	7.88	8.09	Electrometric electrode	Electrometric electrode
pH, lab	standard unit	Jan-95	P23	--	6.58	6.40	na	Electrometric electrode
pH, lab	standard unit	Jul-95	M134	--	7.52	7.72	na	Electrometric electrode
pH, lab	standard unit	Jul-95	P24	--	4.92	4.73	na	Electrometric electrode

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
pH, lab	standard unit	Feb-96	M136	8.0	8.17	8.33	Electrometric electrode	Electrometric electrode
pH, lab	standard unit	Feb-96	P25	--	6.6	6.52	na	Electrometric electrode
pH, lab	standard unit	Apr-96	M138	7.7	7.83	7.81	Electrometric electrode	Electrometric electrode
pH, lab	standard unit	Jun-96	P26	--	4.64	4.70	na	Electrometric electrode
pH, lab	standard unit	Jan-97	M140	--	8.21	8.28	na	Electrometric electrode
pH, lab	standard unit	Jan-97	P27	--	6.99	6.92	na	Electrometric electrode
pH, lab	standard unit	Aug-97	M142	8.6	8.52	8.54	Electrometric electrode	Electrometric electrode
pH, lab	standard unit	Aug-97	P28	--	6.82	6.75	na	Electrometric electrode
pH, lab	standard unit	Feb-98	M144	8.2	8.12	8.40	Electrometric electrode	Electrometric electrode
pH, lab	standard unit	Feb-98	P29	--	6.85	6.85	na	Electrometric electrode
pH, lab	standard unit	Jul-98	M146	--	8.08	8.08	na	Electrometric electrode
pH, lab	standard unit	Jul-98	P30	--	5.47	5.35	na	Electrometric electrode
pH, lab	standard unit	Dec-98	M148	3.4	3.46	3.50	Electrometric electrode	Electrometric electrode
pH, lab	standard unit	Aug-99	GWM4	--	8.16	8.10	na	Electrometric electrode
pH, lab	standard unit	Aug-99	M150	7.2	7.33	7.74	na	Electrometric electrode
pH, lab	standard unit	Aug-99	P32	--	4.43	4.42	na	Electrometric electrode
PO ₄ -P	mg/L	Feb-94	N40p	--	0.053	0.054	na	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Feb-94	P21	--	0.030	0.005	na	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Aug-94	P22	--	<0.001	0.008	na	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Aug-94	N42n	0.54	--	0.62	Colorimetry: phosphomolybdate	--
PO ₄ -P	mg/L	Aug-94	N42p	--	0.54	0.56	na	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Aug-94	P22	--	<0.001	0.0008	na	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Jan-95	N43	0.09	0.110	0.100	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Jan-95	N44	0.91	0.840	0.900	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Jan-95	P23	--	0.140	0.133	na	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Jul-95	N45	0.11	0.12	0.120	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
PO ₄ -P	mg/L	Jul-95	N46	0.84	0.920	0.920	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Jul-95	P24	--	0.190	0.028	na	IC
PO ₄ -P	mg/L	Feb-96	N47	0.13	--	0.151	Colorimetry: phosphomolybdate	na
PO ₄ -P	mg/L	Feb-96	N48	0.53	--	0.580	Colorimetry: phosphomolybdate	na
PO ₄ -P	mg/L	Feb-96	P25	--	0.06	0.068	na	IC
PO ₄ -P	mg/L	Jun-96	P26	--	<0.16	0.004	na	IC
PO ₄ -P	mg/L	Aug-96	N49	0.19	0.150	0.150	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Aug-96	N50	--	0.92	0.73	na	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Jan-97	N51	--	<0.001	0.020	na	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Jan-97	N52	--	1.20	1.16	na	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Jan-97	P27	--	<0.001	0.002	na	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Aug-97	N53	2.15	2.28	2.12	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Aug-97	N54	1.71	1.88	1.72	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Feb-98	N55	0.56	0.574	0.580	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Feb-98	N56	0.62	0.630	0.658	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Feb-98	P29	--	0.04	0.046	na	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Jul-98	N57	0.18	0.208	0.195	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Jul-98	N58	0.68	0.737	0.693	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Jul-98	P30	--	0.084	0.084	na	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Dec-98	N59	0.40	0.447	0.399	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Dec-98	N60	0.65	0.641	0.680	Colorimetry: phosphomolybdate	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Aug-99	N61	--	0.039	0.038	na	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Aug-99	N62	0.81	0.882	0.795	na	Colorimetry: phosphomolybdate
PO ₄ -P	mg/L	Aug-99	P32	--	0.180	0.177	na	IC
Sb	µg/L	Feb-93	T121	<100	10.9	7.61	--	AA: hydride
Sb	µg/L	Aug-93	T123	--	7.18	6.99	na	ICP/MS
Sb	µg/L	Aug-93	T125	--	6.05	6.24	na	ICP/MS
Sb	µg/L	Jan-94	T127	<10	5.10	5.15	ICP	ICP-MS
Sb	µg/L	Aug-94	T129	<100	0.22	0.55	ICP	ICP-MS
Sb	µg/L	Jan-95	T131	<10	57.4	56.2	ICP	ICP-MS
Sb	µg/L	Jan-95	T133	<10	14.7	14.4	ICP	ICP-MS
Sb	µg/L	Jul-95	T135	--	82.3	76.3	na	GFAA
Sb	µg/L	Feb-96	T137	--	15.5	15.5	na	GFAA

