# Hydrogeology of a Biosolids-Application Site Near Deer Trail, Colorado, 1993–99

By Tracy J.B. Yager and L. Rick Arnold

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Prepared in cooperation with the
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**CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS**

| Multiply | By | To obtain |
|---|---|---|
| foot | 0.3048 | meter |
| gallon | 3.785 | liter |
| inch | 2.54 | centimeter |
| mile | 1.609 | kilometer |
| square mile ($mi^2$) | 2.590 | square kilometer |

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

$$°F = (1.8 \times °C) + 32$$

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

$$°C = (°F - 32) / 1.8$$

Vertical coordinate information is referenced to National Geodetic Vertical Datum of 1929 (NGVD 29); horizontal coordinate information is referenced to North American Datum of 1927 (NAD 27) except as noted.

# Hydrogeology of a Biosolids-Application Site Near Deer Trail, Colorado, 1993–99

By Tracy J.B. Yager and L. Rick Arnold

## Abstract

This report presents hydrogeology data and interpretations resulting from two studies related to biosolids applications at the Metro Wastewater Reclamation District property near Deer Trail, Colorado, done by the U.S. Geological Survey in cooperation with the Metro Wastewater Reclamation District: (1) a 1993–99 study of hydrology and water quality for the Metro Wastewater Reclamation District central property and (2) a 1999 study of regional bedrock-aquifer structure and local ground-water recharge. Biosolids were applied as a fertilizer during late 1993 through 1999. The 1993 Metro Wastewater Reclamation District property boundary constitutes the study area, but hydrogeologic structure maps for a much larger area are included in the report. The study area is located on the eastern margin of the Denver Basin, a bowl-shaped sequence of sedimentary rocks. The uppermost bedrock formations in the vicinity of the study area consist of the Pierre Shale, the Fox Hills Sandstone, and the Laramie Formation, parts of which comprise the Laramie-Fox Hills hydrostratigraphic unit and thus, where saturated, the Laramie-Fox Hills aquifer. In the vicinity of the study area, the Laramie-Fox Hills hydrostratigraphic unit dips gently to the northwest, crops out, and is partially eroded. The Laramie-Fox Hills aquifer is either absent or not fully saturated within the Metro Wastewater Reclamation District properties, although this aquifer is the principal aquifer used for domestic supply in the vicinity of the study area. Yield was small from two deep monitoring wells in the Laramie-Fox Hills aquifer within the study area. Depth to water in these wells was about 110 and 150 feet below land surface, and monthly water levels fluctuated 0.5 foot or less. Alluvial aquifers also are present in the unconsolidated sand and loess deposits in the valleys of the study area. Interactions of the deeper parts of the Laramie-Fox Hills aquifer with shallow ground water in the study area include a general close hydraulic connection between alluvial and bedrock aquifers, recharge of the Cottonwood Creek and much of the Muddy Creek alluvial aquifers by the bedrock aquifer, and possible recharge of the bedrock aquifer by a Rattlesnake Creek tributary. Some areas of shallow ground water were recharged by infiltration from rain or ponds, but other areas likely were recharged by other ground water. Data for shallow ground water indicate that ground-water recharge takes less than a day at some sites to about 40 years at another site. Depth to shallow ground water in the study area ranged from about 2 feet to about 37 feet below land surface. Shallow ground-water levels likely were affected by evapotranspiration. Ground water is present in shallow parts of the bedrock aquifer or in alluvial aquifers in four drainage basins: Badger Creek, Cottonwood Creek, Muddy Creek, and Rattlesnake Creek. These drainage basins generally contained only ephemeral streams, which flow only after intense rain.

## Introduction

The Metro Wastewater Reclamation District (MWRD) treats municipal sewage from the Denver area at their plant in Denver, Colo. (fig. 1). Biosolids are solid organic matter recovered from a sewage-treatment process that meet 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 MWRD acquired property (about 15 square miles; fig. 2) on the eastern plains of Colorado in Arapahoe and Elbert Counties east of Deer Trail, Colo. (fig. 1). Beginning in late 1993, MWRD biosolids were trucked from Denver about 75 miles east to MWRD property near Deer Trail. The MWRD applied biosolids as an agricultural fertilizer to nonirrigated farm land on their property. In 1995, the MWRD traded some of their property (land that included Muddy Creek in Elbert County); the resulting part of the original MWRD property became known as MWRD's central property (fig. 3). In 1995, the MWRD also acquired additional property in the same area: the MWRD's north property (about 14.5 square miles) and the MWRD's south property (about 50 square miles) (fig. 3). The MWRD property near Deer Trail is farmed; besides biosolids, other fertilizers and pesticides could have been applied to the property in the past. These applications are called anthropogenic applications because materials of a chemical nature were added to the site by humans.

Biosolids applications can affect soil and water quality. When biosolids are applied to agricultural soil, soil quality either can be improved by biosolids applications through increased nutrients and organic matter or degraded through the accumulation of excessive nutrients or trace elements (Berti and

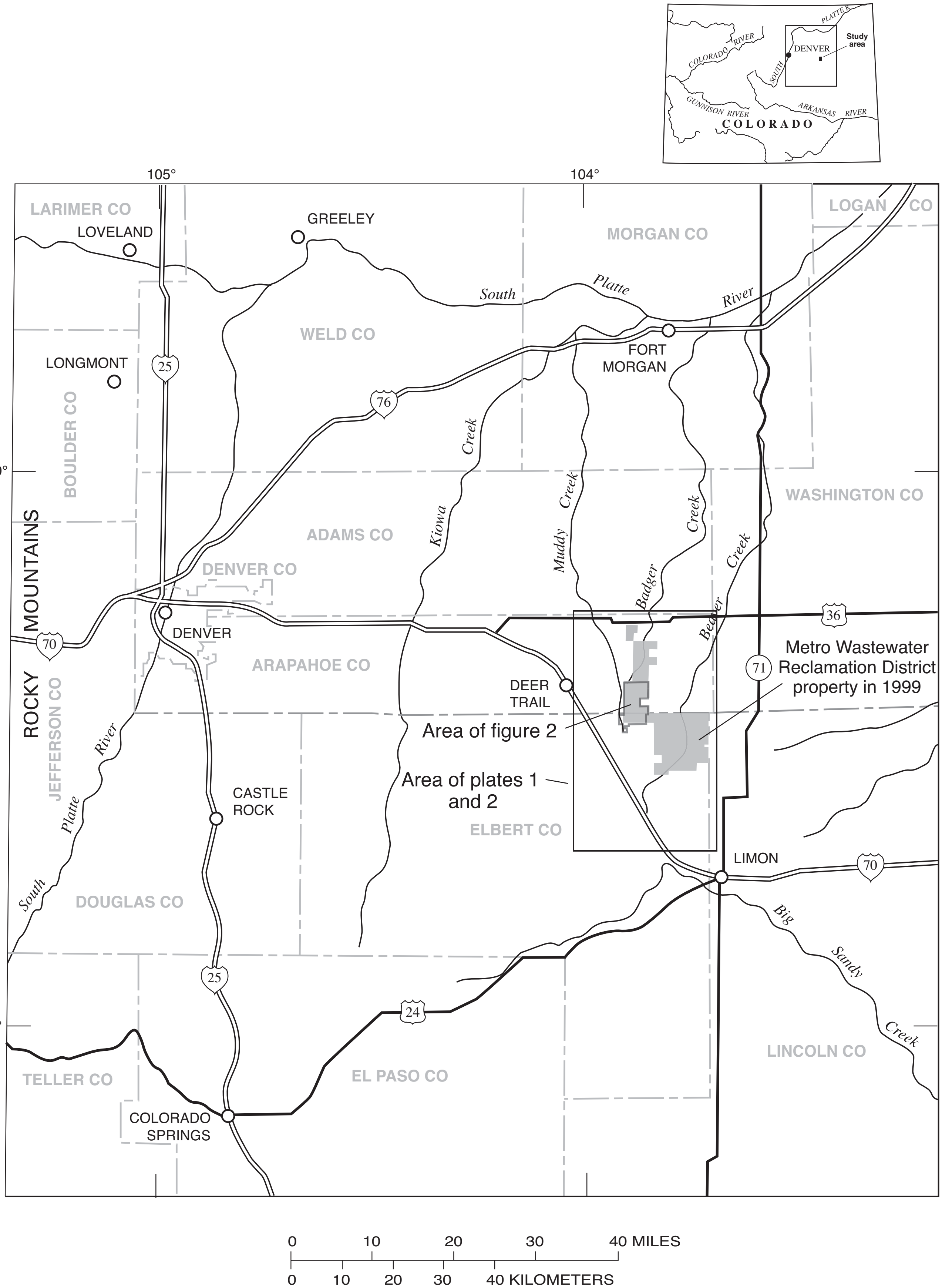


**Figure 1.** Location of mapped areas of figure 2 and plates 1 and 2.

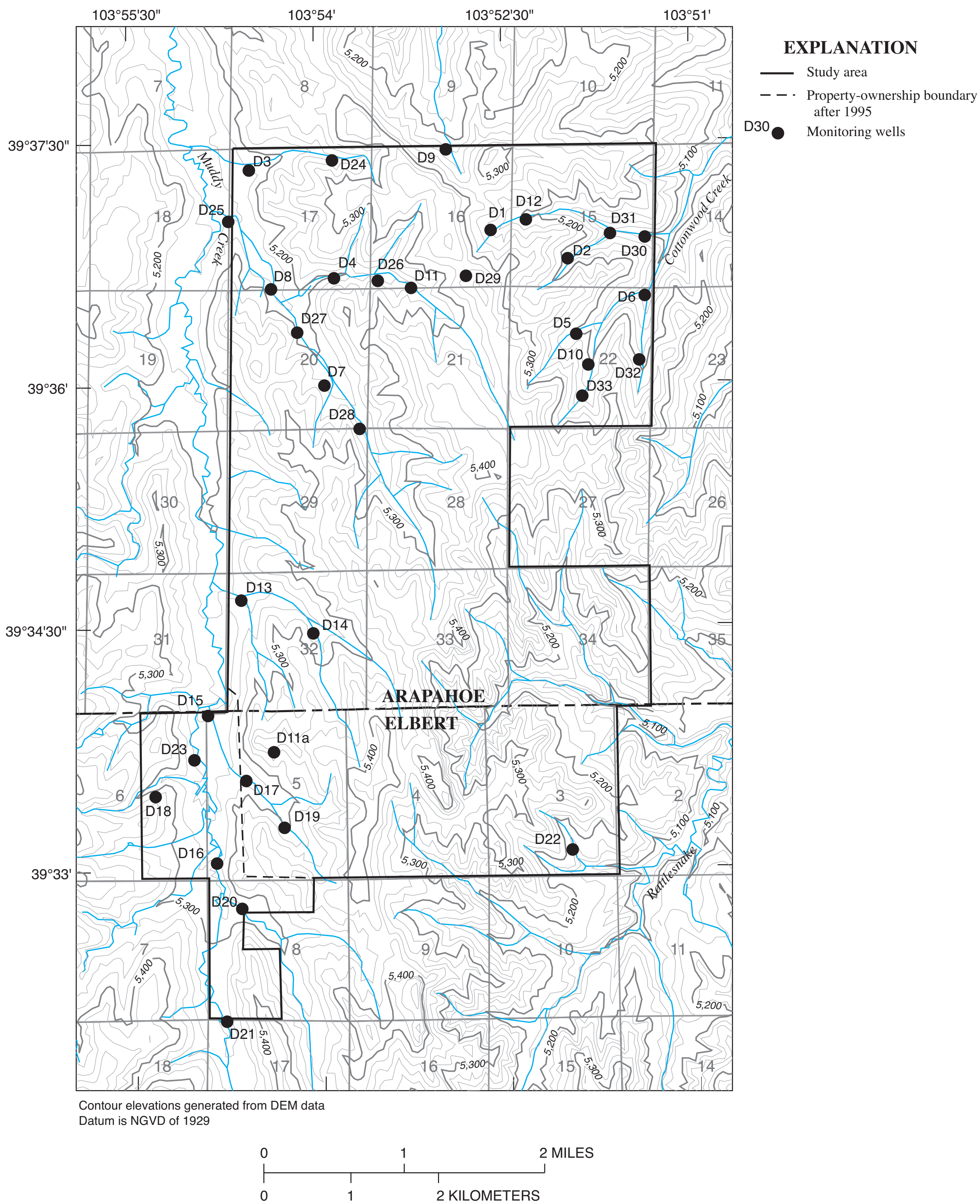


**Figure 2.** Study area and U.S. Geological Survey monitoring sites. (Contour interval is 20 feet. Base from Digital Elevation Maps.)

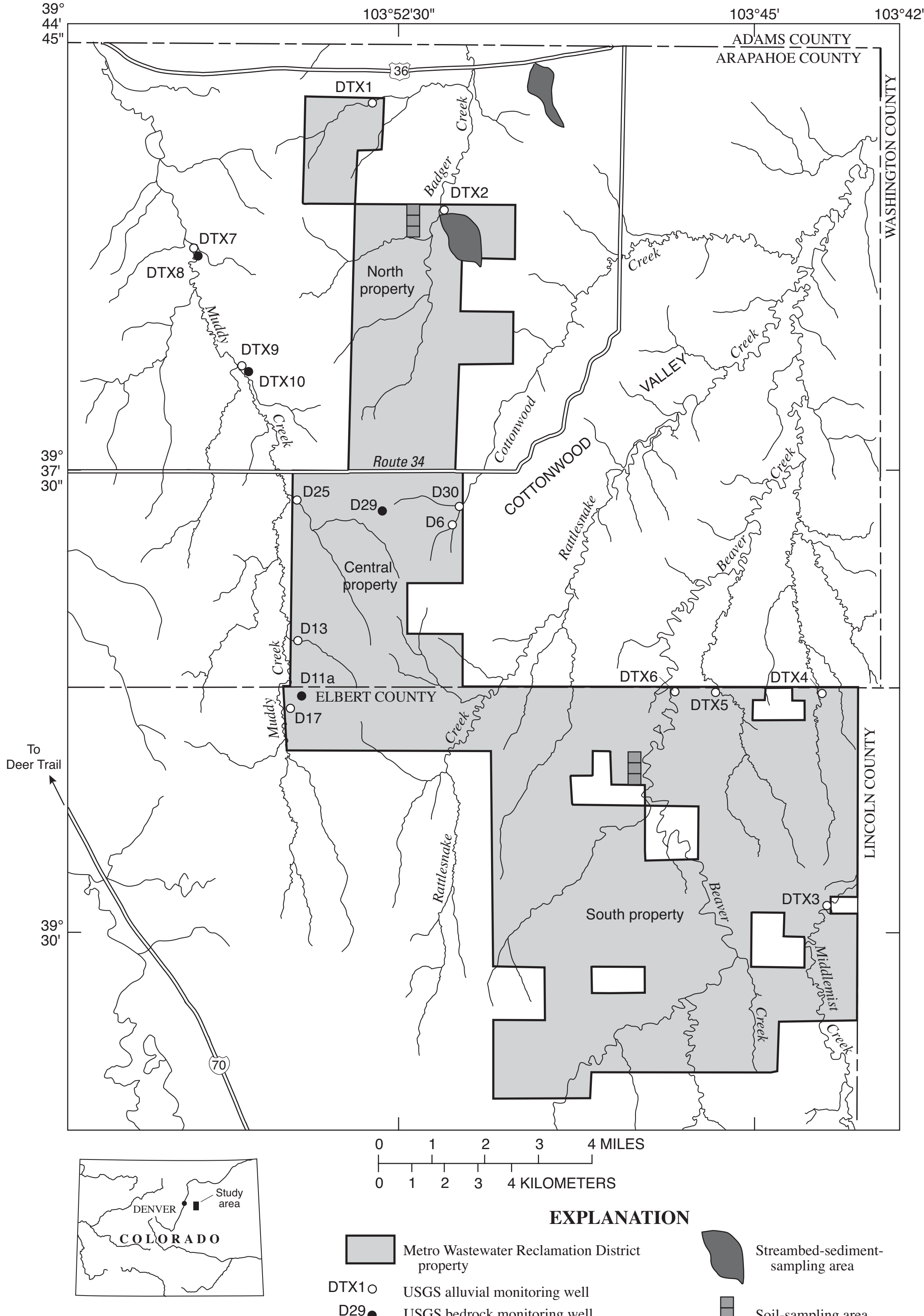


**Figure 3.** Location of Metro Wastewater Reclamation District properties near Deer Trail, Colorado, (1999 property boundaries) and U.S. Geological Survey expanded monitoring program sites (1999). (Base from U.S. Geological Survey, 1976; U.S. Geological Survey, 1980a.)

Jacobs, 1998). Applications of pesticides or fertilizer (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 at a biosolids-application site should not be interpreted as representing effects from biosolids just because biosolids are present at that site. Many of the chemical constituents used as indicators of biosolids contamination (such as trace elements) also can be contributed by geologic materials (Drever, 1988). Other water-quality constituents (such as nutrients and organic matter) attributed to biosolids also can 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. Hydrology (the origin, quantity, transport rate, and flow path of the water) is determined by climate and geology. Climate determines the timing, form, and amount of precipitation. The geology of an area, combined with climatic features, produces the landforms, which affect the occurrence and flow rate of surface water. The geology of an area also determines the porosity and permeability of the subsurface, which affect the flow of ground water. In addition, the chemical constituents of the geologic materials interact in the presence of water through a variety of natural processes. Therefore, 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, and land-use activities of the site.

Previous studies provide some information about the geology and hydrology of the MWRD property near Deer Trail, Colo. Sharps (1980) includes the area in his geologic map. Major and others (1983), Robson (1983, 1987), and Robson and Banta (1987, 1995) include the area in their reports. Little detailed information specifically for the MWRD property is available, however.

In mid-1993, the U.S. Geological Survey (USGS) in cooperation with the MWRD began monitoring hydrology and water quality on the MWRD property near Deer Trail. This study was done to evaluate the combined effects of biosolids applications, other land uses, and natural processes on the quality of shallow ground water and water of the unsaturated zone. The study area consisted of the 1993 MWRD property (fig. 2). Hydrology was monitored from 1993 through 1998 by measuring ground-water levels and precipitation. Water quality was monitored from 1993 through 1998 by sampling for inorganic and bacteria constituents, with some additional sampling in 1999. In 1999, the USGS began an expanded monitoring program (1999–2004), in cooperation with the MWRD and the North Kiowa Bijou Groundwater Management District, that built on the 1993–99 USGS monitoring program but included all three MWRD properties (fig. 3) and expanded monitoring components. The objectives of the expanded monitoring program were (1) to evaluate the combined effects of biosolids applications, other land uses, and natural processes on soils, crops, streambed sediments, alluvial aquifers, and the bedrock aquifer by comparing chemical data to regulatory levels, to data from an unaffected (control) site, or to earlier concentrations from the same site (trends); (2) to investigate the hydrology of the bedrock aquifer in the vicinity of the MWRD properties; and (3) to monitor biosolids for metals and radioactivity and to compare the concentrations with regulatory levels. As part of the expanded monitoring program, the geology of the area was evaluated to identify aquifer materials, and hydrogeologic structure maps were prepared.

## Purpose and Scope

The purpose of this report is to present all hydrogeologic data and interpretations from the first USGS monitoring program near Deer Trail, Colo. (1993–99), and hydrogeologic structure maps and some interpretations from the bedrock ground-water monitoring component of the USGS expanded monitoring program near Deer Trail (1999). The report also summarizes the geologic history and the geologic and hydrologic setting of the area to provide a general understanding of the geology and hydrology and how they interact in this area. The 1993 MWRD property boundaries near Deer Trail are hereinafter referred to as the "study area" (fig. 2); however, the hydrogeologic structure maps encompass an area that contains the study area (fig. 2) and all three MWRD properties (fig. 3), and the summary of geologic history and geologic and hydrologic setting pertains to the entire area shown in figure 1. The report includes geologic data (lithologic descriptions and core textural analyses) and hydrologic data (depth to ground water and climate data), as well as an interpretive discussion of hydrogeology for the study area. The report does not include water-quality data and interpretations, which will be provided in a separate report.