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
Sb	µg/L	Aug-96	T139	--	8.80	9.39	na	GFAA
Sb	µg/L	Aug-96	T141	--	3.8	3.5	na	GFAA
Sb	µg/L	Jan-97	T143	--	15.9	16.6	na	GFAA
Sb	µg/L	Jan-97	T145	--	8.65	8.80	na	GFAA
Sb	µg/L	Aug-97	T147	--	11.0	10.5	na	GFAA
Sb	µg/L	Aug-97	T149	--	22.1	21.1	na	ICP-MS
Sb	µg/L	Feb-98	T151	--	28.7	26.8	na	ICP-MS
Sb	µg/L	Jul-98	T153	--	27.6	25.7	na	ICP-MS
Sb	µg/L	Dec-98	T155	--	17.4	16.8	na	GFAA
Sb	µg/L	Aug-99	GWT5	--	58.7	57.4	na	ICP-MS
Sb	µg/L	Aug-99	T157	--	10.6	10.8	na	GFAA
Se	µg/L	Jan-94	T127	4	6.40	7.38	GFAA	AA: hydride
Se	µg/L	Aug-94	T129	<2	<1	1.60	GFAA	AA: hydride
Se	µg/L	Jan-95	T131	8	11.8	11.2	GFAA	GFAA
Se	µg/L	Jan-95	T133	17	23.2	21.4	GFAA	GFAA
Se	µg/L	Jul-95	T135	--	10.1	10.0	na	GFAA
Se	µg/L	Feb-96	T137	--	<1	1.3	na	GFAA
Se	µg/L	Aug-96	T139	--	4.0	4.83	na	GFAA
Se	µg/L	Aug-96	T141	--	7.7	8.4	na	GFAA
Se	µg/L	Jan-97	T143	--	8.8	9.63	na	GFAA
Se	µg/L	Jan-97	T145	--	10.0	10.1	na	AA: hydride
Se	µg/L	Aug-97	T147	--	9.4	10.1	na	GFAA
Se	µg/L	Aug-97	T149	--	1.3	2.10	na	GFAA
Se	µg/L	Feb-98	T151	--	<1	1.80	na	AA: hydride
Se	µg/L	Jul-98	T153	--	8.6	9.00	na	GFAA
Se	µg/L	Dec-98	T155	7	8.8	8.28	GFAA	GFAA
Se	µg/L	Aug-99	GWT5	--	10.9	11.0	na	GFAA
Se	µg/L	Aug-99	T157	4	4.8	4.60	na	GFAA
SiO ₂	mg/L	Jan-94	M128	--	10.8	10.8	na	ICP
SiO ₂	mg/L	Jan-94	T127	--	9.55	9.63	na	ICP
SiO ₂	mg/L	Aug-94	M130	--	9.52	9.20	na	Colorimetry: molybdate blue
SiO ₂	mg/L	Aug-94	T129	--	9.31	9.15	na	ICP
SiO ₂	mg/L	Jan-95	M132	--	2.47	2.46	na	ICP
SiO ₂	mg/L	Jan-95	T131	--	5.75	5.80	na	ICP
SiO ₂	mg/L	Jan-95	T133	--	9.87	10.1	na	ICP
SiO ₂	mg/L	Jul-95	M134	--	5.43	5.34	na	ICP
SiO ₂	mg/L	Jul-95	T135	--	4.29	4.28	na	ICP
SiO ₂	mg/L	Feb-96	M136	--	12.59	13.0	na	Colorimetry: molybdate blue
SiO ₂	mg/L	Feb-96	T137	--	6.91	6.96	na	ICP
SiO ₂	mg/L	Apr-96	M138	--	8.90	8.94	na	Colorimetry: molybdate blue
SiO ₂	mg/L	Aug-96	T139	--	9.57	9.31	na	ICP
SiO ₂	mg/L	Aug-96	T141	--	8.98	8.70	na	ICP
SiO ₂	mg/L	Jan-97	M140	--	6.89	7.35	na	ICP
SiO ₂	mg/L	Jan-97	T143	--	22.1	23.4	na	ICP
SiO ₂	mg/L	Jan-97	T145	--	10.6	11.3	na	ICP
SiO ₂	mg/L	Aug-97	M142	--	7.44	7.67	na	Colorimetry: molybdate blue
SiO ₂	mg/L	Aug-97	T147	--	24.2	24.0	na	ICP
SiO ₂	mg/L	Aug-97	T149	--	11.8	11.8	na	ICP
SiO ₂	mg/L	Feb-98	GWM2	--	25.6	26.7	na	ICP
SiO ₂	mg/L	Feb-98	M144	--	7.30	7.43	na	ICP

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
SiO ₂	mg/L	Feb-98	T151	--	1.40	1.43	na	ICP
SiO ₂	mg/L	Jul-98	M146	--	9.16	9.36	na	Colorimetry: molybdate blue
SiO ₂	mg/L	Jul-98	T153	--	5.59	5.79	na	ICP
SiO ₂	mg/L	Dec-98	M148	--	5.13	5.21	na	Colorimetry: molybdate blue
SiO ₂	mg/L	Dec-98	T155	--	10.0	10.2	na	ICP
SiO ₂	mg/L	Aug-99	GWM4	--	8.89	9.38	na	Colorimetry: molybdate blue
SiO ₂	mg/L	Aug-99	GWT5	--	9.34	9.34	na	ICP
SiO ₂	mg/L	Aug-99	M150	--	12.1	12.6	na	Colorimetry: molybdate blue
SiO ₂	mg/L	Aug-99	T157	--	14.1	14.2	na	ICP
SO ₄	mg/L	Jan-94	M128	217	210	206	Colorimetry: methyl thymol blue	IC
SO ₄	mg/L	Feb-94	P21	--	0.51	0.50	na	IC
SO ₄	mg/L	Aug-94	M130	60	57.9	58.0	Colorimetry: methyl thymol blue	IC
SO ₄	mg/L	Aug-94	P22	--	0.69	0.728	na	IC
SO ₄	mg/L	Jan-95	M132	60	58.8	60.0	Colorimetry: methyl thymol blue	IC
SO ₄	mg/L	Jan-95	P23	--	1.27	1.28	na	IC
SO ₄	mg/L	Jul-95	M134	--	74.9	78.0	na	IC
SO ₄	mg/L	Jul-95	P24	--	0.32	0.338	na	IC
SO ₄	mg/L	Feb-96	M136	82	151	150	Colorimetry: methyl thymol blue	IC
SO ₄	mg/L	Feb-96	P25	--	2.35	2.34	na	IC
SO ₄	mg/L	Apr-96	M138	24	27.0	28.0	Colorimetry: methyl thymol blue	IC
SO ₄	mg/L	Jun-96	P26	--	0.63	0.67	na	IC
SO ₄	mg/L	Jan-97	M140	--	150	150	na	IC
SO ₄	mg/L	Jan-97	P27	--	2.43	2.42	na	IC
SO ₄	mg/L	Aug-97	M142	248	232	231	Colorimetry: methyl thymol blue	IC
SO ₄	mg/L	Aug-97	P28	--	6.28	6.14	na	IC
SO ₄	mg/L	Feb-98	GWM2	105	91.4	93.6	Colorimetry: methyl thymol blue	IC
SO ₄	mg/L	Feb-98	M144	220	210	210	Colorimetry: methyl thymol blue	IC
SO ₄	mg/L	Feb-98	P29	--	1.14	1.10	na	IC
SO ₄	mg/L	Jul-98	M146	--	68	69.0	na	IC
SO ₄	mg/L	Jul-98	P30	--	.37	0.400	na	IC
SO ₄	mg/L	Dec-98	M148	--	7.50	6.59	na	IC
SO ₄	mg/L	Aug-99	GWM4	--	78.8	82.0	na	IC
SO ₄	mg/L	Aug-99	M150	--	4.57	5.50	na	IC
SO ₄	mg/L	Aug-99	P32	--	1.91	1.88	na	IC
SC, lab	µS/cm	Jan-94	M128	1,080	1,085	1076	Electrometric electrode	Electrometric electrode
SC, lab	µS/cm	Feb-94	P21	--	43.0	41.8	na	Electrometric electrode
SC, lab	µS/cm	Aug-94	M130	342	336	335	Electrometric electrode	Electrometric electrode
SC, lab	µS/cm	Aug-94	P22	--	17.5	17.0	na	Electrometric electrode
SC, lab	µS/cm	Jan-95	M132	422	498	493	Electrometric electrode	Electrometric electrode
SC, lab	µS/cm	Jan-95	P23	--	14.4	14.2	na	Electrometric electrode
SC, lab	µS/cm	Jul-95	M134	--	606	615	na	Electrometric electrode
SC, lab	µS/cm	Jul-95	P24	--	12.1	13.3	na	Electrometric electrode