The report has all data and supplemental information at the back of the report in appendixes. Appendix I describes the methods of data collection and construction of maps and hydrogeologic sections. Appendix II contains hydrogeologic data including lithologic descriptions, monitoring-well information, measurements of monthly water levels for the monitoring wells, continuous-recorder data for ground-water levels and precipitation at two sites, continuous-recorder data for specific conductance and water temperature at one ground-water site, and data used to make the structure maps.

## Acknowledgments

The authors thank the MWRD and the Keen and Turecek families for allowing access to the USGS instrument and well installations on their property. The authors thank John Price for providing to the USGS copies of lithologic logs from titanium exploration on his property. The authors thank Bob Raynolds of the Denver Museum of Nature and Science for sharing his geologic insights. Also, the authors thank volunteer Ingrid Ekstrom, who assisted in the construction of the structure maps. Finally, the authors thank the following students without whom we could not have completed this study: Colleen Green, Orren Doss, Heather Handran, Heather Sproule Eppler, Ben Glass, and Jaime Giesen.

# Description of Study Area

The study area is located on Colorado's eastern plains, about 75 miles east of Denver and about 10 miles east of Deer Trail (fig. 1). Soils in the study area generally are sandy or loamy on flood plains and stream terraces, clayey to loamy on gently sloping to rolling uplands, and sandy and shaley on steeper uplands (Larsen and others, 1966; Larsen and Brown, 1971). Ground water is obtained from alluvial and bedrock aquifers, discussed in a later section of this report. The geology of the study area will be discussed in detail in a later section of this report. The study area generally was vegetated during 1993 through 1999 except where the land surface was rock or where farm fields were freshly tilled. Crops and prairie vegetation dominated the landscape. Tree canopy was sparse and consisted of primarily deciduous varieties like cottonwood trees located along the southern parts of Muddy Creek and Cottonwood Creek.

## Topographic Features

Topographic features of the study area include flood plains, valleys with incised channels, rounded hills, and cliffs. Wide, flat flood plains are associated with Muddy Creek on the west side of the study area. Valleys with incised channels are present throughout the study area, but valleys on the east side are shorter, steeper, and more incised than on the west side of the study area. Rounded hills are characteristic of the northern part of a long, north-south-trending ridge of the study area, but cliffs are more characteristic of this ridge in the southern part. Topographic contours of the study area are shown in figure 2.

## Land Use

Land use in the study area historically was rangeland, cropland, and pasture (U.S. Geological Survey, 1980b). Land use in the study area during 1993 through 1999 mostly was cropland. Four abandoned homesteads were present (Metro Wastewater Reclamation District, 1993, written commun. [map]), along with associated outbuildings, animal pens, and shallow windmill-pumped wells that perhaps were used for watering livestock. No one lived in the study area during 1993 through 1999, but people did live just across the road to the west from monitoring well D13 (fig. 2). Some petroleum exploration was done in the vicinity (Drew and others, 1979), but no oil or gas production took place within the study area during 1993 through 1999. The study area in 1993–99 primarily was farmed with some grazing. Biosolids were applied as a fertilizer. Farm land in the study area was not irrigated; the primary crop was wheat (Stevens and others, 2003). Cattle and sheep were the primary domestic animals grazing this area. Wildlife in the study area included pronghorn, deer, coyotes, herons, hawks, owls, rodents, and turtles.

## Climate

The climate in the study area is semiarid. Less than 20 inches of precipitation usually is received each year. Most of the precipitation is received as rainfall in May or June and late summer (usually July–August). Precipitation data for the study area during 1996–98 are included in Appendix II. Air temperatures ranged from about 0 degrees Fahrenheit October through April to about 105 degrees Fahrenheit in July and August. The study area often is windy; prevailing winds were from the north during winter and from the west in summer. Average annual pan evaporation in the study area for 1946–55 was about 70 inches (Robson and Banta, 1995, fig. 10).

# Data Collection

Various approaches were used for the study. To characterize geology, published reports were reviewed, geophysical logs from oil and gas exploration in the vicinity of the study area were reviewed and correlated, lithologic descriptions from other commercial exploration in the vicinity of the study area were reviewed, boreholes were drilled and drill cuttings and cores were examined, and surficial geology was examined in the field. To characterize hydrology, published reports were reviewed, monitoring wells were installed, ground-water levels were measured, rain gages and temperature sensors were installed, and dissolved-gas and chlorofluorocarbon samples were collected and analyzed in 1998. To provide flood-crest data, three crest-stage gages were installed in 1994; all three crest-stage gages were dislodged by floodwaters during the first summer of operation, and no data were collected.

USGS personnel collected data from numerous sources and locations. Geologic data were collected from throughout the area of plates 1 and 2 shown in figure 1. Most hydrologic data were collected from monitoring-well sites, which are listed in table 1 and shown in figure 2. All methods of data collection are discussed in Appendix I.

The USGS installed 30 shallow monitoring wells and 3 deep wells in the study area. The shallow wells were installed between 1993 and 1995 in the valleys for data collection to evaluate the alluvial aquifers or shallow parts of the bedrock aquifer. Alluvial aquifers are not continuous throughout the study area but are present near stream channels and in paleochannels. Wells were located near MWRD property boundaries

**Table 1.** U.S. Geological Survey ground-water monitoring sites near Deer Trail, Colorado, 1993–99.

[G, ground-water hydrology; W, water quality; A, shallow-deep aquifer interactions; F, water-quality flow-path information; P, water quality at property boundary; S, interactions between surface and ground water; V, aquifer spatial variability; Shallow well could be completed in bedrock aquifer or alluvial aquifer; U, USGS-installed monitoring well; D, Continuous-recorder instrumentation; E, pre-existing well with windmill or other pump; MWRD, Metro Wastewater Reclamation District (central property); R, owned by Metro Wastewater Reclamation District until late 1995, then owned by private resident]

| Site (fig. 2) | Site type | Monitoring purpose | Site type | Site instal-lation | Topo-graphic setting | Drainage basin (fig. 6) | Property owner | County | Location[3] |
|---|---|---|---|---|---|---|---|---|---|
| D1 | G | F, V | Shallow well | U | Upland draw | Cottonwood Creek | MWRD | Arapahoe | T5S R58W S16 NE,SE |
| D2 | G, W | F, V | Shallow well | U, D | Flood plain | Cottonwood Creek | MWRD | Arapahoe | T5S R58W S15 SE,SW |
| D3 | G, W | F, P, V | Shallow well[1] | U | Flood plain | Muddy Creek | MWRD | Arapahoe | T5S R58W S17 NW,NW |
| D4 | G, W | F, V | Shallow well[1] | U | Flood plain | Muddy Creek | MWRD | Arapahoe | T5S R58W S17 SE,SE |
| D5 | G, W | F, S, V | Shallow well | U | Flood plain | Cottonwood Creek | MWRD | Arapahoe | T5S R58W S22 SE,NW |
| D6 | G, W | F, P, V | Alluvial well | U, D | Flood plain | Cottonwood Creek | MWRD | Arapahoe | T5S R58W S22 NE,NE |
| D7 | G, W | F, V | Shallow well[2] | U | Flood plain | Muddy Creek | MWRD | Arapahoe | T5S R58W S20 NW,SE |
| D8 | G, W | F, V | Shallow well[2] | U | Flood plain | Muddy Creek | MWRD | Arapahoe | T5S R58W S17 SE,SW |
| D9 | G, W | F, P, V | Bedrock well | U | Upland draw | Badger Creek | MWRD | Arapahoe | T5S R58W S16 NW,NE |
| D10 | G, W | F, V | Shallow well | U | Stream channel | Cottonwood Creek | MWRD | Arapahoe | T5S R58W S22 NW,SE |
| D11 | G | F, V | Shallow well | U | Flood plain | Muddy Creek | MWRD | Arapahoe | T5S R58W S16 SE,SW |
| D11a | G, W | A, F, V | Bedrock well | U | Hilltop | Muddy Creek | MWRD | Arapahoe | T6S R58W S5 NE,NW |
| D12 | G, W | F, V | Shallow well[1] | E | Flood plain | Cottonwood Creek | MWRD | Arapahoe | T5S R58W S15 SE,NW |
| D13 | G, W | F, P, V | Shallow well | U | Flood plain | Muddy Creek | MWRD | Arapahoe | T5S R58W S32 NW,NW |
| D14 | G, W | F, V | Shallow well | U | Flood plain | Muddy Creek | MWRD | Arapahoe | T5S R58W S32 SW,NE |
| D15 | G, W | F, P, S, V | Shallow well[2] | U | Flood plain | Muddy Creek | R | Elbert | T6S R58W S5 NW,NW |
| D16 | G, W | F, S, V | Shallow well | U | Flood plain | Muddy Creek | R | Elbert | T6S R58W S6 SE,SE |
| D17 | G, W | F, V | Alluvial well | U | Flood plain | Muddy Creek | MWRD | Elbert | T6S R58W S5 SE,NW |
| D18 | G | F, P, V | Shallow well | U | Stream channel | Muddy Creek | R | Elbert | T6S R58W S6 SW,NE |
| D19 | G, W | F, V | Shallow well[1] | U | Upland draw | Muddy Creek | MWRD | Elbert | T6S R58W S5 NW,SE |

**Table 1.** U.S. Geological Survey ground-water monitoring sites near Deer Trail, Colorado, 1993–99.—Continued

[G, ground-water hydrology; W, water quality; A, shallow-deep aquifer interactions; F, water-quality flow-path information; P, water quality at property boundary; S, interactions between surface and ground water; V, aquifer spatial variability; Shallow well could be completed in bedrock aquifer or alluvial aquifer; U, USGS-installed monitoring well; D, Continuous-recorder instrumentation; E, pre-existing well with windmill or other pump; MWRD, Metro Wastewater Reclamation District (central property); R, owned by Metro Wastewater Reclamation District until late 1995, then owned by private resident]

| Site (fig. 2) | Site type | Monitoring purpose | Site type | Site instal-lation | Topo-graphic setting | Drainage basin (fig. 6) | Property owner | County | Location[3] |
|---|---|---|---|---|---|---|---|---|---|
| D20 | G, W | F, V | Shallow well | U | Flood plain | Muddy Creek | R | Elbert | T6S R58W S8 NW,NW |
| D21 | G, W | F, P, V | Shallow well | U | Flood plain | Muddy Creek | R | Elbert | T6S R58W S8 SW,SW |
| D22 | G, W | F, P, V | Shallow well[1] | U | Flood plain | Rattlesnake Creek | MWRD | Elbert | T6S R58W S3 SW,SE |
| D23 | G, W | F, S, V | Shallow well[2] | U, D | Flood plain | Muddy Creek | R | Elbert | T6S R58W S6 NE,NE |
| D24 | G, W | A, F, S, V | Shallow well[1] | U | Stream channel | Muddy Creek | MWRD | Arapahoe | T5S R58W S17 NW,NE |
| D25 | G, W | F, P, S, V | Alluvial well | U | Flood plain | Muddy Creek | MWRD | Arapahoe | T5S R58W S17 SW,NW |
| D26 | G, W | F, V | Shallow well[1] | U | Flood plain | Muddy Creek | MWRD | Arapahoe | T5S R58W S16 SW,SW |
| D27 | G, W | F, V | Shallow well[2] | U | Flood plain | Muddy Creek | MWRD | Arapahoe | T5S R58W S20 SW,NE |
| D28 | G, W | F, V | Shallow well[2] | U | Stream channel | Muddy Creek | MWRD | Arapahoe | T5S R58W S20 SE,SE |
| D29 | G, W | A, F, V | Bedrock well | U | Hilltop | Cottonwood Creek | MWRD | Arapahoe | T5S R58W S16 SW,SW |
| D30 | G, W | F, P, S, V | Shallow well[2] | U | Stream channel | Cottonwood Creek | MWRD | Arapahoe | T5S R58W S15 NE,SE |
| D31 | G, W | F, V | Alluvial well | U | Flood plain | Cottonwood Creek | MWRD | Arapahoe | T5S R58W S15 NW,SE |
| D32 | G, W | F, V | Shallow well[1] | U | Stream channel | Cottonwood Creek | MWRD | Arapahoe | T5S R58W S15 SE,NE |
| D33 | G, W | F, V | Alluvial well | U | Flood plain | Cottonwood Creek | MWRD | Arapahoe | T5S R58W S22 NW,SE |

[1]Probably bedrock-aquifer well.

[2]Probably alluvial-aquifer well.

[3]Location indicated by township, range, and section. The letters after the section number represent successive quarter subdivisions of the section.

to evaluate the quality of ground water entering and leaving the study area. Wells were located upgradient from property boundaries to evaluate chemical and hydrologic variability within each alluvial aquifer. A windmill well installed before the study began was included in the monitoring network from 1993 through 1998, although little was known about that well's construction, well-screen location, or drilling methods. Two of the wells (D1 and D11) constructed in 1993 and one of the wells (D18) constructed in 1994 were dry, despite their locations in downgradient parts of stream valleys. These wells were checked for water throughout the study period but remained dry. Continuous recorders were installed at three shallow wells: at D2 and D23 to provide detailed information about hydrologic variability by recording water level, water temperature, and precipitation; and at D6 to provide detailed information about hydrologic and water-quality variability by recording water temperature and specific conductance. To provide ground-water recharge and flow-path information, dissolved-gas and chlorofluorocarbon (DG-CFC) samples were collected in November 1998 at 10 shallow wells in the study area that had chemical concentrations of concern or anomalous water quality compared to other nearby wells. Data for DG-CFC samples are listed in Appendix II. Two deep bedrock wells were installed by the USGS in 1997 to evaluate the sandstone part of the bedrock aquifer, interactions of the bedrock aquifer with the alluvial aquifers, and the subsurface geology. The bedrock-well locations were planned to coincide with shallow-well locations at D17 and D25, but drilling of the first bedrock well at the D17 location showed no discernible sandstone part of the bedrock aquifer beneath the alluvial aquifer, so the bedrock wells (D11a and D29) were installed on the ridges that had known sandstone sequences. The monitoring wells were surveyed to a common vertical datum (North American Vertical Datum of 1988, converted to NGVD 29 for this report) to enable detailed comparison of water-level altitudes and direction of ground-water flow. Monitoring-well locations are included in table 1 and figure 2. Ground-water and well-construction data are provided in Appendix II.

Access to the monitoring sites in the study area was challenging due to a lack of roads and the rough terrain. Muddy conditions, large sand dunes, and large desiccation cracks in the ground occasionally prevented access to monitoring sites. In addition, access to the study area was restricted by the property owners (both MWRD and local landowners) beginning in 1995. Generally, the USGS was not allowed access to the monitoring sites if the surrounding field was tilled or planted. These access restrictions resulted in limited data collection and temporal gaps in the data sets.

# Hydrogeology

The study area is located in the Colorado Piedmont Section of the Great Plains physiographic province in northeastern Colorado about 75 miles east of the Rocky Mountains. The study area overlies the Denver Basin, an asymmetrical, bowl-shaped geological structure (fig. 4) that covers approximately 60,000 square miles in parts of Colorado, Nebraska, Wyoming, and Kansas and reaches a maximum depth of about 13,000 feet near the city of Denver (Rocky Mountain Association of Geologists, 1972). The basin is composed of Phanerozoic-age sedimentary bedrock layers overlying a basement of Precambrian-age igneous and metamorphic rock. Bedrock layers dip steeply into the basin along the western margin and dip gently inward along the eastern, northern, and southern margins of the basin. Near the study area, the Denver Basin is approximately 9,000 feet deep (Robson and Banta, 1987, sheet 1), and bedrock layers dip gently to the northwest. Although many geologic formations, ranging in age from Pennsylvanian to Late Cretaceous, are present in the Denver Basin in the vicinity of the study area, only the uppermost geologic materials are likely to be used for water supply or affected by land use. Therefore, only the upper formations of the Denver Basin and overlying surficial units are considered in this report. The geologic and hydrologic characteristics of these formations are described in the following sections and summarized in figure 5.

## Geology

An overview of geology is included in this report to provide the reader with an understanding of how the study area is part of a larger geologic system, the Denver Basin. Therefore, this description includes the study area (fig. 2) as well as the surrounding area (figs. 1 and 3). Geology can be described in terms of history and lithology. Geologic history is the story of how the rocks were formed and changed over time. Lithology is the description of the rock characteristics in the geologic formations.

### History

This discussion of the history of formations present in the study area is based primarily on work published by Hunt (1954), Rocky Mountain Association of Geologists (1972), Trimble (1980), Tweto (1980), Robson and Banta (1987), and Sonnenberg and Bolyard (1997). The history of the geologic materials of interest in the study area begins with the deposition of the Pierre Shale during Late Cretaceous time (about 78 million years ago [Kiteley, 1978, sheet 1]). The Pierre Shale was formed by the accumulation of sediments in a shallow sea that stretched from the Gulf of Mexico to the Arctic Ocean and from central Utah to the Mississippi River. The Fox Hills Sandstone was deposited as a sandy shoreline along the margin of this sea. Inland from the shoreline of the Fox Hills Sandstone were materials deposited in a lush delta plain that became the Laramie Formation. Decaying vegetation in poorly drained swamps within the delta plain became coals and lignitic shales in the Laramie Formation.

Beginning about 68 million years ago, major uplift (part of the Laramide Orogeny) occurred in the area of the present-day

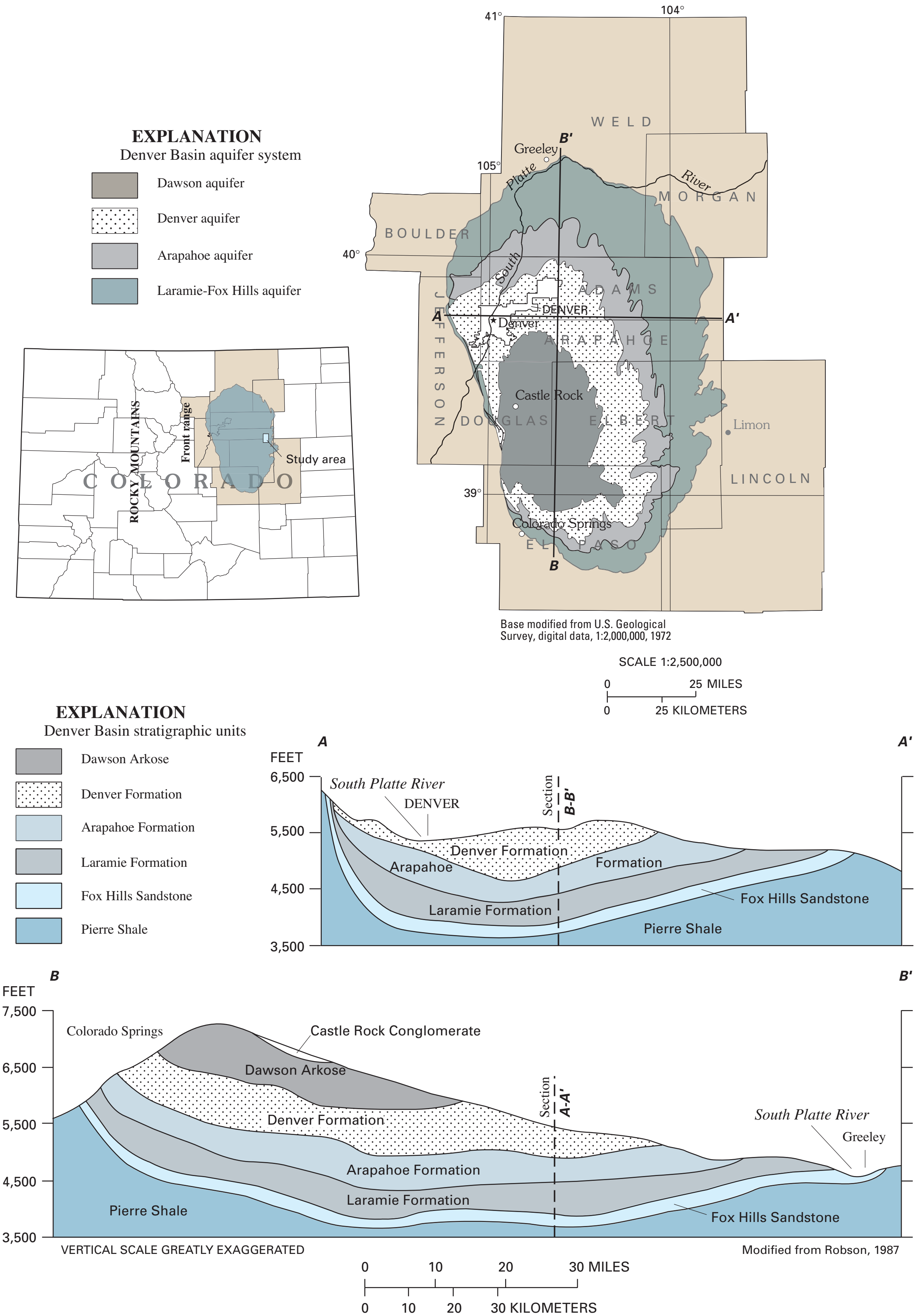


**Figure 4.** The Denver Basin aquifer system and generalized geologic sections A-A′ and B-B′ through the Denver Basin (modified from Robson and Banta, 1995, figs. 80–81).

| Era | System | Series | Stratigraphic unit | Unit thickness (feet) | Physical characteristics | Hydrogeologic unit | | Saturated thickness (feet) | Hydrologic characteristics |
|---|---|---|---|---|---|---|---|---|---|
| Cenozoic | Quaternary | Holocene<br>Pleistocene | Alluvium | 0 – 125 | Unconsolidated gravel, sand, silt, and clay | Alluvial aquifer | | 0 – 100 | Shallow water-table aquifer. Very permeable. May yield as much as 3,000 gallons per minute |
| Cenozoic | Tertiary | Oligocene | Castle Rock Conglomerate | 0 – 50 | Fine to coarse arkosic sandstone and conglomerate. Exposed in cliffs | none | | 0 | Generally forms caprock on buttes. Well drained. Does not yield water |
| Cenozoic | Tertiary | Eocene<br>Paleocene | Dawson Arkose | 800 – 1,400 | Sandstone and conglomeratic sandstone with interbedded siltstone and shale. Sandstone generally coarse, quartzose, arkosic, poorly to well consolidated | Denver Basin aquifer system | Dawson aquifer | 0 – 400 | Uppermost Denver Basin aquifer. Contains a water table in shallow units but generally confined at depth. Moderately permeable. May yield as much as 200 gallons per minute |
| Cenozoic<br>Mesozoic | Tertiary<br>Cretaceous | Paleocene<br>Upper Cretaceous | Denver Formation | 600 – 1,100 | Shale, silty claystone, and interbedded sandstone. Beds of lignite and carbonaceous siltstone and shale common. Sandstone generally andesitic, lenticular, moderately consolidated | Denver Basin aquifer system | Denver aquifer | 0 – 350 | Confined in central part. Contains a water table only near outcrops. Moderately permeable. May yield as much as 200 gallons per minute |
| Mesozoic | Cretaceous | Upper Cretaceous | Arapahoe Formation | 400 – 700 | Sandstone, conglomeratic sandstone, and interbedded shale and siltstone. Sandstone generally quartzose, fine to coarse, poorly to well consolidated | Denver Basin aquifer system | Arapahoe aquifer | 0 – 400 | Confined in central part. Contains a water table only near outcrops. Most permeable of Denver Basin aquifers. May yield as much as 700 gallons per minute |
| Mesozoic | Cretaceous | Upper Cretaceous | Laramie Formation | 100 – 600 | Upper part shale, silty shale, siltstone, and interbedded fine sandstone. Bituminous coal seams | Denver Basin aquifer system | Laramie confining unit | 0 – 400 | Shale is impermeable |
| | | | | | Lower part sandstone and shale. Sandstone fine to medium, friable, carbonaceous | Denver Basin aquifer system | Laramie-Fox Hills aquifer | 0 – 300 | Lowermost Denver Basin aquifer. Confined in central part. Contains a water table only near outcrops. Moderaly permeable. May yield as much as 300 gallons per minute |
| Mesozoic | Cretaceous | Upper Cretaceous | Fox Hills Sandstone | 100 – 200 | Sandstone and siltstone interbedded with shale. Sandstone generally very fine to fine, poorly consolidated | | | | |
| Mesozoic | Cretaceous | Upper Cretaceous | Pierre Shale | 5,000 – 7,000 | Shale, silty, dense, calcareous, fossiliferous | Lower confining unit | | 0 | Impermeable. Forms base of Denver Basin aquifer system |

**Figure 5.** Geologic and hydrologic characteristics of the Denver Basin aquifers (modified from Robson and Banta, 1995, fig. 83).

Rocky Mountains. As the mountains were uplifted, the sea retreated, and the Precambrian-age rocks and overlying sedimentary rocks east of the mountains were warped downward to form the Denver Basin (fig. 4). The sediments of the Pierre Shale were successively covered by the sediments of the Fox Hills Sandstone and the Laramie Formation as the shoreline regressed and delta plain sediments were deposited over the former sea bottom. Intermittent rates of uplift and differing rates of basin subsidence during this time caused the sea to retreat and advance several times before finally retreating completely. This cycle of regression and transgression is recorded in the alternating layers of shale and sandstone in a transition zone near the top of the Pierre Shale. Other sediments derived from the erosion of the Rocky Mountains were deposited on top of the Laramie sediments and became the Arapahoe and Denver Formations and the Dawson Arkose (figs. 4 and 5).

During late Tertiary time, between 5 and 10 million years ago, continued uplift caused the environment to change from one of deposition to one of erosion, and many of the previously deposited sediments were incised by streams and removed by erosion. In the vicinity of the study area, the Dawson Arkose and Denver and Arapahoe Formations were completely removed by erosion, and only a little of the Laramie Formation, part of the Fox Hills Sandstone, and the Pierre Shale remain in the study area near the surface (fig. 4).

Quaternary-age glaciation in the mountains followed and eroded the granite and other igneous, metamorphic, and sedimentary rocks of the Rocky Mountains west of the study area. As the glaciers melted, large loads of sediments derived from the eroding mountain rocks were carried and deposited in streams draining the east side of the Rocky Mountains. These sediments were carried onto the plains by streams, and the fine-grained materials were blown by the wind and deposited in thick blankets of loess on top of the eroded Denver Basin formations. After deposition, these sediments were further eroded and redeposited by wind and streams. In the vicinity of the study area, the geologic materials that resulted from these glacial and postglacial periods are the Pleistocene- and Holocene-age Peoria Loess and alluvium (Sharps, 1980). Modern streams and winds continue to remove and redeposit loess and alluvium, as well as new sediments formed from the continuing erosion of the Laramie Formation, Fox Hills Sandstone, and Pierre Shale. The topography of the study area generally has been shaped by processes occurring within the past 2 million years.

## Lithology

Bedrock units present near the land surface in the vicinity of the study area are of Late Cretaceous age and consist of the Pierre Shale, Fox Hills Sandstone, and Laramie Formation (figs. 4 and 5). In the study area, sandstone layers are the units most resistant to erosion and commonly occur as ridges and hilltops. Shale layers weather easily to clay at the land surface and, therefore, commonly are not readily apparent in outcrop. In this report, “outcrop” (or in verb form, “crops out”) refers to the part of geologic formations that appears at land surface, and “subcrop” refers to bedrock covered only by surficial deposits such as soil, loess, or alluvium.

The Pierre Shale crops out and subcrops east of the study area (figs. 2 and 4) and consists of dark gray shale with layers of limonitic siltstone and fine-grained sandstone. The Pierre Shale is about 4,200 feet thick in the vicinity of the study area (Sharps, 1980). Approximately the upper 200 feet of the Pierre Shale is interbedded with siltstone and sandstone and becomes increasingly sandy toward the top of the formation, forming a gradational contact with the overlying Fox Hills Sandstone.

The Fox Hills Sandstone crops out and subcrops in the study area (fig. 4) and consists of 60 to 130 feet of massive, yellow-orange to tan, poorly consolidated, fine-grained sandstone with layers of claystone and well-cemented sandstone. Thin lenses of lignitic (coal-rich) shale, large iron- and calcite-cemented concretions, and trace fossils of burrows are present within the formation. Resistant layers in the Fox Hills Sandstone form caprocks along the crests of some hills of the study area. Within the study area, the sandstone layers containing fossil burrows commonly are well cemented and therefore among the most resistant parts of the formation. One such layer crops out and forms the ridge near well D11a (fig. 2). The Fox Hills Sandstone is conformably overlain by the Laramie Formation in areas where the Laramie Formation has not been removed by erosion.

The Laramie Formation crops out and subcrops west of the study area (fig. 4) and in the upland areas along the eastern margin of the Muddy Creek drainage basin. The Laramie Formation has a total thickness of about 300 to 350 feet west of the study area, but the thickness generally is less than this in the study area because much of the formation has been removed by erosion. Regionally, the Laramie Formation consists of an upper part that is composed predominantly of shale and siltstone with lenses of sandstone and coal and a lower part that is composed predominantly of sandstone interbedded with shale and coal (Robson and Banta, 1987). In the vicinity of the study area, the Laramie Formation was found to be predominantly fine grained, consisting of brown to gray shale containing lenses of sandstone, lignitic shale, and coal.

Unconsolidated sediments in the vicinity of the study area consist of Peoria Loess, windblown sand deposits, and alluvium. The Peoria Loess generally is Pleistocene in age with some materials of Holocene age and covers the bedrock in much of the study area (Sharps, 1980). The loess is covered by modern soil horizons and may be interbedded with buried soil horizons (Muhs and others, 1999). More detailed information about the Peoria Loess is described by Muhs and others (1999). The maximum observed thickness of unconsolidated sediments that include the Peoria Loess in the vicinity of the study area is about 50 feet near well D9 (fig. 2). In the study area, the loess consists of fairly homogeneous tan to brown windblown clay and silt derived from weathered bedrock and older alluvium. Windblown sand deposits probably are Pleistocene to modern in age and were less than 1 foot thick in the cores obtained from drilling at or near wells D6, D9, D25, D31, and D33 (fig. 2). Like the Peoria Loess, the windblown sand deposits are derived from weathered bedrock and alluvium. Alluvium at the site probably is Pleistocene to Holocene in age. The alluvium is present in paleochannels and along the flood plains and bottoms of larger stream valleys, sometimes beneath the Peoria Loess. Alluvium was less than 1 foot thick in the cores obtained from drilling at or near wells D6, D9, D25, D31, and D33 (fig. 2). The composition and texture of the alluvium are not homogeneous but range from pink, white, and gray arkosic sands and gravels derived from igneous and metamorphic rock of the Rocky Mountains to dark yellowish gray to tan clay, silt, and sand locally derived from sedimentary rocks.

## Hydrology

An overview of hydrology is included in this report to provide the reader with an understanding of the hydrologic system. Hydrology refers to the amount and movement of water in the study area, including precipitation (snow and rain), humidity, surface water, and ground water. Natural processes that can affect a hydrologic system include precipitation, runoff, transpiration, evaporation, infiltration, ground-water flow, and seepage. Anthropogenic processes that can affect a hydrologic system include ground-water pumping, surface-water impoundment, diversion, and irrigation, although no irrigation or diversion took place in the study area from 1993 through 1999.

Most of the precipitation in the study area is in the form of rain (precipitation data are included in Appendix II). Although the study area receives snow between October and April, snow accumulation is diminished by the frequent winds in the study area, which can drift the snow, and solar radiation, which can melt the snow or even sublimate it. Most rain is received in the summer during mid-July through August, and sometimes in spring during May or June. The presence, duration, and intensity of rain varied across the study area (compare July–September data from the D2 location with data from the D23 location) and with time (compare 1997 data with 1998 data from the same location). The spatial variability in precipitation data (Appendix II) indicates that much of the rain originated from localized rather than regional thunderstorms.

Much of the rain that falls in the study area runs off the land surface into streams. The hills and valleys of the study area form four drainage basins: Badger Creek, Cottonwood Creek, Muddy Creek, and Rattlesnake Creek (fig. 6). All four drainage basins are part of the larger South Platte River drainage basin (Seaber and others, 1987; U.S. Geological Survey, 1974). Surface water can be supplied by precipitation, runoff, springs, or ground-water seeps or can be lost to the unsaturated zone or ground water by infiltration. Short segments of some of the streams in the vicinity of the study area are intermittent and flow only at certain times of the year; but in general, the streams are ephemeral and flow only after intense rain. Streams flowed in or out of the study area from 1993 through 1999 only after intense rain. Ponds were present in valleys of the study area during 1993–99; most ponds were impoundments created by detention structures. Floodwaters (especially in July and August) deposited sediments and filled in some existing ponds or scoured out depressions and formed new ponds. A pond that was present near well D5 in 1993 and 1994 gradually dried up and filled in by 1997. In August 1996, a large, shallow pond was observed east of well D25 (fig. 2); in late 1997 through 1998, the ponded area near D25 was drained and regraded by the MWRD, and smaller ponds formed behind check dams that were installed between wells D8 and D25. Only a few ponds were consistently present in the study area from 1993 through 1999; larger ponds, such as in Cottonwood Creek east of well D30, Muddy Creek between wells D20 and D21, and Rattlesnake Creek south of well D22, were fairly stable and routinely supported aquatic bird and plant communities. The ponds that were present year round likely were recharged by ground-water seepage and indicate a hydraulic connection between surface water and shallow ground water in the study area.

Intense rainfall in the study area washed surface materials off the hillslopes and usually caused streamflow and flooding. After floodwaters receded, horizontal lines of flood debris were observed about 5 feet above the streambed in some of the steeper valleys such as Cottonwood Creek in July and August. Flood debris deposited along hillslopes in valleys contained topsoil and much plant material, but biosolids in flood debris are difficult to detect by visual inspection and were not observed by the USGS.

Some of the precipitation in the study area was evaporated, and some of the precipitation was consumed by plants through absorption and root uptake and then transpired. The term for these combined processes is evapotranspiration. The study area in general is not wooded, but cottonwood trees were present in some valleys including along the southern parts of Muddy Creek and Cottonwood Creek. Other vegetation in the study area included prairie grasses, wetland plants in some flood plains, and agricultural crops. Uptake and transpiration likely were more prevalent in flood plains where ground water is closer to the land surface and vegetation is denser. Plants uptake the most water from soils and shallow ground water during daylight during their growing season, which is usually spring and summer for grasses and deciduous trees but also winter for some varieties of wheat. Phreatophytes such as cottonwood trees draw water directly from the water table, causing potentially substantial losses of ground water through uptake and transpiration. Evaporation occurs year round but is highest during the clear, dry, sunny days of summer. Evapotranspiration represents natural and possibly substantial losses of water in the study area.

Some of the precipitation in the study area infiltrated the land surface, percolated through the unsaturated zone, and recharged the ground water. Precipitation can directly recharge ground water by percolation through porous rock outcrops or through the unsaturated zone. Precipitation can indirectly recharge ground water by producing streamflow or pond water that infiltrates. Ground-water discharges include seepage to streams, evapotranspiration, and pumping from wells. Ground-water flow between aquifers can be a discharge for one aquifer

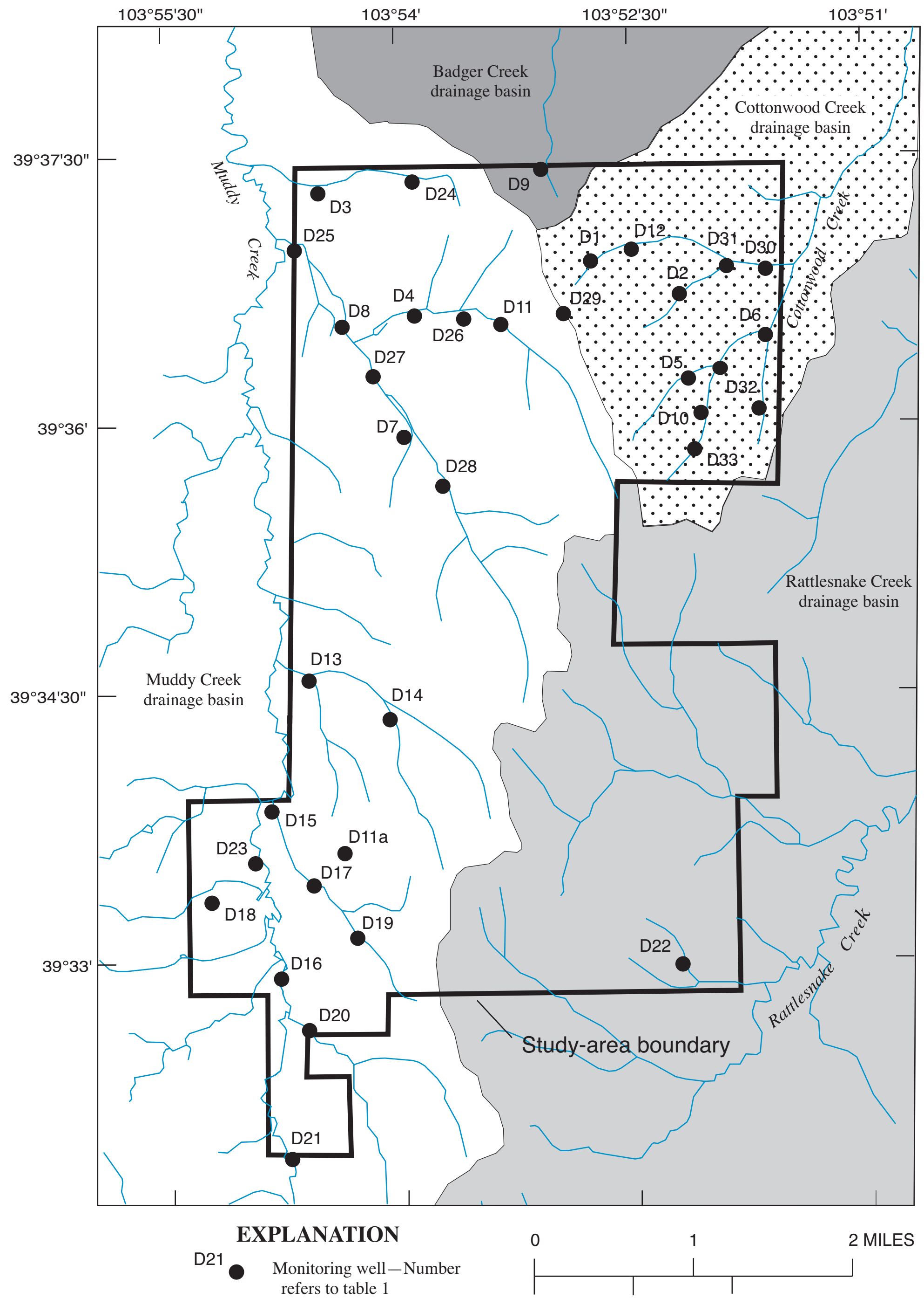


**Figure 6.** Drainage basins in the study area.

and a recharge for another aquifer. In the study area, two types of aquifers are important: bedrock aquifers and alluvial aquifers. Deep ground water commonly is part of the bedrock aquifer. Shallow ground water can be either a shallow part of the bedrock aquifer or an alluvial aquifer. For this report, "deep" ground water refers to a depth to ground water greater than 50 feet, and "shallow" ground water refers to a depth to ground water less than 50 feet. Ground water can be confined or unconfined. Confined ground water is under pressure significantly greater than atmospheric, and its upper limit is the bottom of a bed of substantially lower hydraulic conductivity than that of the geologic material in which the confined water occurs (Lohman and others, 1972). Unconfined ground water has a water table, which means the ground-water surface is at atmospheric pressure (Lohman and others, 1972). Ground water of the study area generally is unconfined. The following sections of this report discuss the hydrology of the bedrock and shallow aquifers in detail, and recharge processes are further discussed in the subsequent "Aquifer Interaction" section.