120 Water Quality at a Biosolids-Application Area near Deer Trail, Colorado, 1993–1999

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
SC, lab	µS/cm	Feb-96	M136	848	917	920	Electrometric electrode	Electrometric electrode
SC, lab	µS/cm	Feb-96	P25	--	20.9	20.9	na	Electrometric electrode
SC, lab	µS/cm	Apr-96	M138	265	263	263	Electrometric electrode	Electrometric electrode
SC, lab	µS/cm	Jun-96	P26	--	38.3	36.1	na	Electrometric electrode
SC, lab	µS/cm	Jan-97	M140	--	600	600	na	Electrometric electrode
SC, lab	µS/cm	Jan-97	P27	--	26.8	26.1	na	Electrometric electrode
SC, lab	µS/cm	Aug-97	M142	--	1,204	1,200	na	Electrometric electrode
SC, lab	µS/cm	Aug-97	P28	--	36.8	36.6	na	Electrometric electrode
SC, lab	µS/cm	Feb-98	GWM2	691	937	934	Electrometric electrode	Electrometric electrode
SC, lab	µS/cm	Feb-98	M144	594	857	853	Electrometric electrode	Electrometric electrode
SC, lab	µS/cm	Feb-98	P29	--	19.2	19.2	na	Electrometric electrode
SC, lab	µS/cm	Jul-98	M146	--	427	423	na	Electrometric electrode
SC, lab	µS/cm	Jul-98	P30	--	6.4	6.0	na	Electrometric electrode
SC, lab	µS/cm	Dec-98	M148	363	375	380	Electrometric electrode	Electrometric electrode
SC, lab	µS/cm	Aug-99	GWM4	--	737	718	na	Electrometric electrode
SC, lab	µS/cm	Aug-99	M150	140	143	137	na	Electrometric electrode
SC, lab	µS/cm	Aug-99	P32	--	41	40.2	na	Electrometric electrode
Sr	µg/L	Jan-94	M128	--	700	705	na	ICP
Sr	µg/L	Jan-94	T127	--	50	51.1	na	ICP
Sr	µg/L	Aug-94	M130	--	177	180	na	ICP
Sr	µg/L	Aug-94	T129	--	177	181	na	ICP
Sr	µg/L	Jan-95	M132	--	243	248	na	ICP
Sr	µg/L	Jan-95	T131	--	287	295	na	ICP
Sr	µg/L	Jan-95	T133	--	119	123	na	ICP
Sr	µg/L	Jul-95	M134	--	299	291	na	ICP
Sr	µg/L	Jul-95	T135	--	47	46.0	na	ICP
Sr	µg/L	Feb-96	M136	--	557	567	na	ICP
Sr	µg/L	Feb-96	T137	--	230	230	na	ICP
Sr	µg/L	Apr-96	M138	--	109	106	na	ICP
Sr	µg/L	Aug-96	T139	--	399	401	na	ICP
Sr	µg/L	Aug-96	T141	--	157	157	na	ICP
Sr	µg/L	Jan-97	M140	--	666	671	na	ICP
Sr	µg/L	Jan-97	T143	--	301	306	na	ICP
Sr	µg/L	Jan-97	T145	--	198	203	na	ICP
Sr	µg/L	Aug-97	M142	--	650	646	na	ICP
Sr	µg/L	Aug-97	T147	--	304	313	na	ICP-MS
Sr	µg/L	Aug-97	T149	--	323	331	na	ICP-MS
Sr	µg/L	Feb-98	M144	--	654	673	na	ICP-MS
Sr	µg/L	Feb-98	T151	--	389	387	na	ICP
Sr	µg/L	Jul-98	M146	--	218	216	na	ICP
Sr	µg/L	Jul-98	T153	--	313	311	na	ICP
Sr	µg/L	Dec-98	M148	--	32	32.7	na	ICP-MS
Sr	µg/L	Dec-98	T155	--	357	363	na	ICP-MS
Sr	µg/L	Aug-99	GWT5	--	613	620	na	ICP
Sr	µg/L	Aug-99	M150	--	51	51.0	na	ICP
Sr	µg/L	Aug-99	T157	--	59	59.6	na	ICP-MS
Tl	µg/L	Feb-96	T137	--	165	162	na	ICP-MS
Tl	µg/L	Aug-96	T139	--	3.6	3.10	na	ICP-MS
Tl	µg/L	Aug-96	T141	--	3.8	4.0	na	ICP-MS
Tl	µg/L	Jan-97	T143	--	10.4	10.0	na	GFAA
Tl	µg/L	Jan-97	T145	--	16.7	15.3	na	GFAA
Tl	µg/L	Aug-97	T147	--	19.1	20.0	na	ICP-MS
Tl	µg/L	Aug-97	T149	--	31.0	31.4	na	ICP-MS
Tl	µg/L	Feb-98	T151	--	63.2	62.0	na	ICP-MS
Tl	µg/L	Jul-98	T153	--	22.1	20.4	na	GFAA

Appendix 8. Performance-evaluation data from the U.S. Geological Survey Standard Reference Program for the Metro Wastewater Reclamation District Laboratory (1993–1998) and the U.S. Geological Survey National Water Quality Laboratory (1993–1999).—Continued

[All abbreviations explained in appendix 2; USGS, U.S. Geological Survey; Metro District, Metro Wastewater Reclamation District Laboratory; NWQL, National Water Quality Laboratory; µg/L, micrograms per liter; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; ICP, inductively coupled plasma; MS, mass spectrometry; --, no data; na, not applicable; AA, atomic absorption spectrometry; GFAA, graphite-furnace atomic absorption spectrometry; <, less than; DCP, direct current plasma; IC, ion chromatography]

Analyte	Reported-value units	Date (month-year)	USGS standard reference sample	Metro District value	USGS NWQL value	Most probable value	Metro District analytical method	NWQL analytical method
Tl	µg/L	Dec-98	T155	--	9.0	9.47	na	ICP-MS
Tl	µg/L	Aug-99	T157	--	9.4	8.75	na	GFAA
U	µg/L	Aug-96	T139	--	4.8	5.00	na	ICP-MS
U	µg/L	Aug-96	T141	--	3.7	3.85	na	ICP-MS
U	µg/L	Jan-97	T143	--	10.8	12.0	na	ICP-MS
U	µg/L	Jan-97	T145	--	1.1	1.10	na	ICP-MS
U	µg/L	Aug-97	T147	--	3.0	3.21	na	ICP-MS
U	µg/L	Aug-97	T149	--	2.4	2.71	na	ICP-MS
U	µg/L	Feb-98	T151	--	15.0	15.0	na	ICP-MS
U	µg/L	Jul-98	T153	--	7.1	6.90	na	ICP-MS
U	µg/L	Dec-98	T155	--	7.0	7.50	na	ICP-MS
U	µg/L	Aug-99	GWT5	--	6.4	6.42	na	ICP-MS
U	µg/L	Aug-99	T157	--	3.2	3.19	na	ICP-MS
V	µg/L	Jan-94	M128	--	3.53	2.6	na	Colorimetry
V	µg/L	Jan-94	T127	--	10.1	10.2	na	ICP
V	µg/L	Aug-94	T129	--	<6	1.0	na	ICP
V	µg/L	Jan-95	M132	--	1.05	2.00	na	Colorimetry
V	µg/L	Jan-95	T131	--	31.7	34.2	na	ICP
V	µg/L	Jan-95	T133	--	11.9	13.0	na	ICP
V	µg/L	Jul-95	M134	--	2.73	3.55	na	Colorimetry
V	µg/L	Jul-95	T135	--	52.9	52.8	na	ICP
V	µg/L	Feb-96	M136	--	5.98	6.9	na	Colorimetry
V	µg/L	Feb-96	T137	--	13.3	14.0	na	ICP
V	µg/L	Apr-96	M138	--	19.7	16.5	na	Colorimetry
V	µg/L	Aug-96	T139	--	4.3	5.0	na	ICP
V	µg/L	Aug-96	T141	--	9.30	9.45	na	ICP
V	µg/L	Jan-97	M140	--	1.40	3.42	na	Colorimetry
V	µg/L	Jan-97	T143	--	31.1	30.0	na	ICP
V	µg/L	Jan-97	T145	--	12.0	11.7	na	ICP
V	µg/L	Aug-97	M142	--	22.7	22.7	na	ICP
V	µg/L	Aug-97	T147	--	15.3	15.2	na	ICP-MS
V	µg/L	Aug-97	T149	--	31.0	31.0	na	ICP
V	µg/L	Feb-98	T151	--	58.3	59.0	na	ICP
V	µg/L	Jul-98	M146	--	33.1	32.6	na	ICP
V	µg/L	Jul-98	T153	--	18.7	19.0	na	ICP
V	µg/L	Dec-98	T155	--	26.5	25.4	na	ICP
V	µg/L	Aug-99	M150	--	32.3	31.0	na	ICP
V	µg/L	Aug-99	T157	--	17.1	15.7	na	ICP-MS
Zn	µg/L	Jan-94	T127	30	31.8	32.9	ICP	ICP-MS
Zn	µg/L	Aug-94	T129	70	67.7	72.0	ICP	ICP-MS
Zn	µg/L	Jan-95	T131	80	74.4	72.0	ICP	ICP
Zn	µg/L	Jan-95	T133	50	51.5	53.0	ICP	ICP-MS
Zn	µg/L	Jul-95	T135	--	65.3	48.2	na	ICP-MS
Zn	µg/L	Feb-96	T137	50	45.9	49.5	ICP	ICP-MS
Zn	µg/L	Aug-96	T139	60	7.9	11	ICP	ICP-MS
Zn	µg/L	Aug-96	T141	220	216	218	ICP	ICP
Zn	µg/L	Jan-97	T143	--	18.7	20.0	na	ICP-MS
Zn	µg/L	Jan-97	T145	--	11.4	10.0	na	ICP-MS
Zn	µg/L	Aug-97	T147	<20	12.6	14.0	ICP	ICP-MS
Zn	µg/L	Aug-97	T149	<20	4.90	5.80	ICP	ICP-MS
Zn	µg/L	Feb-98	T151	--	6.30	6.57	na	ICP-MS
Zn	µg/L	Jul-98	T153	--	78.1	72.6	na	ICP
Zn	µg/L	Dec-98	T155	--	55.9	58.7	na	ICP-MS
Zn	µg/L	Aug-99	GWT5	19	15.1	15.9	GFAA	ICP-MS
Zn	µg/L	Aug-99	T157	34	23.5	23.5	GFAA	ICP-MS