## Bedrock Aquifer

Rock formations that contain sufficient saturated permeable material to yield significant quantities of ground water to wells are called bedrock aquifers (Lohman and others, 1972). The shallowest bedrock aquifer in the vicinity of the study area is the Laramie-Fox Hills aquifer (figs. 4 and 5), which is the primary water-supply aquifer and has a saturated thickness of as much as about 200 feet in the vicinity of the study area (Robson and others, 1981; Robson and Banta, 1995). Ground water in this bedrock aquifer is present in the pore spaces between the grains of sand or particles, not in large fractures or large voids. The Arapahoe, Denver, and Dawson aquifers (figs. 4 and 5) are important sources of ground water in other parts of the Denver Basin, but the geologic units that comprise these aquifers are eroded away in the study area (fig. 4). Ground water also is present in bedrock layers deep below the Laramie-Fox Hills aquifer, but this ground water is separated from the Laramie-Fox Hills aquifer by 5,000 to 6,000 feet of very low permeability Pierre Shale and other fine-grained Cretaceous-age rocks (Robson and Banta, 1987, sheet 1), which limit hydraulic interaction between the Laramie-Fox Hills aquifer and the deeper ground water. Therefore, discussion of bedrock aquifers in this report is limited to the Laramie-Fox Hills aquifer.

At full saturated thickness, the Laramie-Fox Hills aquifer includes discrete sandstone units in the lower part of the Laramie Formation and all of the Fox Hills Sandstone (figs. 4 and 5). Locally, the aquifer also may include sandstone and siltstone beds in the transition zone (upper part) of the Pierre Shale. Coal seams present in the Laramie Formation are considered to be above the top of the aquifer (fig. 5). The predominantly fine-grained composition of the upper part of the Laramie Formation acts as a confining layer above the Laramie-Fox Hills aquifer where the aquifer is fully saturated in the central part of the Denver Basin west of the study area. In the vicinity of the study area, the geologic formations that comprise the Laramie-Fox Hills aquifer are only partially saturated, and the aquifer is unconfined. The Laramie-Fox Hills aquifer potentially includes parts of three formations because saturated sandstones in the lower part of the Laramie Formation and in the transition zone of the Pierre Shale commonly have direct hydraulic connection with the Fox Hills Sandstone.

By definition, "Laramie-Fox Hills aquifer" refers to the geologic layers that are sufficiently saturated to yield significant quantities of water to a well; the term does not refer just to the geologic layers of the three formations described in the preceding paragraph. In this report, the full sequence of geologic layers that have the potential to be saturated with water and form the aquifer, whether or not the layers actually are saturated, is called the Laramie-Fox Hills hydrostratigraphic unit (LFH-HU); only the saturated part of the LFH-HU is the aquifer. Throughout much of the Denver Basin, the LFH-HU is fully saturated and confined beneath overlying bedrock layers, so the term "Laramie-Fox Hills aquifer" can be used interchangeably with the term, "Laramie-Fox Hills hydrostratigraphic unit" (LFH-HU). However, where the LFH-HU crops out along the margins of the Denver Basin, the LFH-HU is dry or not fully saturated, so the aquifer either is not present at all or is thin and unconfined (Robson, 1983; Romero, 1976). Because not all of the LFH-HU is saturated in the vicinity of the study area, it is important to distinguish between the aquifer and the hydrostratigraphic unit.

### Location and Extent

The location and extent of the Laramie-Fox Hills aquifer in the vicinity of the study area determines aquifer interactions, areas of the aquifer that could be affected by biosolids applications, and the amount of available ground-water resources. This information has not been defined in detail for the study area by previous investigations. Moreover, historical delineations may be outdated because the location and extent of the aquifer can change as water levels in the aquifer fluctuate over the years. Characterization of the location and extent of the aquifer within the LFH-HU requires many test wells drilled into the LFH-HU; this well coverage was not available in the vicinity of the study area. However, the location and extent of the Laramie-Fox Hills aquifer can be approximated from the presence of the LFH-HU with more detailed information provided by three monitoring wells, D9, D11a, and D29.

The presence of the LFH-HU is determined by the outcrop and subcrop areas, thickness, and structure of the LFH-HU. Outcrops of the Laramie Formation and Fox Hills Sandstone in the vicinity of the study area previously have been described and mapped by Dane and Pierce (1936), Romero (1976), and Sharps (1980). The regional structure and extent of the Laramie-Fox Hills aquifer previously have been mapped by Romero and Hampton (1972), Romero (1976), Robson and others (1981), and Van Slyke and others (1988). This information for the LFH-HU, however, is not provided in detail for the vicinity of the study area. Therefore, in 1999, the LFH-HU in the vicinity of the study area was mapped in detail to provide more information about the possible location and thickness of the Laramie-Fox Hills aquifer. The LFH-HU in the vicinity of the study area was mapped (pls. 1 and 2) using data from geophysical logs (pl. 3), lithologic logs, field observations, and available geologic maps and reports. Mapping methods are described in Appendix I.

Areas where the Laramie Formation continuously crops out or subcrops could have confined ground water and substantial ground-water resources, such as the western part of the mapped area (pls. 1 and 2). Areas where the LFH-HU crops out or subcrops have unconfined ground water, and the Laramie-Fox Hills aquifer is thin or absent. Areas where the Pierre Shale crops out or subcrops could have little ground-water resources. Areas where the LFH-HU is visible at land surface (outcrop areas) and areas where the LFH-HU is covered by soil, loess, or alluvium (subcrop areas) were mapped as a single unit of undifferentiated outcrop-subcrop area in plates 1 and 2. All of the central MWRD property (the study area) and the north MWRD property overlie the outcrop-subcrop area of the LFH-HU or the Laramie Formation, but only the western edge of the south MWRD property overlies the outcrop-subcrop area of the LFH-HU. The LFH-HU is not present in much of the MWRD south property (pls. 1 and 2). The LFH-HU outcrop-subcrop area is an irregular pattern in the vicinity of the study area (pls. 1 and 2). Width of the outcrop-subcrop area ranges from about 1 mile at places in the southern part of the mapped area to about 11 miles in the north. The irregular pattern of the outcrop-subcrop area primarily is caused by the topography of the land surface rather than by the configuration of the LFH-HU. Topographic relief in the northern part of the mapped area generally is less than in the southern part of the area, resulting in a wider outcrop-subcrop area in the north.

The LFH-HU structure contours in plate 1 provide an estimate of the altitude of the base of the Laramie-Fox Hills aquifer if the LFH-HU is at least partially saturated. The LFH-HU structure contours in plate 2 provide an estimate of the altitude of the top of the Laramie-Fox Hills aquifer if the LFH-HU is fully saturated. A comparison of the structure-contour altitude with land-surface altitude will indicate depth below land surface. The structure contours indicate that the maximum depth below land surface to the top or bottom of the Laramie-Fox Hills aquifer is in the northwest part of the mapped area (pls. 1 and 2). The LFH-HU dips to the northwest at an average inclination of about 40 feet per mile (pls. 1 and 2) over most of the mapped area. In the northern part of the mapped area, broad folds are present in the structure of the LFH-HU, and the LFH-HU dips in a more westerly direction. Locally, dips range from about 30 to 60 feet per mile.

The difference in the top and base LFH-HU structure-contour altitudes (pls. 1 and 2) provide an estimate of the thickness of the Laramie-Fox Hills aquifer if the LFH-HU is fully saturated. The total thickness of the LFH-HU ranges from about 240 to 360 feet in the vicinity of the study area, primarily as a function of changes in lithology at the top and base of the hydrostratigraphic unit. The LFH-HU is less than 200 feet thick in parts of the study area, however, because part of the LFH-HU has been eroded. A gradual facies change occurs in the LFH-HU from the northeast to the southwest across the southern part of the mapped area as sediments that compose the base of the unit become more fine grained. The facies change results in a decrease of about 30 feet in the thickness of the LFH-HU to the southwest, but because the change in thickness is gradual and is less than the contour interval of the map, structural contours for the base of the LFH-HU were drawn continuously across the change.

### Hydrologic Properties

Various published reports provide information about the hydrologic properties of the Laramie-Fox Hills aquifer (Romero, 1976; Robson and others, 1981; Major and others, 1983; Robson, 1983, 1987). Saturated thickness of the aquifer in the vicinity of the study area likely is 200 feet or less (Robson and others, 1981; Robson and Banta, 1995; Robson, 1987, fig. 6). The aquifer yields about 5 to 250 gallons per minute (Romero, 1976; Major and others, 1983) but yields as much as 900 gallons per minute in a few places in the Denver Basin farther west (Romero and Hampton, 1972). Hydraulic conductivity is a measure of the relative ease with which a porous material transmits water. Robson (1983, fig. 7) reported that hydraulic conductivity averages about 6 feet per day in the study area and was measured at 7 feet per day at one location in the study area. The storage coefficient of a confined aquifer is the volume of water the aquifer releases or stores per unit surface area per unit change in head. The storage coefficient of the Laramie-Fox Hills aquifer is estimated to be about 0.0002 or less in the study area but is as much as 0.0004 in deeper parts of the basin (Robson, 1983, fig. 17). Water-level data for the aquifer from 1978 indicated a potentiometric-surface altitude in the study area that ranged from about 5,200 to 5,300 feet above NGVD 29 and indicated the general direction of ground-water flow in the study area was from south to north with a component of flow to the east (Robson and others, 1981, fig. 8).

Because hydrologic data for the Laramie-Fox Hills aquifer within the study area were sparse, one shallow bedrock well was constructed in 1993 (well D9; fig. 2), and two deep bedrock wells were constructed in 1997 (wells D11a and D29; fig. 2). These monitoring wells were intended to provide hydrologic and water-quality information for the sandstone part of the bedrock aquifer (the upper and likely more permeable part of the LFH-HU). A shallow borehole was drilled near the north boundary of the study area into the Fox Hills Sandstone where the formation begins to transition into shale. This borehole yielded water from the lower 5 feet of the formation, was completed as monitoring well D9 (fig. 2), and was screened at about 49 to 59 feet below land surface. A borehole that was drilled through the sandstone ridge north of well D17 yielded water from the lower 10 feet of approximately the same part of the formation about 4 miles southwest of well D9. This borehole was completed as monitoring well D11a and was screened at about 110 to 120 feet below land surface. Another borehole yielded water from the lower 4 feet of approximately the same part of the formation about 1 mile south of well D9, was completed as monitoring well D29, and was screened at about 145 to 155 feet below land surface. Well information is listed in table 1 and Appendix II. The other USGS monitoring wells in the study area (fig. 2, table 1, and Appendix II) are shallow (less than about 58 feet deep), but some of these wells likely are completed in the bedrock aquifer (table 1). All shallow wells will be discussed in the next section, "Shallow Aquifers."

Water levels were measured monthly and water-quality samples were collected quarterly at the bedrock monitoring wells, D9, D11a, and D29. Depth to water in feet below land surface was about 55 at well D9, 110 at well D11a, and 150 at well D29; these water levels represented maximum observed depth to water in the study area. Water levels fluctuated only about 1 foot at well D9, 0.25 foot at well D11a, and about 0.5 foot at well D29 (Appendix II). These water-level data indicate unconfined conditions and a potentiometric altitude of 5,160 feet above NGVD 29 at well D9, 5,261 feet above NGVD 29 at well D11a, and 5,214 feet above NGVD 29 at well D29. These data are similar to those shown by Robson and others (1981). Well D9 is completed in the LFH-HU, but at a place where much of the upper part of the Fox Hills Sandstone is eroded away, and the well does not yield sufficient ground water to be considered the Laramie-Fox Hills aquifer. Yield from the other two bedrock monitoring wells also was relatively small; the wells were easily pumped dry at about 0.25 gallon per minute or less. At these monitoring locations, the Laramie-Fox Hills aquifer was only partly saturated. Wells D9, D11a, and D29 do not fully penetrate all 240–360 feet of the LFH-HU (pls. 1 and 2); these wells penetrate only the Fox Hills Sandstone interval in the upper part of the LFH-HU (pl. 3) above the shaley part of the LFH-HU (fig. 5 and pl. 3). Within the upper sandstone interval of the Laramie-Fox Hills aquifer, saturated thickness was less than 10 feet (about 10 percent) at well D11a and less than 5 feet (about 5 percent) at well D29; the aquifer likely is hydraulically continuous for about another 250 feet of depth below these wells (pls. 2 and 3), but yield is likely to be even less in the lower part of the aquifer because the more shaley part of the aquifer generally has less permeability. Water levels in these wells and other wells completed in the bedrock aquifer (tables 1 and II.3) indicate a component of ground-water flow to the north in the study area and recharge to the bedrock aquifer along the main ridge of the study area. Additional bedrock wells would be needed to further assess the extent, saturated thickness, and ground-water flow directions within the Laramie-Fox Hills aquifer in the study area.

## Shallow Aquifers

The remaining monitoring wells (fig. 2, table 1) are completed in either alluvial aquifers or shallow parts of the bedrock aquifer where depth to water is less than about 50 feet. The location and quantity of alluvium commonly were not determined as part of this study, so both bedrock and alluvial aquifers are included in this discussion of shallow ground water. Lithologic and well-completion information for the shallow wells are provided in Appendix II.

A number of alluvial aquifers are present, are associated with the stream network in the study area, and are of limited extent. For the purposes of this report, unconsolidated (uncemented) sediments and gravels in current or historical stream channels or flood plains that yield significant quantities of ground water to wells are called alluvial aquifers, regardless of whether wind or water deposited the sediments. Geologic information from the boreholes of the two hills containing wells D11a and D29 indicate that saturated alluvium and loess are not present continuously on or beneath all hills of the study area, so alluvial aquifers are discrete and associated with streams. A thin alluvial aquifer was observed in the upper part of Badger Creek at the location of well D9 at about 28 feet below land surface, but this ground-water zone was not monitored. Alluvial aquifers are present in the Muddy Creek and Cottonwood Creek valleys, although not all loess and alluvium deposits in the valleys are saturated, even in streambeds. Wells D1, D11, and D18 were constructed in stream valleys but were dry whenever checked for water level after 1993. In contrast, wells D6, D17, D25, D31, and D33 yielded at least 0.2 gallon per minute and are known to be completed in loess or alluvial aquifers because boreholes at these locations were cored. Wells D15, D23, and D30 likely are completed in alluvial aquifers because the well depths are 23 feet or less, and the wells are located in downgradient parts of relatively large drainage basins. Wells D3, D4, D19, D22, D24, D26, and D32 likely are completed in shallow parts of the bedrock aquifer because these wells are screened below the probable extent of the alluvial deposits.

Depth to shallow ground water in the study area ranged from about 2 feet below land surface at well D23 to about 37 feet below land surface at well D3. Water levels commonly were lowest between June and early July, and water levels commonly were highest between late July and December (Appendix II).

Water-table contour maps indicate generalized, horizontal hydraulic gradients. Water-level data measured October 3–4, 1996, in the shallow wells were contoured for the study area. The resulting water-table map (fig. 7) indicates that steeper hydraulic gradients coincide with steeper topography in the study area. The map also indicates that a component of ground-water flow is down valleys. Well coverage was not sufficient to determine if another component of ground-water flow is perpendicular to the valley floor down the hill slopes. Water-level data for well D22 were not contoured in figure 7 because the well D22 data indicated an improbable flow path if considered part of the water table. Water-level data for well D24 were not contoured in figure 7 because the well D24 data indicated an improbable hydraulic gradient if considered part of the water table. Hydraulic connection between the bedrock and alluvial aquifers will be discussed in the next section, "Aquifer Interaction."

Water levels in the shallow wells fluctuated differently. Water levels fluctuated most in summer and least in winter, and water levels fluctuated most in the shallower wells and least in the deeper wells (Appendix II). Monthly water-level data for the shallow monitoring wells and continuous-recorder data for wells D2 and D23 illustrate this point. Well D2 is located in a small, steep valley incised in the shaley part of the LFH-HU, the transition zone of the Pierre Shale, and had water levels ranging from about 8 to 10 feet below land surface. Well D23 is located in a longer, flatter valley incised in the sandier part of the LFH-HU compared to well D2 and had water levels ranging from about 1.5 to 5.5 feet below land surface. Both sites were vegetated but not wooded, and ponds usually were present during 1993–98 within 20 feet of both sites. Comparison of continuous-recorder data for wells D2 and D23 provides detailed information about water-level fluctuations at hourly, daily, and seasonal time scales.

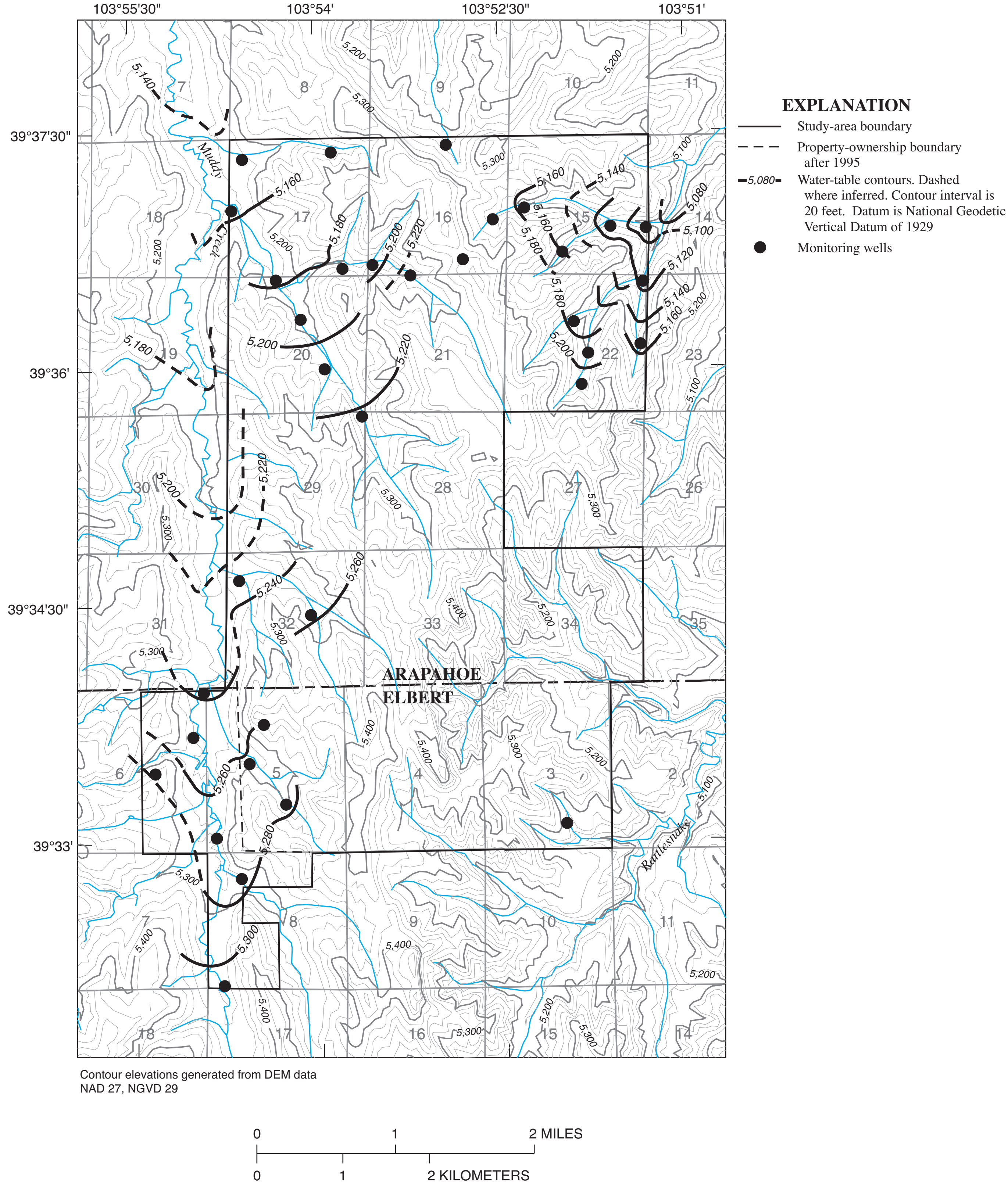


**Figure 7.** Water-table contours for the study area, October 3–4, 1996.

Hourly water-level data can indicate daily hydrologic cycles affecting ground water. Hourly data for a 5-day period during the (*A*) summer and (*B*) winter are shown in figure 8 for well D2 and figure 9 for well D23. Comparing these four graphs shows that water levels were slightly higher in the winter than in the summer, and evaporation affects ground water at these two sites less in winter. Winter water levels at wells D2 and D23 fluctuated about 0.05 foot or less during the 5-day period shown in figures 8 and 9, whereas summer water levels at wells D2 and D23 fluctuated more and indicated a distinct diurnal pattern. Evapotranspiration has a 24-hour cycle and is a more dominant process during summer when air temperatures are warm. Summer water levels at both wells have a 24-hour cycle that indicates evapotranspiration, although the 24-hour cycle at well D23 is more pronounced and typical of diurnal evapotranspiration fluctuations. Evapotranspiration is more likely to affect ground water in the vicinity of well D23 than D2 because the water table is closer to the land surface at D23 and is more available to plant roots and more likely to be affected by changes in surficial temperatures and humidity. The timing of the diurnal cycles in the data can indicate whether evapotranspiration is taking place close to the monitoring well or farther away. If evapotranspiration takes place close to the well, water levels would decline throughout the hot, daylight hours, then rise during the cool, dark, night hours. If evapotranspiration takes place farther from the well, the diurnal cycle could be offset. At both wells, the summer water levels declined through the daylight hours and were lowest from about 8 p.m. to midnight, which is consistent with evapotranspiration taking place near the well.