122 Water Quality at a Biosolids-Application Area near Deer Trail, Colorado, 1993–1999

Appendix 9. Geochemical modeling results for well D6 using NETPATH for groundwater samples collected near Deer Trail, Colorado, 1993 to 1999.

[Mont, montmorillonite; K-spar, orthoclase; "CH2O," organic matter, such as biosolids; EX, ion exchange]

Saturation of major minerals in well D6 groundwater calculated from water-quality data by using the NETPATH model (Plummer and others, 1994):

Mineral name	Mineral formula	Saturation index	Mineral status
Anhydrite	CaSO ₄	-0.05	Stable, or precipitating slightly
Gypsum	CaSO ₄ ·7H ₂ O	0.19	Dissolving
Calcite	CaCO ₃	0.21	Dissolving
Dolomite	(Ca,Mg)(CO ₃) ₂	1.20	Dissolving
Quartz	SiO ₂	0.90	Dissolving
Chalcedony	SiO ₂	0.42	Dissolving
Amorphous SiO ₂	SiO ₂	-0.46	Precipitating

Simulation 1 to determine if groundwater from well D6 evolved from upgradient wells D5, D10, D29, or D32

Initial Well 1: D29
 Initial Well 2: D5
 Initial Well 3: D10
 Initial Well 4: D32
 Final well: D6

Constituent	Final well	Initial well 1	Initial well 2	Initial well 3	Initial well 4							
C	11.0964	5.9986	4.1627	8.3823	5.8406							
S	137.0132	31.3221	25.7201	34.9691	24.3758							
Ca	13.6586	16.2698	12.4074	14.3953	14.8926							
Mg	92.4959	14.1358	11.4155	17.7619	9.5967							
Na	82.3245	6.0903	8.8408	13.9122	6.1737							
Si	0.4579	0.3578	0	0	0							
Mn	0.0893	0.0148	0	0	0							
Fe	0	0.1234	0	0	0							
Aragonite	Ca	1	C	1	RS	4	I1	0	I2	0		
Exchange	Ca	-1	Na	2	Mg	0						
Lignite	C	1	RS	-0.4	I1	-25	I2	0				
Pyrite	Fe	1	S	2	RS	0	I3	-60				
Calcite	Ca	1	C	1	RS	4	I1	0	I2	0		
Gypsum	Ca	1	S	1	RS	6	I3	22				
"CH2O"	C	1	I1	-25	I2	0						
Dolomite	Ca	1	Mg	1	C	2	RS	8	I1	0	I2	0
CO2 gas	C	1	RS	4	I1	-25	I2	100				
Goethite	Fe	1	RS	3								
Anorthosite	Ca	1	Al	2	Si	2						
Barite	Ba	1	S	1	RS	6						
Mn(OH)3	Mn	1	RS	3								
Albite	Na	1	Al	1	Si	3						
K-Spar	K	1	Al	1	Si	3						
Kaolinite	Al	2	Si	2								
Ca-Mont	Ca	0.167	Al	2.33	Si	3.67						
Na-Mont	Na	0.33	Al	2.33	Si	3.67						
SiO2	Si	1										
0	models found											