The relation of recharge to precipitation is apparent when precipitation and water-level data are compared at a seasonal time scale. Water levels and precipitation data during and after the rainy season from the continuous recorders are shown in figure 10 for well D2 in 1997 and figure 11 for well D23 in 1996. In general, water levels at both wells were declining before the rainy season began in July. The water-level data indicate that the first rains did not recharge the aquifers; rain that infiltrated did not sufficiently saturate the unsaturated zone to recharge ground water. Additional rainfall in late July 1997 at D2 or late August 1996 at D23 did infiltrate and recharge shallow ground water. The magnitude of water-level increase did not always correlate with the magnitude of precipitation, indicating that preceding conditions affect whether the portion of the precipitation that infiltrates the ground surface recharges the ground water (wet preceding conditions) or remains in the soil zone (drier preceding conditions). The lag in water-level response to precipitation during this period was less than one week at both wells and often within one day, indicating that ground water often recharges soon after infiltration. Water levels rose and stayed fairly high at well D23 throughout October, but water levels declined again at well D2 in September. Locations such as D2 and D23 where ground-water recharge is nearly simultaneous with rainfall may be most susceptible to ground-water contamination from anthropogenic applications.

A possible relation of recharge to precipitation is apparent when specific-conductance, water-temperature, precipitation, and water-level data are compared at a seasonal time scale. Specific-conductance and water-temperature data from well D6 were paired with precipitation records from nearby well D2 for 1998 (fig. 12) to examine ground-water recharge. The slight decline in specific conductance at well D6 in late summer and fall is consistent with dilution of major ions and coincides with increased ground-water temperature (fig. 12) and increased water level (Appendix II). This relation indicates that warm summer rains or ponds can recharge the ground water in the vicinity of well D6 from about 8 days to several months after large rainfall accumulations.

Another concept related to ground-water recharge is flow paths. The pathway that water takes to reach the aquifer and the pathways that water in the aquifer travels are known as ground-water flow paths. Flow paths affect the amount of water that is recharged, the timing of ground-water recharge, and the amount of time water travels within the aquifer. Where the water in the aquifer originates, what processes affect that water, and what properties and chemistry are characteristic of that water are related to flow paths. The likelihood that ground water is contaminated by the application of agricultural chemicals or biosolids at the land surface largely is determined by ground-water flow paths. Dissolved-gas and chlorofluorocarbon (DG-CFC) data provide some flow-path information. DG-CFC's are present in air, trapped in the water that infiltrates through the subsurface, and isolated from the atmosphere when the water enters the saturated zone. Some DG-CFC's can stay unchanged in the ground water after recharge and sometimes can be used as tracers, or indicators, of ground-water recharge history and flow paths. The theory supporting the use of DG-CFC's as tracers, as well as the specific sampling and analytical methods and interpretive calculations, is explained by Busenberg and Plummer (1992), Busenberg and others (1999), Heaton (1981), Heaton and Vogel (1981), Heaton and others (1983), Plummer and Friedman (1999), Stute and Schlosser (1999), Stute and others (1992), and Wilson and McNeill (1997). Descriptions of USGS DG-CFC applications also are provided on the Internet (http://water.usgs.gov/lab/cfc/ and http://water.usgs.gov/lab/dissolved-gas/, accessed October 2001).

Ground-water recharge information indicated by the 1998 dissolved-gas sampling for the study area (table 2) includes calculated recharge water temperature, suggested recharge source, and recharge altitude calculated from thermodynamic equilibrium principles applied to gas concentrations in ground-water samples. Comparison of ground-water temperature during dissolved-gas sampling with the apparent recharge temperature (fig. 13) can indicate whether the recharge water likely was warmer than ground water as in the case of recharge from summer rain or ponding, about the same temperature as ground water as in the case of recharge or flow from other ground water, or colder than ground water as in the case of recharge from ponds during the spring or fall (Plummer and others, 2001). The dissolved-gas results indicate that recharge sources in the study area vary, but of the wells selected for DG-CFC sampling, well D6 yielded the only ground-water sample that indicates recharge directly from precipitation or perhaps warm

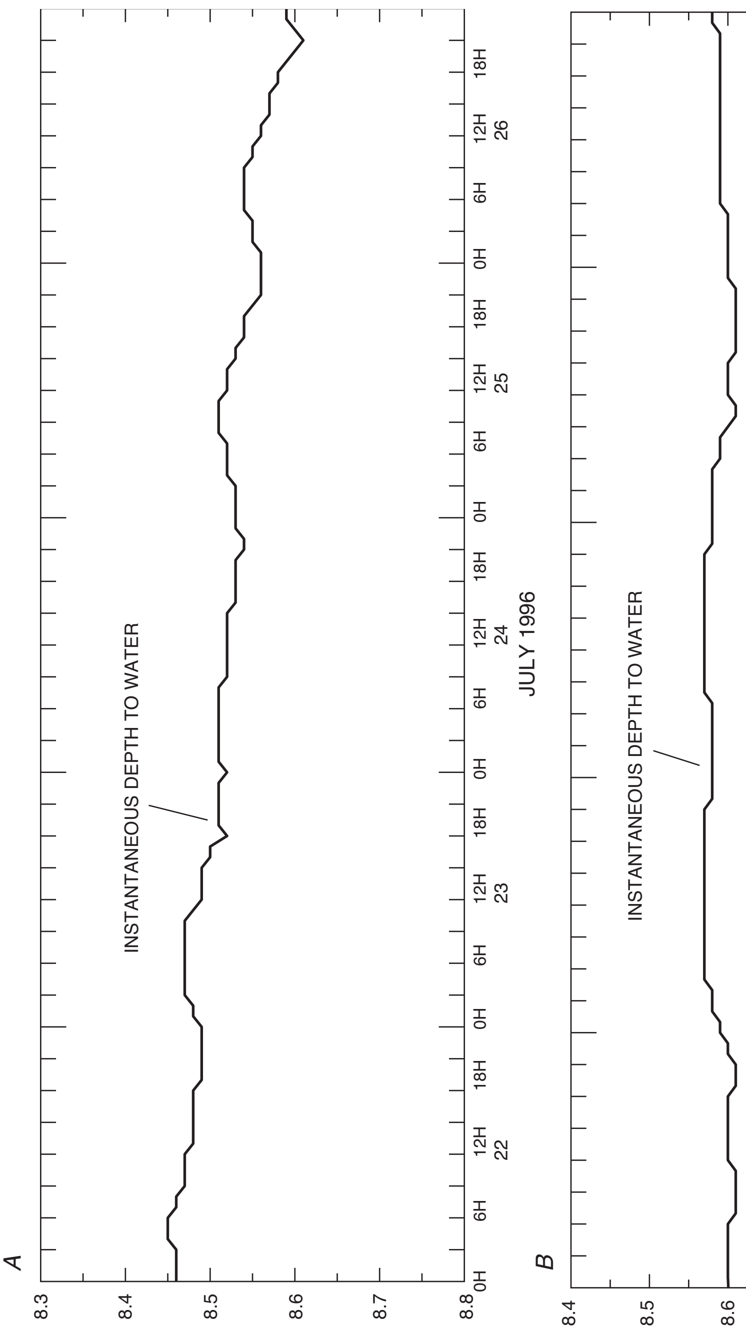


**Figure 8.** Diurnal fluctuations in water level at well D2 during: (*A*) summer and (*B*) winter, 1996.

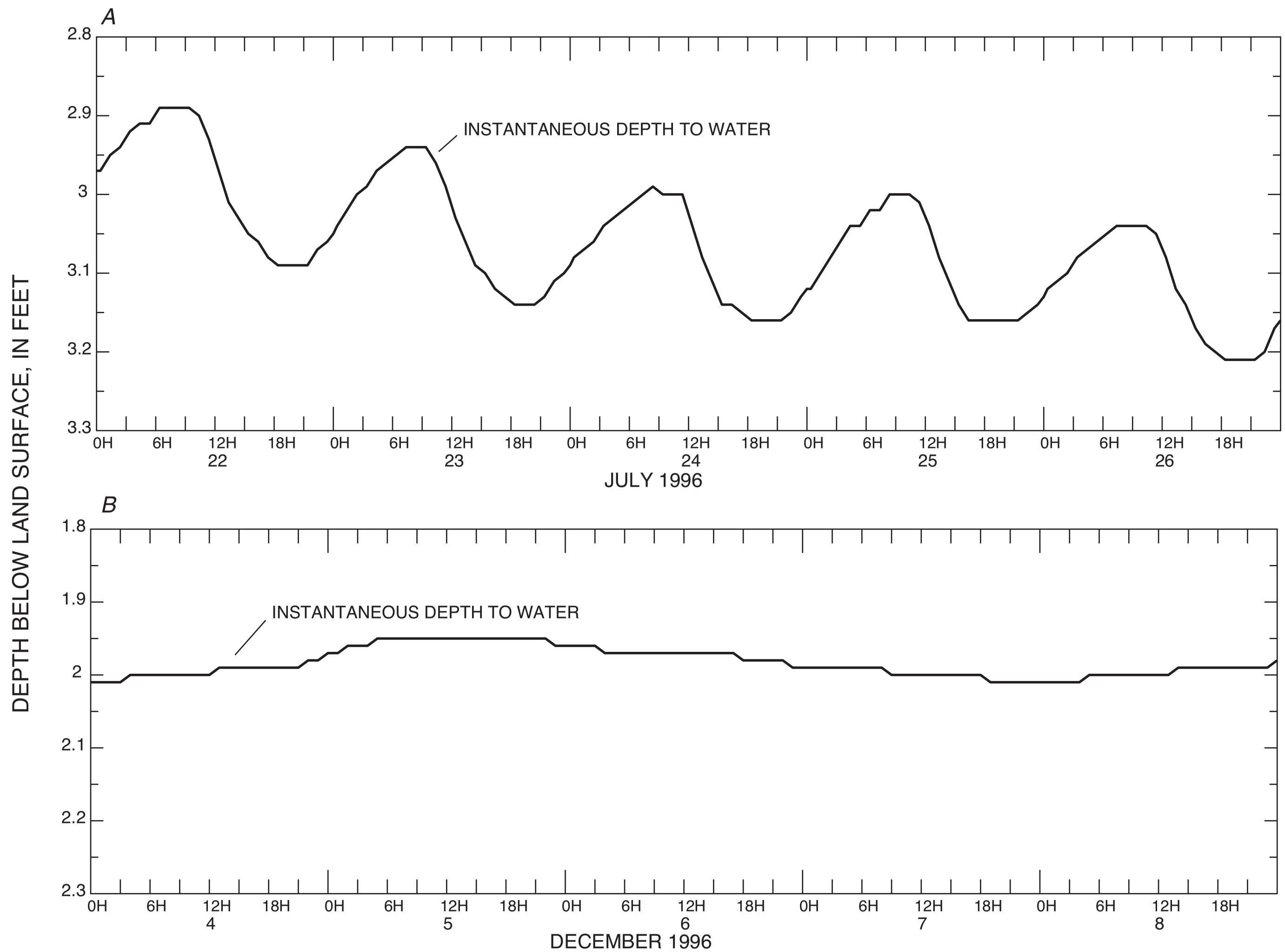


**Figure 9.** Diurnal fluctuations in water level at well D23 during: (*A*) summer and (*B*) winter, 1996.

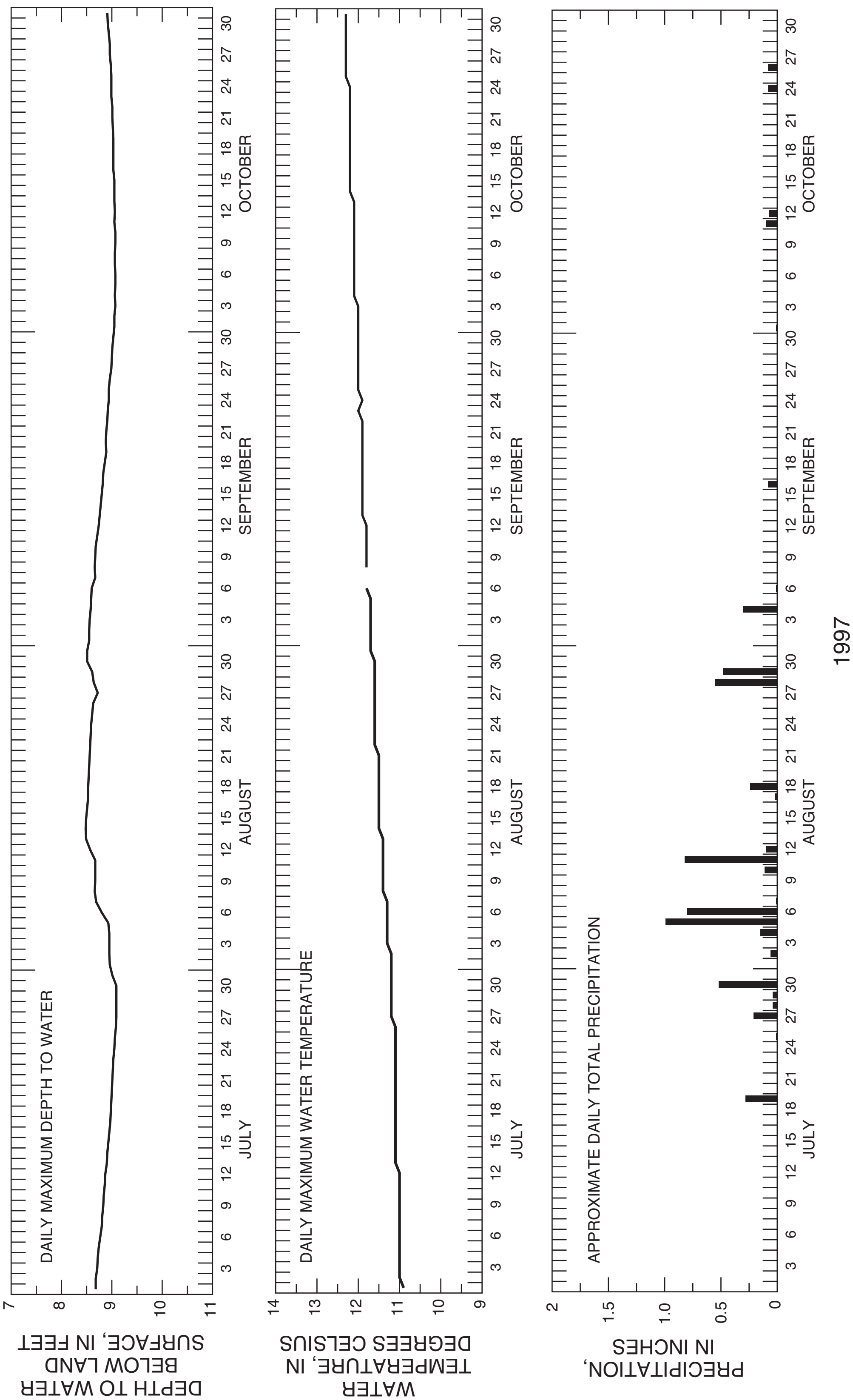


**Figure 10.** Continuous-recorder water levels, water temperature, and precipitation at well D2 during summer and fall, 1997.