Appendix 9. Geochemical modeling results for well D6 using NETPATH for groundwater samples collected near Deer Trail, Colorado, 1993 to 1999.—Continued

Simulation 2 to determine if groundwater from well D6 evolved from pure rainwater

Initial well: pure rainwater

Final well: D6

Constituent	Final well	Initial well										
C	11.0964	0										
S	137.0132	0										
Ca	13.6586	0										
Mg	92.4959	0										
Na	82.3245	0										
Si	0.4579	0										
Gypsum	Ca	1	S	1	RS	6	I3	22				
Dolomite	Ca	1	Mg	1	C	2	RS	8	I1	0	I2	0
NaCl	Na	1	Cl	1								
Mg/Na EX	Na	2	Mg	-1								
Calcite	Ca	1	C	1	RS	4	I1	0	I2	0		
"CH2O"	C	1	I1	-25	I2	0						
Kaolinite	Al	2	Si	2								
Ca-Mont	Ca	0.167	Al	2.33	Si	3.67						
Na-Mont	Na	0.33	Al	2.33	Si	3.67						
MgSiO3	Mg	1	Si	1								
Lignite	C	1	RS	-0.4	I1	-25	I2	0				
56	models checked											
12	models found:											

Model 1			Model 2			Model 3		
Gypsum	+ F	137.0132	Gypsum	+ F	137.0132	Gypsum	+ F	137.0132
Dolomite	+ F	5.54818	Dolomite	+ F	5.54818	Dolomite	+ F	92.49593
NaCl	+ F	256.21995	NaCl	+ F	1.46067	NaCl	+ F	82.32445
Mg/Na EX		-86.94775	Mg/Na EX		-86.94775	Calcite		-215.85055
Kaolinite		1416.61598	Ca-Mont		-771.87305	"CH2O"	+	41.95505
Ca-Mont		-771.87305	Na-Mont		771.99781	Kaolinite		0.22893
Model 4			Model 5			Model 6		
Gypsum	+ F	137.0132	Gypsum	+ F	137.0132	Gypsum	+ F	137.0132
Dolomite	+ F	92.49593	Dolomite	+ F	92.49593	Dolomite	+ F	92.03807
NaCl	+ F	82.32445	NaCl	+ F	82.28328	NaCl	+ F	82.32445
Calcite		-215.87138	Calcite		-215.85055	Calcite		-215.39269
"CH2O"	+	41.97588	"CH2O"	+	41.95505	"CH2O"	+	42.41291
Ca-Mont		0.12476	Na-Mont		0.12476	MgSiO3	+	0.45786
Model 7			Model 8			Model 9		
Gypsum	+ F	137.0132	Gypsum	+ F	137.0132	Gypsum	+ F	137.0132
Dolomite	+ F	92.49593	Dolomite	+ F	92.49593	Dolomite	+ F	92.49593
NaCl	+ F	82.32445	NaCl	+ F	82.32445	NaCl	+ F	82.32445
Calcite		-173.8955	Calcite		-215.85055	Calcite		-215.87138
Kaolinite		461.23202	Kaolinite		0.22893	Ca-Mont		0.12476
Ca-Mont		-251.22784	Lignite	+	41.95505	Lignite	+	41.97588
Model 10			Model 11			Model 12		
Gypsum	+ F	137.0132	Gypsum	+ F	137.0132	Gypsum	+ F	137.0132
Dolomite	+ F	92.49593	Dolomite	+ F	92.03807	Dolomite	+ F	5.54818
NaCl	+ F	82.28328	NaCl	+ F	82.32445	NaCl	+ F	82.32445
Calcite		-215.85055	Calcite		-215.39269	Kaolinite		1373.14211
Na-Mont		0.12476	MgSiO3	+	0.45786	Ca-Mont		-771.87305
Lignite	+	41.95505	Lignite	+	42.41291	MgSiO3	+	86.94775

124 Water Quality at a Biosolids-Application Area near Deer Trail, Colorado, 1993–1999

Appendix 9. Geochemical modeling results for well D6 using NETPATH for groundwater samples collected near Deer Trail, Colorado, 1993 to 1999.—Continued