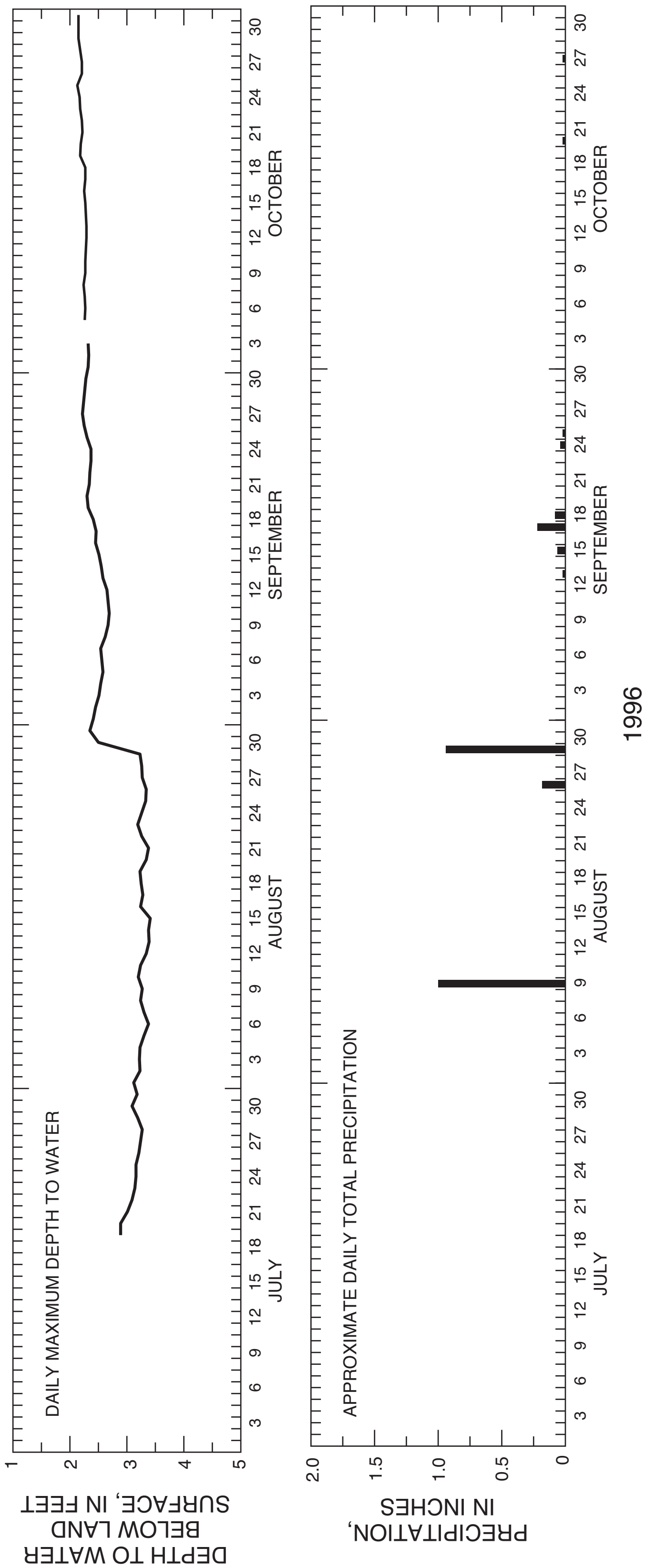


**Figure 11.** Continuous-recorder water levels and precipitation at well D23 during summer and fall, 1996.

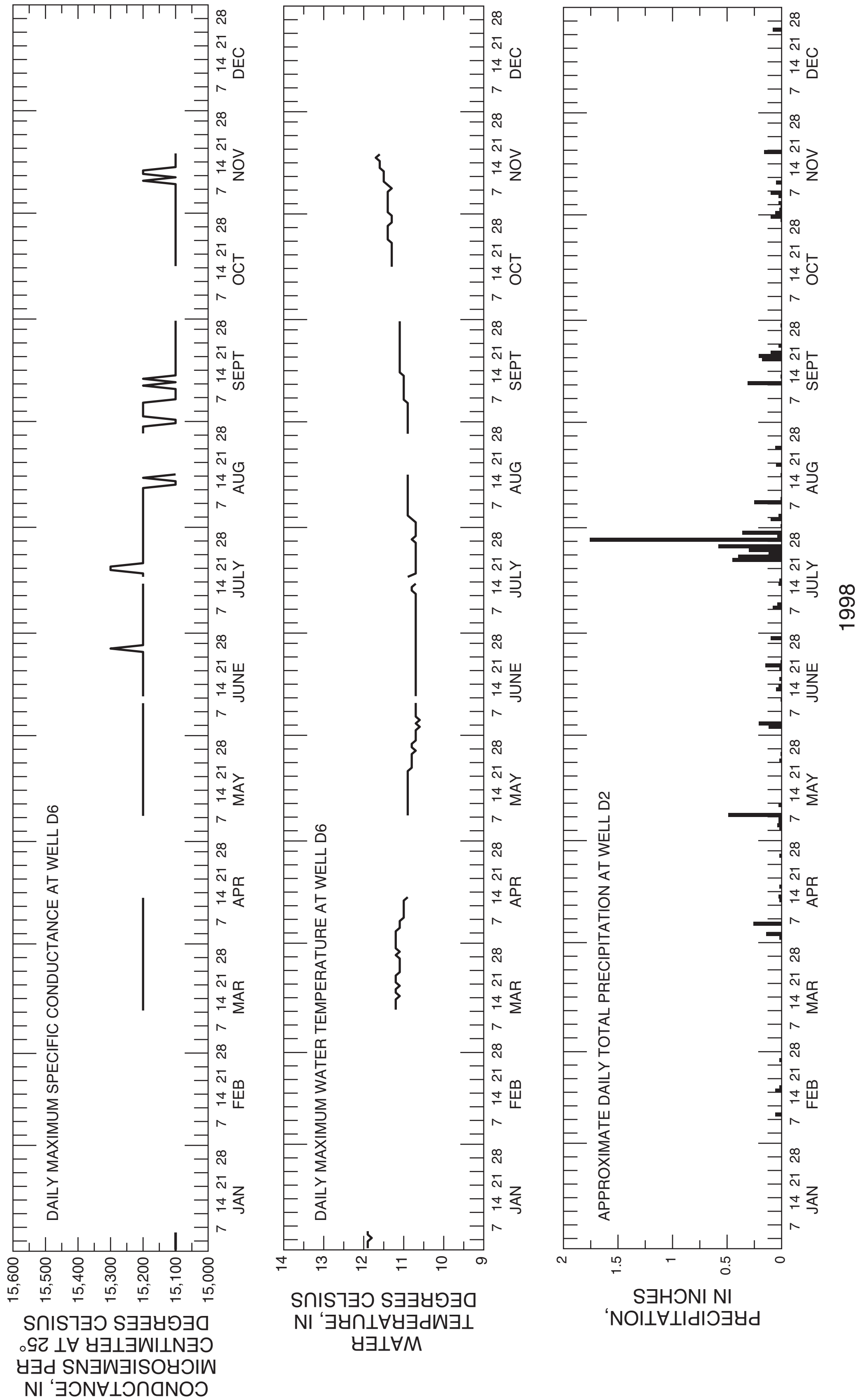


**Figure 12.** Continuous-recorder water temperature and specific conductance at well D6 and precipitation at well D2 during 1998.

**Table 2.** Ground-water recharge information indicated by dissolved-gas data collected at selected wells near Deer Trail, Colorado, 1998.

[Temperature in degrees Celsius; Alt. Ft., altitude in feet above NGVD 29; dissolved-gas data and calculated information are in table II.5 in the back of the report; the uncertainty of the calculated recharge temperatures is less than 2 degrees Celsius; dissolved-gas sampling and analytical methods and calculations are described by Busenberg and others (1999), Heaton (1981), Heaton and Vogel (1981), Heaton and others (1983), Plummer and others (2001), Stute and Schlosser (1999), Stute and others (1992), and Wilson and McNeill (1997)]

| Sampling location and date | Temperature | | Suggested recharge source (fig. 13) | Estimated recharge (Alt. Ft.) |
|---|---|---|---|---|
| | Sample, field | Calculated recharge | | |
| D5 11/19/98 | 12 | 11.2 | Pond or other ground water | 5,217 |
| D5 11/19/98 | 12 | 11.1 | Pond or other ground water | 5,217 |
| D6 11/24/98 | 12.9 | 15.5 | Rain or warm pond | 5,217 |
| D6 11/24/98 | 12.9 | 15.6 | Rain or warm pond | 5,217 |
| D9 11/17/98 | 16.5 | 12.0 | Cold pond or snowmelt | 5,225 |
| D10 11/19/98 | 13.2 | 11.5 | Cold pond or snowmelt | 5,220 |
| D13 11/18/98 | 11.9 | 11.0 | Pond or other ground water | 5,264 |
| D14 11/24/98 | 12.4 | 12.3 | Other ground water | 5,264 |
| D17 11/18/98 | 14.3 | 11.0 | Cold pond or snowmelt | 5,264 |
| D17 11/18/98 | 14.3 | 10.8 | Cold pond or snowmelt | 5,264 |
| D24 11/17/98 | 12.8 | 12.6 | Other ground water | 5,200 |
| D24 11/17/98 | 12.8 | 13.0 | Other ground water | 5,200 |
| D25 11/18/98 | 13 | 9.9 | Cold pond or snowmelt | 5,160 |

(summer) ponding (table 2). These results are consistent with the interpretation of the continuous-recorder data for well D6 (fig. 12). The estimated recharge altitudes (table 2) are approximate but reasonable for the study area.

Ground-water recharge information indicated by the 1998 chlorofluorocarbon (CFC) sampling for the study area is listed in table 3 and includes the apparent ground-water recharge date and the degree of apparent mixing of old pre-1940 water and young post-1940 water during recharge. Old water does not contain CFC's, and this generally is water recharged before 1940. Young water contains detectable CFC concentrations, and this generally is water recharged after the 1940's to 1950's. CFC data for DG-CFC-sampled wells in 1998 indicate apparent ground-water recharge dates from 1993–98 at well D9 to about 1955–60 at well D25. Of the ground water sampled, only samples from well D9 and possibly well D24 appear to have been

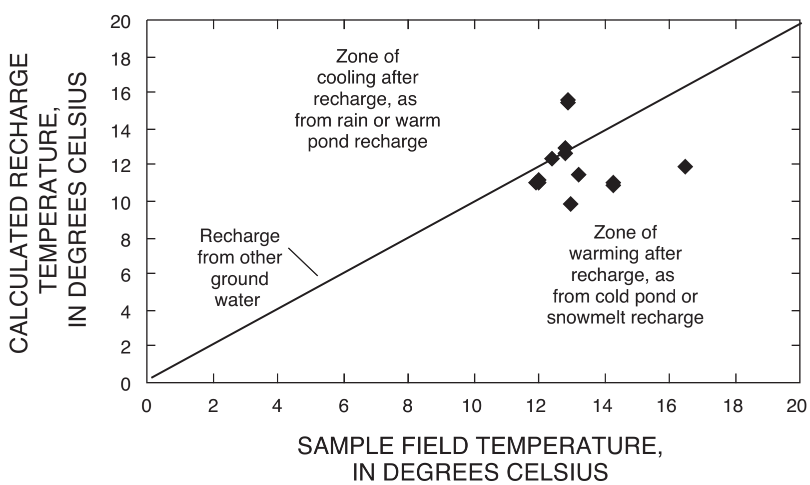


**Figure 13.** Comparison of sample temperature with calculated recharge temperature for selected wells near Deer Trail, Colorado, based on 1998 dissolved-gas data.

**Table 3.** Ground-water recharge information indicated by chlorofluorocarbon data collected at selected wells near Deer Trail, Colorado, 1998.

[Temp., temperature; Alt, altitude; °C, degrees Celsius; ft, feet above NGVD 29; a range of recharge dates are listed to indicate amount of uncertainty in the calculated dates; chlorofluorocarbon sampling and age-dating methods from Busenberg and Plummer (1992, Plummer and Busenberg (1999), and Plummer and others (2001)]

| Well name | Sampling date | Calculated recharge | | Calculated apparent ground-water recharge date | Certainty of age | Apparent mixing of old and young ground water |
|---|---|---|---|---|---|---|
| | | Temp. (°C) | Alt. (ft) | | | |
| D3 | 11/17/98 | 11.0 | 5,217 | 1970–74 | High | Possibly |
| D5 | 11/19/98 | 11.1 | 5,217 | 1975–80 | High | No |
| D6 | 11/24/98 | 15.6 | 5,217 | 1961–69 | Moderate[1] | Yes[4] |
| D9 | 11/17/98 | 12.0 | 5,163 | 1993–98 | Low[2] | Possibly |
| D10 | 11/19/98 | 11.5 | 5,220 | 1982–87 | High | No |
| D13 | 11/18/98 | 11.0 | 5,264 | 1970–74 | High | Slight |
| D14 | 11/24/98 | 12.3 | 5,264 | 1970–75 | High | No |
| D17 | 11/18/98 | 11.0 | 5,264 | 1964–68 | High | Slight |
| D24 | 11/17/98 | 12.6 | 5,200 | 1989–95 | Low | Possibly |
| D25 | 11/18/98 | 9.9 | 5,160 | 1955–60 | Moderate[3] | No |

[1]Results indicate mixing of old ground water, such as bedrock ground water, with younger water. The age of the older fraction likely is older than calculated, and the age of the younger fraction likely is younger than calculated.

[2]Well was pumped dry during sampling, which could introduce modern levels of chlorofluorocarbons into the sample and make the sample appear to be more recently recharged than actual.

[3]Sample contained methane, which means the chlorofluorocarbon amounts likely have been microbially decreased since recharge, so actual age is more recent than calculated by the model. A tritium analysis is needed to confirm this age.

[4]Ratios of chlorofluorocarbons indicate that at least 50 percent of this water is young (post-1940).

recharged during the 1990's, although the D9 sample may have been affected by modern air when the well was pumped dry during sampling. Pumping the well dry can introduce modern air into the sampling tubing and yield a recharge date more recent than actual. Ground water in the other sampled wells appears to have been recharged during the 1950's through 1980's (table 3), which was before biosolids applications to the study area. Ground water at some of the sites sampled for DG-CFC's, however, may be old ground water such as from the bedrock aquifer mixing with young ground water such as from recent recharge or alluvial aquifers. The use of DG-CFC data to indicate mixing of bedrock and alluvial water is discussed in the following section, "Aquifer Interaction."

## Aquifer Interaction

Interactions between the bedrock and alluvial aquifers are an important part of ground-water flow paths and affect contaminant transport. Bedrock ground water can be recharged from overlying aquifers in the deeper parts of the Denver Basin, which causes ground-water flow outward toward the basin margins (fig. 14). Bedrock ground water also can be recharged by alluvial ground water or provide recharge to alluvial ground water, depending on the hydraulic gradient between the aquifers (fig. 14). Where alluvial aquifers or surface water recharges the bedrock aquifer, surficial contaminants could be transported to the bedrock aquifer. Where the bedrock aquifer recharges alluvial aquifers, surficial contaminants are unlikely to be transported to the bedrock aquifer. Flow paths and hydraulic gradients are not permanent, however; additional ground-water withdrawals such as pumping from new wells can reverse the hydraulic gradients and change flow paths. Hydrologic and hydrogeologic data for the study area are not sufficient to indicate all specific flow paths between the aquifers but enable some general flow-path inferences. Altitudes of water levels in bedrock wells D11a and D29 were similar to those in nearby shallow wells, indicating a close hydraulic connection between the bedrock aquifer and alluvial aquifers at these locations. A detailed comparison of water-level altitudes indicates that a component of ground-water flow in these parts of the bedrock aquifer could be toward the alluvial aquifers. Aquifer interaction in the study area is further explored through four hydrogeologic sections (figs. 15 and 16).

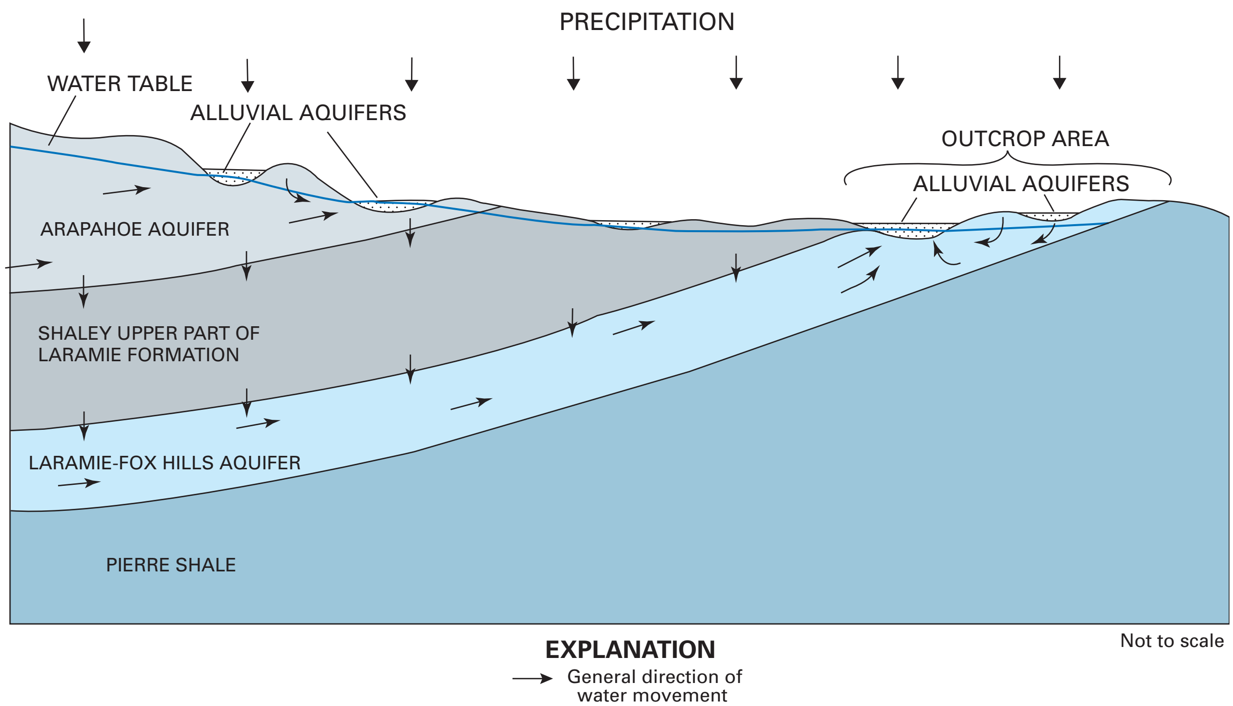


**Figure 14.** Ground-water movement (from Robson and others, 1981, fig. 7).

Section E-E' (fig. 16) shows Muddy Creek and Cottonwood Creek drainage basins and indicates that the alluvial aquifer in Cottonwood Creek probably receives recharge from the Laramie-Fox Hills aquifer because water-level altitudes decrease away from the ridge where well D29 is located. The bedrock aquifer in the vicinity of well D29 lies beneath a remnant section of the Laramie Formation, but data from well D29 indicate that the aquifer is unconfined at this location with only a few feet of water in the sandstone above the shaley units. Bedrock ground water at this location could be recharged by rain infiltration on the hill and from other bedrock ground water that flows northward in the aquifer. Well D1 could be dry because no alluvial aquifer is present at that location, and the well is screened above the bedrock aquifer. Well D12 is a windmill well drilled by landowners before 1993. The well had low yield; this well pumped dry during sampling when pumped at 0.3 gallon per minute. Well D12 could be completed in a shallow part of the bedrock aquifer because water levels in that well were below the likely altitude of the base of the alluvium at that location. From well D12, the water table slopes eastward toward wells D31 and D30 before the ground water flows off the MWRD property. The alluvium in the lower part of Cottonwood Creek receives water from the bedrock aquifer. Well D31 was constructed in a cored borehole and is completed in Cottonwood Creek alluvium that is incised into the LFH-HU in the transition zone of the Pierre Shale. Well D25, on the other hand, is completed in the extensive flood-plain deposits of Muddy Creek alluvium that are incised into the sandstone part of the LFH-HU. Therefore, in the vicinity of wells D25, D30, and D31, the alluvial aquifers likely are in close hydraulic connection with the bedrock aquifer, and the bedrock aquifer likely contributes at least some ground water to the alluvial aquifers.

Section F-F' (fig. 16) shows Muddy Creek and Rattlesnake Creek drainage basins. The line of section follows the stream valleys (fig. 15). The section also includes well D25 but shows the entire alluvial aquifer from D28 to D25 that underlies the tributary valley to Muddy Creek where these wells are located. The water table could be continuous between wells D22 and D28, but no water-level data were available for that area. If a water table is present in the LFH-HU under the hill as in section E-E', then the bedrock aquifer in the LFH-HU outcrop area of the hilltop could be contributing ground water to the alluvial aquifer in the lower part of the tributary valley to Muddy Creek that contains wells D25 and D28. The lower part of this valley contains alluvium that is incised into the sandstone part of the LFH-HU. The bedrock ground water in the lower part of this tributary valley to Muddy Creek likely is hydraulically connected with the alluvial ground water. Well D22, however, is located in a small, steep Rattlesnake Creek valley incised into the Pierre Shale transition zone within the LFH-HU. The small, steeply sided shape of this valley makes it unlikely to contain thick alluvial deposits; the water-level altitude in well D22 is beneath the probable base of the alluvium. In addition, the water-level altitude in well D22 is below that of a downgradient pond in the same valley. Therefore, well D22 probably is completed in a shallow part of the Laramie-Fox Hills aquifer. Surface water, when present in this part of Rattlesnake Creek, could infiltrate and recharge the bedrock aquifer.

Section G-G' (fig. 16) shows the Muddy Creek drainage basin. This section is entirely within the wide, flat Muddy Creek flood plain. Alluvial deposits probably are extensive in this

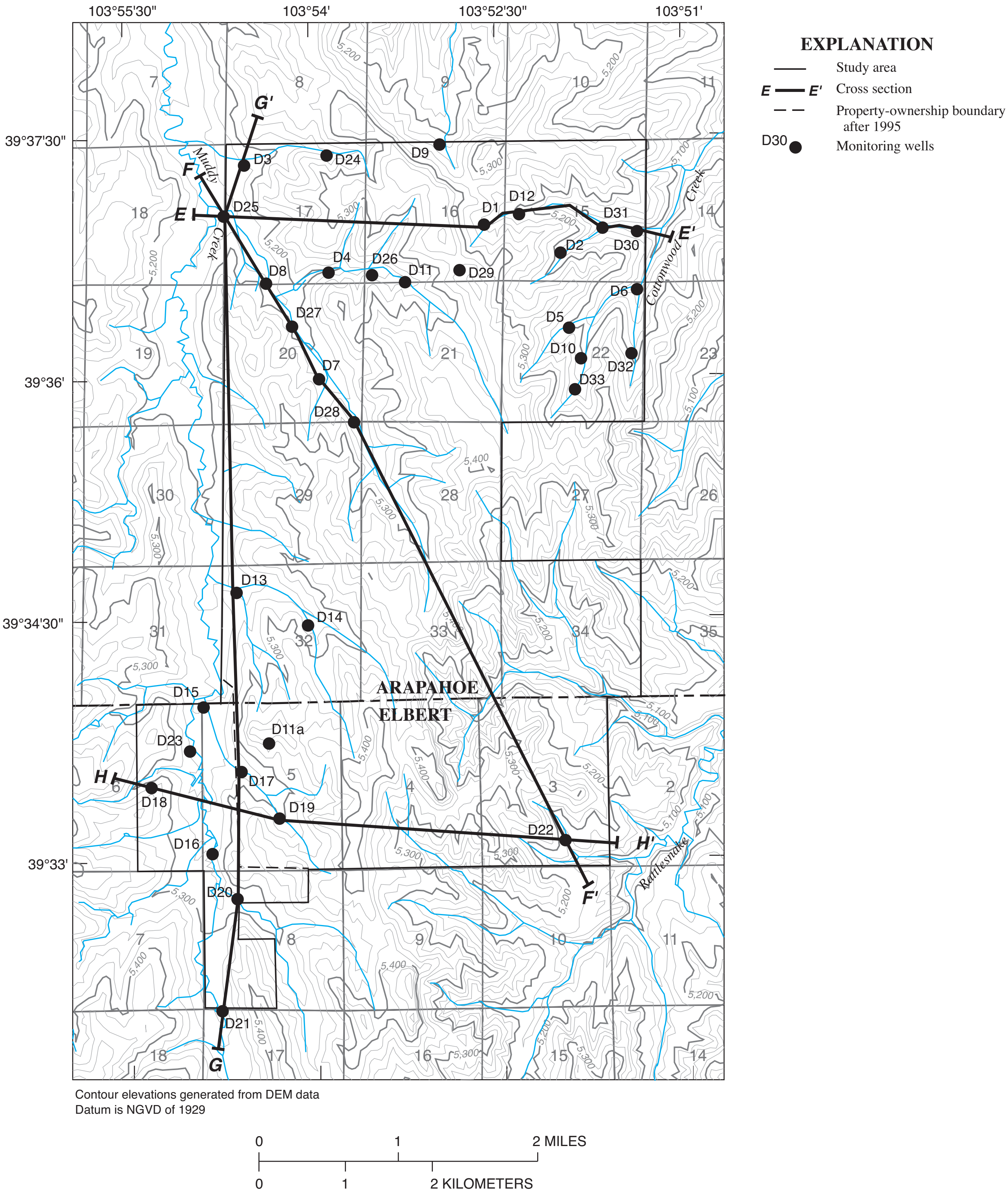


**Figure 15.** Locations of hydrogeologic sections E-E′, F-F′, G-G′, and H-H′.

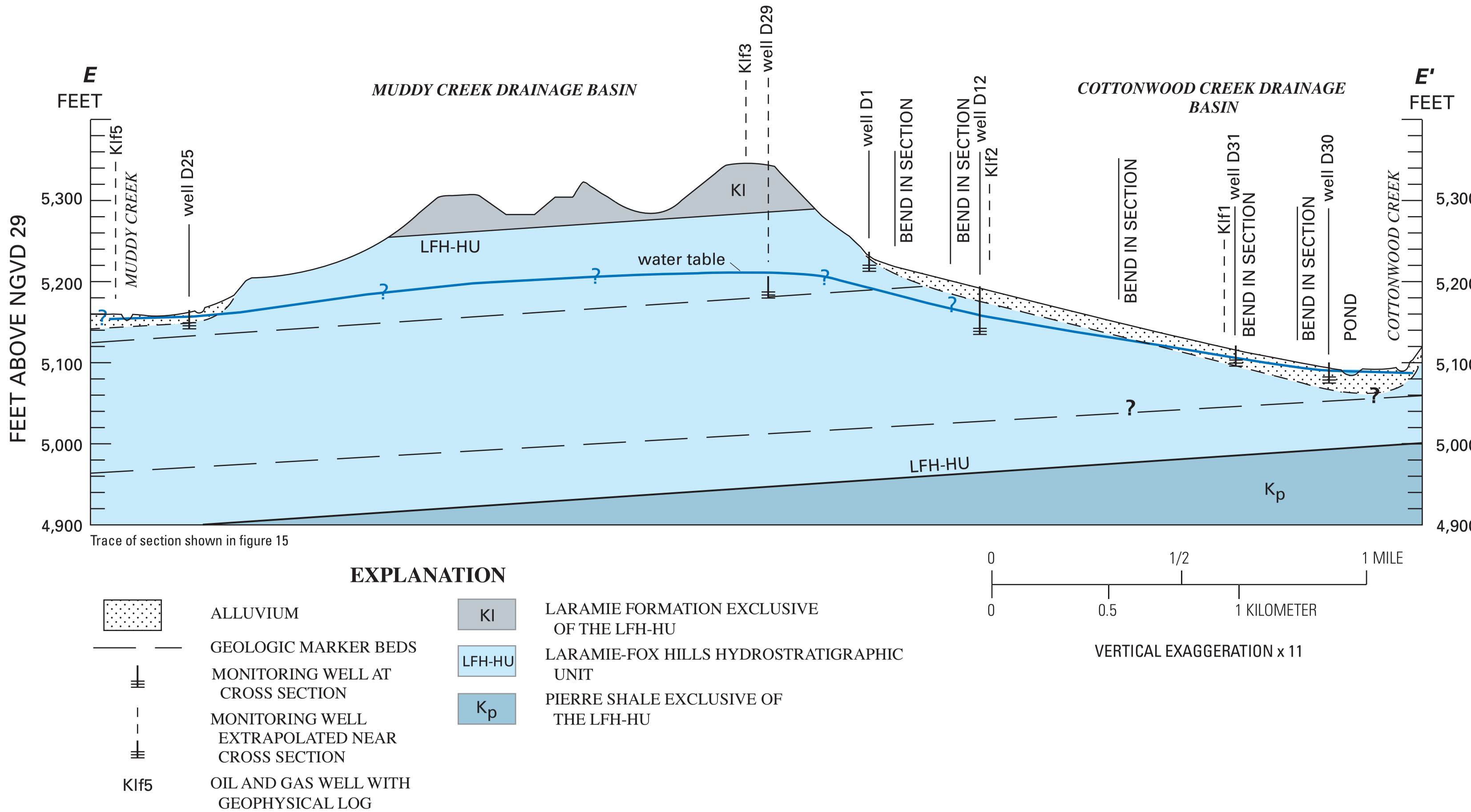


**Figure 16.** Hydrogeologic sections E-E′, F-F′, G-G′, and H-H′.

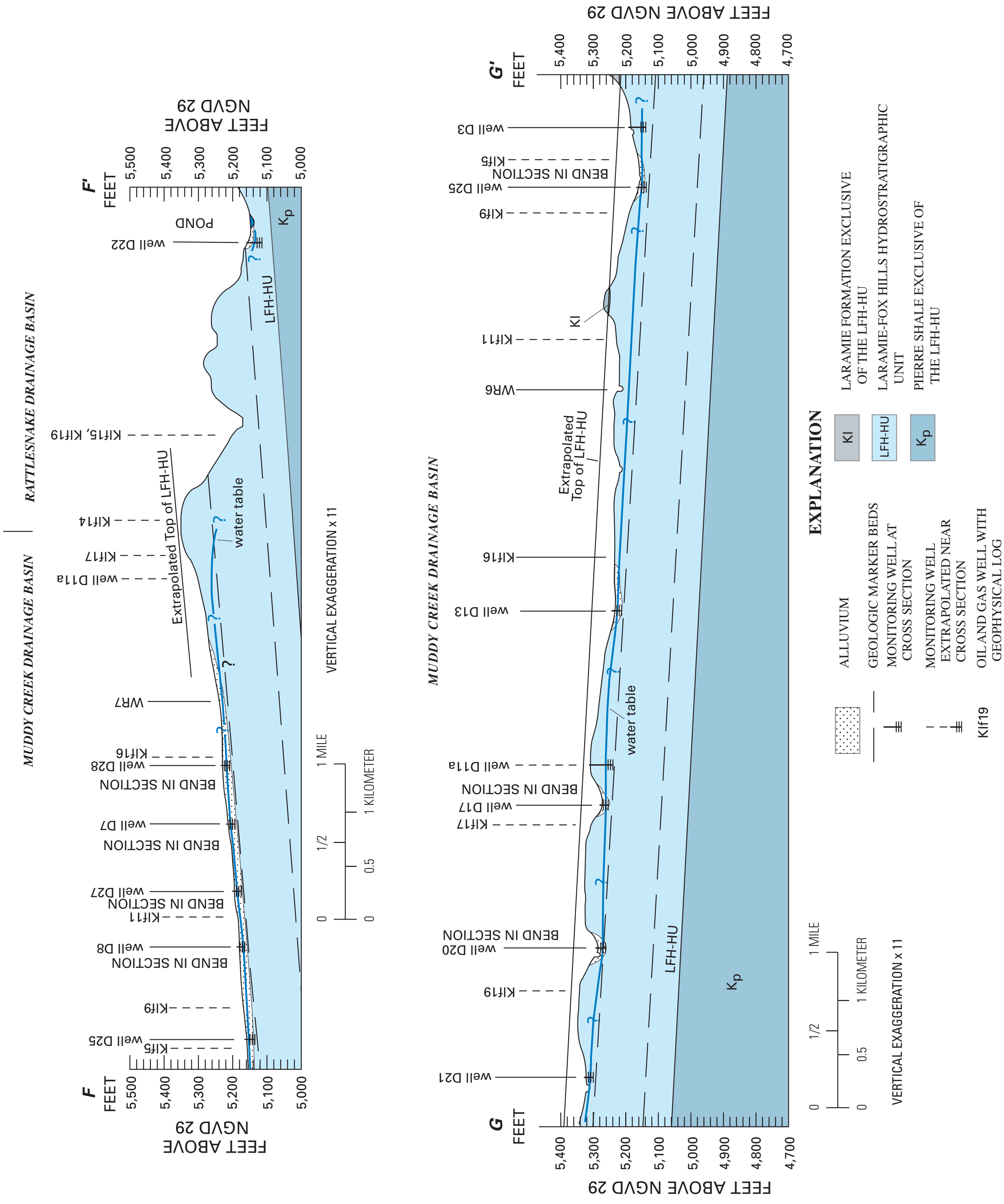


**Figure 16.** Hydrogeologic sections E-E′, F-F′, G-G′, and H-H′.—Continued

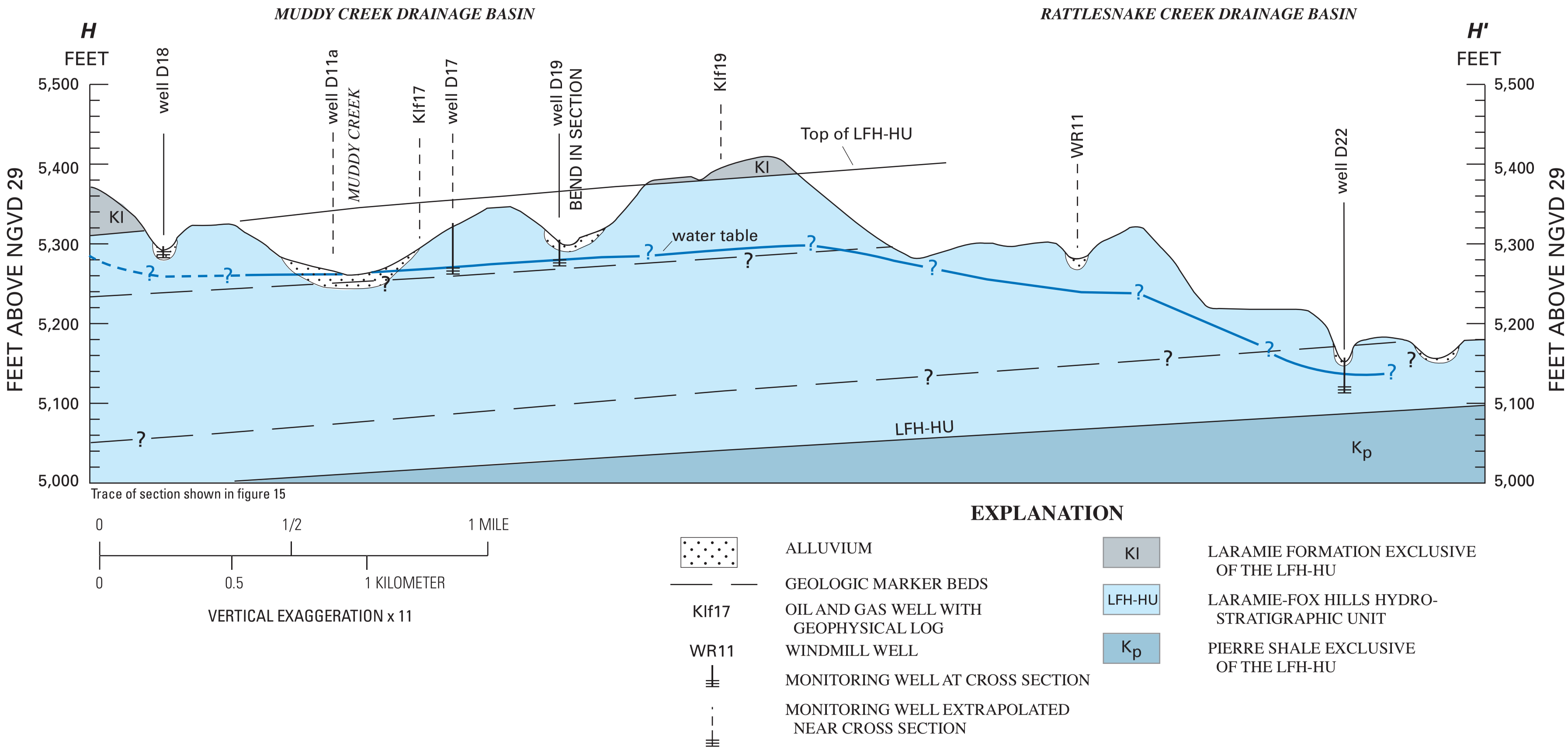


**Figure 16.** Hydrogeologic sections E-E′, F-F′, G-G′, and H-H′.—Continued

large valley, which appears mostly to be incised in the sandstone part of the LFH-HU. The alluvial aquifer associated with Muddy Creek probably is hydraulically connected with the Laramie-Fox Hills aquifer. The proximity of Muddy Creek to the confined part of the Laramie-Fox Hills aquifer to the west (Robson, 1987) indicates a possible eastward component of bedrock ground-water flow toward Muddy Creek (as shown in fig. 14). If the confining pressure in the west is sufficient to produce upward vertical flow gradients from the bedrock aquifer toward the alluvial aquifer, the bedrock aquifer would not be affected by alluvial ground water or by anthropogenic applications such as biosolids in the vicinity of Muddy Creek. However, additional bedrock-aquifer wells would be needed to determine whether upward flow gradients are present. Yields from Muddy Creek wells D3, D25, D13, D17, and D20 were higher than yields from well D21, which was pumped dry during sampling (pumping at about 0.25 gallon per minute for about 45 minutes). The lesser yield from well D21 can be explained if well D21 is completed in a shaley part of the LFH-HU and the other Muddy Creek wells are completed in alluvium (D13, D17, D20, and D25) or the sandy part of the LFH-HU (D3), as shown in figure 16.

Section H-H' (fig. 16) shows parts of the Muddy Creek and Rattlesnake Creek drainage basins. As mentioned previously, Muddy Creek alluvium probably is incised into the sandy part of the LFH-HU, whereas the part of Rattlesnake Creek in the vicinity of well D22 is incised into the shaley part of the LFH-HU. This view of well D22 again supports the ideas that alluvium in the small valley where well D22 is located is thin and that this well is completed in the shaley lower part of the bedrock aquifer; streamflow in this small valley could recharge the bedrock aquifer and introduce surficial contaminants. The base of the alluvium of the valley containing well D18, a dry well, probably is above the bedrock aquifer; streamflow in the small valley could recharge the bedrock aquifer and introduce surficial contaminants. Well D19 also is completed deeper than the probable base of the alluvium and could be completed in the bedrock aquifer. The water table could be continuous and reflect topography between wells D19 and D22, but few water-level data were available for that area.

Chlorofluorocarbon (CFC) data also can be used to evaluate aquifer interaction. CFC data indicate that ground water recharges slowly near wells D3, D5, D6, D13, D14, D17, and D25, but ground water recharges rapidly near wells D9 and D24. If all CFC concentrations are in the dateable range and CFC-113 concentrations indicate much younger ages than the CFC-11 and CFC-12 data for a single sample, then old, pre-1940 water probably is mixing with young, usually post-1940 water at each site (Plummer and Busenberg, 1999). Of the wells where DG-CFC sampling was done in 1998 (table 3), only CFC data from well D6 all are in the dateable range and are consistent with binary mixing of young water with old, pre-1940 water. If old, pre-1940 water mixes with young water that recharged after 1950, ratios of the CFC concentrations can be used to estimate the age of the young fraction and to determine the percentage of young water in the mixture (Plummer and Busenberg, 1999). The CFC concentration ratios for the sample from well D6 indicate the young fraction makes up at least 50 percent of the ground-water mixture (table 3). This result is consistent with the short delay between time of precipitation and time of recharge indicated by the continuous-recorder data. CFC data from wells D3, D9, and D24 are not all in the dateable range but indicate possible mixing of old ground water with young ground water (table 3). Old ground water probably is water from deeper parts of the bedrock or alluvial aquifers and is characteristic of long flow paths. Young ground water probably is recharged locally and is characteristic of short flow paths. Sampling more wells in the study area for DG-CFC's could further define flow paths and ground-water recharge in the study area, and future resampling of some wells for DG-CFC's could confirm apparent ages of ground water and general flow paths presented in this report.

Thus, some shallow monitoring wells in the study area probably yield water from shallow bedrock, some shallow wells yield water from alluvium, and some shallow wells yield mixed-aquifer water. Figures 14 and 16 and table 3 indicate that, throughout the study area, the bedrock and alluvial aquifers generally are in close hydraulic connection. In some valleys, such as those containing wells D18 and D22, alluvial aquifers likely are not present or are thin and above the ground-water level of the bedrock aquifer (shown on the far right side of figure 14); streamflow or the alluvial aquifer could recharge the bedrock aquifer because flow gradients are downward. In many valleys, however, the alluvial aquifer likely is within an erosional channel incised into the LFH-HU, and the bedrock aquifer could recharge the alluvial aquifer where upward flow gradients exist. These interpretations indicate that contaminants at the land surface could eventually affect water quality in the alluvial aquifers and shallow parts of the bedrock aquifer recharged by infiltrating precipitation or surface water, but contaminants likely would not affect the deeper parts of the bedrock aquifer in the vicinity of the study area. Production wells in the bedrock aquifer, however, could induce ground-water flow from the alluvial aquifers to the bedrock aquifer and, therefore, increase the effect of land-surface contaminants on the bedrock aquifer. More detailed hydrologic and geologic information would be needed to further define alluvial/bedrock aquifer interactions and other components of ground-water flow.