Simulation 3 to determine if groundwater from well D6 evolved from pure rainwater

Initial Well : pure rainwater
Final Well : D6

Constituent	Final well	Initial well											
C	11.0964	0											
S	137.0132	0											
Ca	13.6586	0											
Mg	92.4959	0											
Na	82.3245	0											
Si	0.4579	0											
Cl	10.6481	0											
Gypsum	Ca	1	S	1	RS	6	I3	22					
Dolomite	Ca	1	Mg	1	C	2	RS	8	11	0	12	0	
NaCl	Na	1	Cl	1									
Mg/Na EX	Na	2	Mg	-1									
Calcite	Ca	1	C	1	RS	4	I1	0	12	0			
"CH2O"	C	1	I1	-25	I2	0							
Kaolinite	Al	2	Si	2									
Ca-Mont	Ca	0.167	Al	2.33	Si	3.67							
Na-Mont	Na	0.33	Al	2.33	Si	3.67							
MgSiO3	Mg	1	Si	1									
Lignite	C	1	RS	-0.4	I1	-25	I2	0					
70	models checked												
12	models found: (ignoring 1 dissolution/precipitation constraint)												

Model 1		
Gypsum	- F	137.0132
(Constraint ignored)		
Dolomite	- F	-123.35462
NaCl	+ F	10.64808
Mg/Na EX		-215.85055
"CH2O"	+	257.8056
Kaolinite		-2798.85488
Na-Mont		1525.38627

Model 2		
Gypsum	- F	137.0132
(Constraint ignored)		
Dolomite	- F	-123.35462
NaCl	+ F	10.64803
Mg/Na EX		35.83818
"CH2O"	+	257.8056
Kaolinite		-125.61544
MgSiO3	+	251.68874

Model 3		
Gypsum	- F	137.0132
(Constraint ignored)		
Dolomite	- F	-112.42015
NaCl	+ F	10.64808
Mg/Na EX		35.83818
"CH2O"	+	235.93666
Ca-Mont		-65.47586
MgSiO3	+	240.75427

Model 4		
Gypsum	- F	137.0132
(Constraint ignored)		
Dolomite	- F	-123.35462
NaCl	+ F	10.64808
Mg/Na EX		47.66503
"CH2O"	+	257.8056
Na-Mont		-71.67785
MgSiO3	+	263.51558

Model 5		
Gypsum	- F	137.0132
(Constraint ignored)		
Dolomite	- F	-123.35462
NaCl	+ F	10.64808
Mg/Na EX		-215.85055
Kaolinite		-2798.85488
Na-Mont		1525.38627
Lignite	+	257.8056

Model 6		
Gypsum	- F	137.0132
(Constraint ignored)		
Dolomite	- F	-123.35462
NaCl	+ F	10.64808
Mg/Na EX		35.83818
Kaolinite		-125.61544
MgSiO3	+	251.68874
Lignite	+	257.8056

Model 7		
Gypsum	- F	137.0132
(Constraint ignored)		
Dolomite	- F	-112.42015
NaCl	+ F	10.64808
Mg/Na EX		35.83818
Ca-Mont		-65.47586
MgSiO3	+	240.75427
Lignite	+	235.93666

Model 8		
Gypsum	- F	137.0132
(Constraint ignored)		
Dolomite	- F	-123.35462
NaCl	+ F	10.64808
Mg/Na EX		47.66503
Na-Mont		-71.67785
MgSiO3	+	263.51558
Lignite	+	257.8056

Model 9		
Gypsum	- F	137.0132
(Constraint ignored)		
Dolomite	- F	-123.35462
NaCl	+ F	10.64808
"CH2O"	+	257.8056
Kaolinite		-506.2604
Na-Mont		217.20112
MgSiO3	+	215.85055

Model 10		
Gypsum	- F	137.0132
(Constraint ignored)		
Dolomite	- F	-79.28608
NaCl	+ F	10.64808
"CH2O"	+	169.66853
Ca-Mont		-263.88345
Na-Mont		217.20112
MgSiO3	+	171.78201

Model 11		
Gypsum	- F	137.0132
(Constraint ignored)		
Dolomite	- F	-123.35462
NaCl	+ F	10.64808
Kaolinite		-506.2604
Na-Mont		217.20112
MgSiO3	+	215.85055
Lignite	+	257.8056

Model 12		
Gypsum	- F	137.0132
(Constraint ignored)		
Dolomite	- F	-79.28608
NaCl	+ F	10.64808
Ca-Mont		-263.88345
Na-Mont		217.20112
MgSiO3	+	171.78201
Lignite	+	169.66853

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