# Summary

The study area is located on the eastern margin of the Denver Basin, a bowl-shaped sequence of sedimentary rocks. In the vicinity of the study area, the uppermost rock formations are highly eroded and consist of the upper part of the Cretaceous-age Pierre Shale, the Fox Hills Sandstone, and the lower part of the Laramie Formation. These geologic units were deposited in a marine or near-shore environment and comprise the Laramie-Fox Hills hydrostratigraphic unit (LFH-HU) and, where saturated, the Laramie-Fox Hills aquifer. The Laramie-Fox Hills aquifer is the only Denver Basin bedrock aquifer present in the vicinity of the study area and so is used for domestic supply. The LFH-HU is present beneath the entire study area and much of the Metro Wastewater Reclamation District (MWRD) properties near Deer Trail and dips about 40 feet per mile to the northwest. The LFH-HU is not present in the eastern two-thirds of the MWRD's south property, which is underlain by Pierre Shale. The LFH-HU crops out or subcrops in much of the study area.

Within the study area, the LFH-HU does not yield sufficient water throughout to be called an aquifer. Depth to bedrock ground water was about 55 feet below land surface at well D9 in the upper part of the Badger Creek drainage basin, but yield from this well was insufficient to consider this ground water an aquifer. Where present, the bedrock aquifer generally is unconfined and has little saturated thickness and yield in the study area. Two monitoring wells were constructed on hills and were completed in the sandstone upper part of the Laramie-Fox Hills aquifer. Water levels in these two wells fluctuated about 0.5 foot or less and were about 110 and 150 feet below land surface during the 11 months of record. Depths to water in these wells were the maximum measured in the study area. Potentiometric altitude calculated from water levels in the two monitoring wells was about 5,261 feet above NGVD 29 at well D11a in the southern part of the study area and about 5,214 feet above NGVD 29 in well D29 in the northern part of the study area. Saturated thickness of the upper, more permeable part of the Laramie-Fox Hills aquifer was about 5 to 10 feet at these well locations; yield was about 0.25 gallon per minute or less. Water levels in these wells and other wells completed in the bedrock aquifer indicate a component of ground-water flow to the north in the study area and recharge to the bedrock aquifer along the ridge. Additional wells would be needed to further assess the extent of the bedrock aquifer, saturated thickness, and directions of flow in the study area.

Ground water also is present in shallow parts of the bedrock aquifer or in alluvial aquifers in four drainage basins: Badger Creek, Cottonwood Creek, Muddy Creek, and Rattlesnake Creek. These drainage basins generally contained only ephemeral streams, which flowed only after intense rain. Most of the precipitation in the study area was in the form of rain and was received during late summer. Depth to shallow ground water ranged from about 2 feet below land surface at well D23 in the alluvium of Muddy Creek to about 37 feet below land surface at well D3. Water levels fluctuated more in shallow wells than in deep wells. Water levels commonly were lowest during June through early July and highest during late July through December. Shallow ground-water levels likely were affected by evapotranspiration, especially during summer. Evapotranspiration likely takes place close to wells D2 and D23. Hydrologic data indicate that a component of ground-water flow for the shallow aquifers is down valleys and generally follows topography. The level of shallow ground water of the bedrock aquifer and alluvial aquifers generally represents the water table in the study area.

Ground-water recharge of the shallow aquifers is variable in space and time. Continuous-recorder data indicate that at least some of the shallow ground water is recharged quickly after rain—commonly within a day at wells D2 and D23 and within months at well D6. The magnitude of water-level increases does not always correspond to the amount of rainfall, however, because recharge likely depends on preceding moisture conditions in the unsaturated zone. Hydrologic and dissolved-gas data indicate that some areas of the shallow aquifers were recharged by infiltration from rain or ponds, whereas other areas likely were recharged by other ground water. Chlorofluorocarbon data for selected wells indicate that apparent groundwater ages ranged from 1 year or less at one site (D9) to about 40 years at another site (D25).

Interactions of the deeper parts of the bedrock aquifer with shallow ground water include a general close hydraulic connection between alluvial and bedrock aquifers. Hydrologic and hydrogeologic data for the study area are not sufficient to indicate all specific flow paths between the aquifers but enable some general flow-path inferences. These data indicate that general ground-water flow paths in the study area could be from the deeper parts of the Denver Basin outward toward the basin margins, from the bedrock aquifer toward the alluvial aquifers, from alluvial aquifers toward the bedrock aquifer, or from the land surface downward through the unsaturated zone into the bedrock or alluvial aquifers. Where the alluvial aquifer recharges the bedrock aquifer, surficial contaminants could be transported to the bedrock aquifer. Where the bedrock aquifer recharges alluvial aquifers, surficial contaminants are unlikely to be transported to the bedrock aquifer. Future production wells could reverse the hydraulic gradient between the aquifers, however, and increase effects from land-surface contaminants on the Laramie-Fox Hills aquifer. Some alluvium or streamflow in the study area such as near Rattlesnake Creek probably recharges the bedrock aquifer, but the bedrock aquifer likely provides recharge to the alluvial aquifers associated with Muddy Creek and Cottonwood Creek. Chlorofluorocarbon data indicate that water follows a long flow path to recharge ground water near wells D3, D5, D6, D13, D14, D17, and D25, but follows a short flow path despite a thick unsaturated zone to recharge ground water near wells D9 and D24. Old ground water apparently is mixing with younger ground water in the vicinity of well D6, and possibly at wells D3, D9, and D24. More wells in the study area would need to be sampled for dissolved gases and chlorofluorocarbons to further define flow paths and ground-water ages in the study area, and resampling of some wells in the future would help confirm apparent ages of ground water and general flow paths presented in this report. These data could be used to better evaluate relative susceptibility of the aquifer to contamination from surface infiltration in different parts of the study area.

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# Appendixes

# Appendix I
# Methods of Data Collection and Construction of Maps and Hydrogeologic Sections

# Methods of Data Collection and Construction of Maps and Hydrogeologic Sections

## Introduction

Geologic and hydrologic data were collected from the study area during 1993 through 1999. Geologic data in this report include lithologic descriptions and core data (Appendix II). Geologic data used but not included in the report consist of geophysical well logs from oil and gas exploration and lithologic logs from titanium exploration (these data were not collected by the USGS). The information from these logs that was used to make plates 1 and 2 is shown in figure II.7 (Appendix II). Hydrologic data in this report include ground-water level, precipitation, and water temperature measurements (Appendix II). Data for chlorofluorocarbons and dissolved gas in ground water are also included (Appendix II). Methods of data collection followed USGS protocols whenever possible.

## Geologic Data

Lithologic descriptions (table II.2 in Appendix II) were compiled from driller's notes prepared during the 1993–95 drilling of the monitoring wells, from descriptions of cores or drill cuttings from the boreholes during 1995–97 well drilling, and from geologists' observations of outcrops at the study area in 1997–99. Samples of alluvium from cores obtained when wells D31 and D33 were drilled in 1995 were analyzed for texture using a hydrometer at a USGS research laboratory in Denver, Colorado. Data for these core samples are listed in table II.4 in Appendix II. Geophysical well logs on file with the Colorado Oil and Gas Conservation Commission from oil and gas exploration and lithologic logs from USGS drilling in the vicinity of the study area were used to prepare structure-contour maps and hydrogeologic sections (pls. 1–3; figs. 15 and 16). A geophysical well log for USGS monitoring well DTX8 (drilled in 1999) also was considered in preparing the structure-contour maps (pls. 1–3; figs. 3 and II.7).

## Hydrologic Data

Ground-water monitoring wells were constructed according to standard USGS methods. The monitoring wells were surveyed thoroughly by professional surveyors to a common vertical datum to enable detailed comparison of water-level altitudes.

Ground-water levels were measured monthly in USGS monitoring wells during 1993–98 using standard USGS methods (Garber and Koopman, 1968); data are listed in table II.3 in Appendix II. Monthly water-level measurements were made September 1993 through May 1995 using a steel tape (Garber and Koopman, 1968, p. 2–6; Driscoll, 1986, p. 549–550). Monthly water-level measurements were made June 1995 through September 1998 and in July 1999 using vinyl-coated electric tapes. Water-level measuring equipment was checked regularly in the office and compared against each other about once a year in the field as a measure of variability of the equipment.

Continuous recorders were installed at two well locations (D2 and D23) during 1994 and 1995. Water level was recorded at these sites by automatic digital recorders (ADR's), machines attached to floats (Garber and Koopman, 1968, p. 15) that punched a paper tape hourly (Buchanan and Somers, 1982, p. 5–7). The tapes were then read into a computer, which translated the values into water-level measurements. In May 1996, the ADR's were replaced by electric digital recorders (EDR's). The EDR's enabled multiple parameters to be monitored and logged at the same site, so rain gages were added to the well sites at wells D2 and D23. Precipitation was measured continuously at each EDR site by a tipping-bucket type rain gage mounted on a ground-level cement pad. A plastic collection-container rain gage (mounted on a 6-foot post) provided a second, discrete measurement of rainfall, but these data were recorded manually during site visits. Water level depth (depth below land surface, in feet) was determined at each EDR from floats. The EDR's were upgraded in January 1997 to data-collection platforms (DCP's), which had various sensors to continuously monitor rainfall, air temperature, water temperature, and ground-water levels at the two well locations, D2 and D23. The DCP's provided more extensive information about the hydrology in this area (including the response of ground water to climate) and data that could be viewed remotely (such as from the Denver office) to enable enhanced troubleshooting of the equipment. Water-level, water temperature, air temperature, and precipitation values were recorded every hour from the DCP sites during 1997–98. The DCP data were transmitted every 4 hours from satellites to the USGS and were available to the public on the Internet. Water level at each DCP site was determined using a submersible pressure transducer (Garber and Koopman, 1968, p. 16–18; Driscoll, 1986, p. 552); precipitation was determined using the tipping-bucket rain gage and collection-container rain gage. Water temperature was measured continuously at each DCP with a thermistor submersed in the well. Air temperature was to be measured by a thermistor enclosed in a heat shield mounted on a post, but these instruments malfunctioned and did not provide accurate data. Status of the instrumentation and accuracy relative to manual field measurements was checked during onsite visits at least once per month from 1995 through 1998.

Specific conductance and ground-water temperature were continuously monitored at well D6 from 1996 through 1998 by use of submersible sensors cabled to a CR-10 data logger. The conductance sensor was calibrated or checked periodically with standard solutions. These sensors were inspected during monthly site visits, and data were downloaded approximately monthly from the data logger. The resulting data are provided in figures 12 and II.6 (Appendix II). Large periods of missing record in these data were the result of flooding in the nearby drainage that also flooded the continuous-recorder instrumentation.

Ground-water sampling of selected wells took place in November 1998 for dissolved gases and chlorofluorocarbons; data are listed in tables II.5 and II.6. Equipment and methods used for this sampling 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 in January of 2001). These samples were shipped to a USGS research laboratory in Virginia for analysis. Data and a calculations spreadsheet containing equations were provided by the research laboratory after analysis.

### 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 internal project reviews, and data verification. All equipment was checked regularly and, if calibration was possible, calibrated in the field or office. 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.

### Maps and Hydrogeologic Sections

Geophysical well logs on file with the State from oil and gas exploration, lithologic logs from titanium exploration and USGS drilling, and field observations in the vicinity of the study area were used to prepare the structure-contour maps (pls. 1 and 2) in 1999. A geophysical well log for USGS monitoring well DTX8 (drilled in 1999) also was considered in preparing the structure-contour maps (pls. 1–3; figs. 3 and II.7). An example of how geophysical well-log data were used in this report is provided in plate 3.

Geophysical logs from more than 300 oil and gas wells were interpreted to map the altitudes of the top and the base of the LFH-HU in the subsurface at a scale of 1:50,000. The top of the LFH-HU generally is discernible in the geophysical logs for the area by a sharp increase in resistivity (pl. 3) that is interpreted to be the top of a thick sandstone sequence in the Fox Hills Sandstone. Sharp increases in resistivity above the thick sandstone sequence are interpreted as coal seams and are not mapped as part of the LFH-HU. In some places, broad resistivity increases above the thick sandstone sequence are interpreted as discrete channel sandstones in the lower Laramie Formation and are included as part of the LFH-HU. The base of the LFH-HU was selected on the geophysical logs as the point below which resistivity becomes relatively uniform and low (pl. 3). This point is interpreted as the base of the transition zone of the Pierre Shale. Where the LFH-HU is near the land surface and within the interval of the well's surface casing, the LFH-HU is not recorded in the geophysical log because the casing interferes with some types of geophysical signals. In these cases, the altitudes of the top and base of the LFH-HU were estimated by correlating marker beds below the casing shown on the geophysical logs. The top of the D sandstone member of the Pierre Shale (Kiteley, 1978) was the principal marker bed used to estimate the altitude of the LFH-HU (pl. 3). Because of uncertainties associated with mapping the LFH-HU in the subsurface and in outcrop, structural contours were drawn for the top and base of the unit by using the preponderance of data rather than rigidly honoring every data value.

Inferences from the geophysical logs that were used to construct the structure-contour maps were then field checked in 1999 by examining road cuts and outcrops (shown on pl. 2 as a filled triangle symbol) in the vicinity of the study area. The presence of thin, discontinuous siltstone and sandstone layers in outcrops were interpreted as part of the Pierre Shale transition zone (part of the LFH-HU) and were used to help define the eastern limit of the LFH-HU. The base of the LFH-HU generally was not discernible in outcrop because of the transitional nature of the lithology between the LFH-HU and the rest of the underlying Pierre Shale. The top of the LFH-HU is easily identifiable in outcrop in some places by a prominent, well-cemented sandstone layer that contains abundant trace fossils of burrows and lies below a coal seam. In other places, the top of this unit is not easily identifiable because a well-cemented sandstone layer is not evident at the top of the LFH-HU or is present at one or more horizons below the top of the LFH-HU. Mapped areas of the LFH-HU, Laramie Formation, and Pierre Shale shown on plate 2 include both outcrop areas (no unconsolidated material above the bedrock at the surface) and subcrop areas (unconsolidated materials such as loess and alluvium unconformably overlie the bedrock). Outcrop areas were not differentiated from subcrop areas for this mapping effort because the presence and thickness of the overlying unconsolidated deposits varied throughout the mapped area, and subscrop data were limited. Mapped areas of the LFH-HU commonly were defined by intersecting the top and base contours of the LFH-HU with the topography of the land surface as represented by county maps (U.S. Geological Survey, 1976, sheet 3; U.S. Geological Survey, 1980a, sheet 2). Data from lithologic logs of mineral-exploration borings and water wells, field observations, and existing geologic maps and reports were correlated to data from geophysical logs to further delineate or check mapped outcrop-subcrop areas. The accuracy of the LFH-HU outcrop areas delineated on plates 1 and 2 generally is limited by the accuracy of the structural contours and the accuracy of the topographic maps used to derive the outcrop areas, as well as by the lack of detailed data about occurrence and thickness of loess or alluvial deposits in the vicinity of the study area.

Geophysical well logs on file with the Colorado Oil and Gas Conservation Commission from oil and gas exploration and lithologic logs from USGS drilling in the vicinity of the study area also were used to prepare hydrogeologic sections (figs. 15 and 16). Water levels, screened interval, and lithology for all the USGS monitoring wells were compared with geophysical logs from oil and gas wells in the vicinity of the study area. The sandstone-shale boundary observed during drilling of wells D11a and D29 was used as the upper marker bed (fig. 16) because this boundary also was apparent on some geophysical logs (pl. 3). A sharp increase in the resistivity apparent on most geophysical logs in the lower part of the LFH-HU was used as a second, lower marker bed (pl. 3, fig. 16) to project structure across the sections in figure 16. Water-table information shown on these sections was extrapolated from USGS monitoring-well data (Appendix II). Gaps or queries in the water table shown in figure 16 resulted from a lack of information in some areas.

# Appendix II
# Hydrogeologic Data

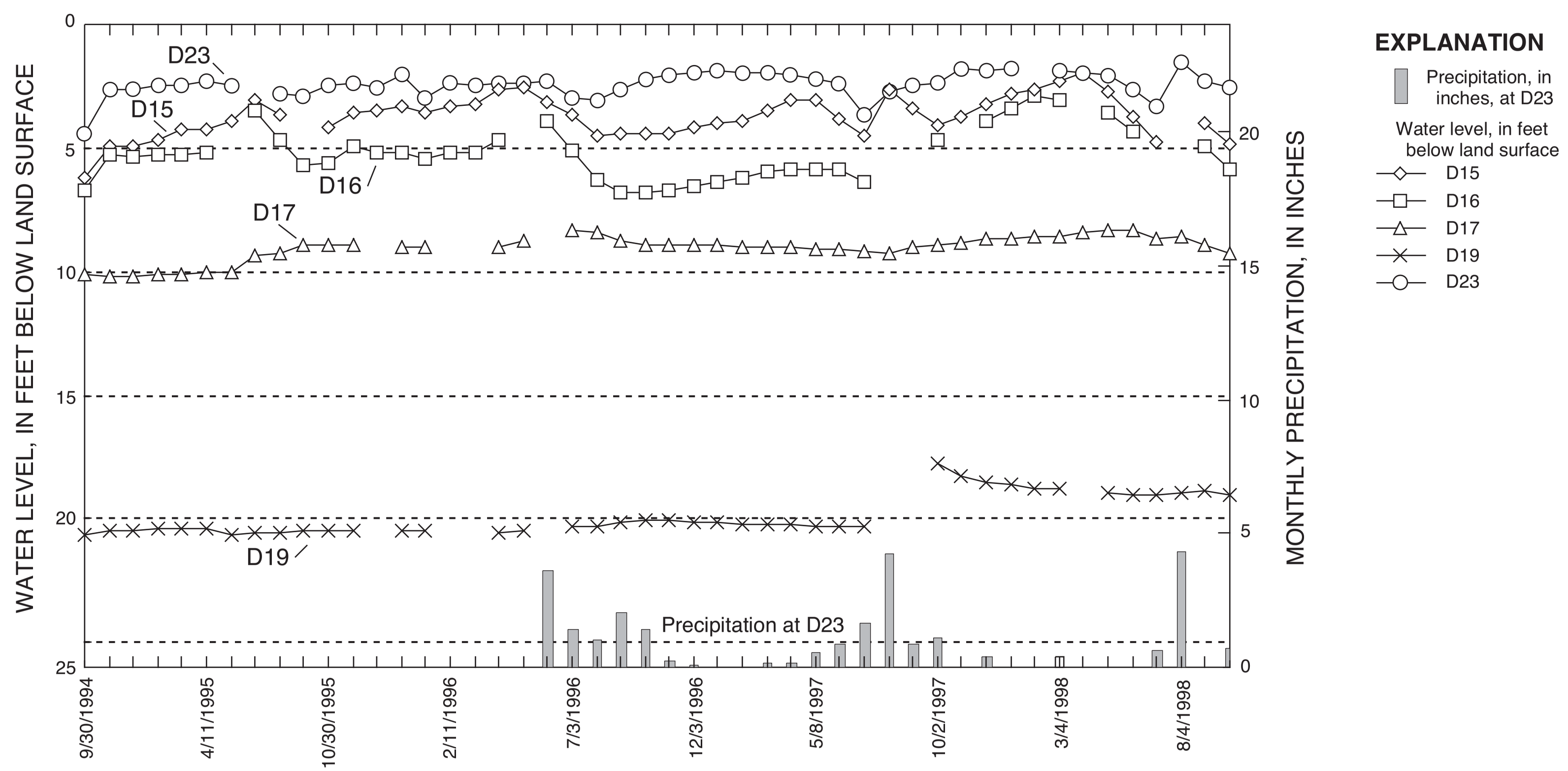


**Figure II.1.** Monthly water levels and precipitation for wells along Muddy Creek near Deer Trail, Colorado, 1993–98.

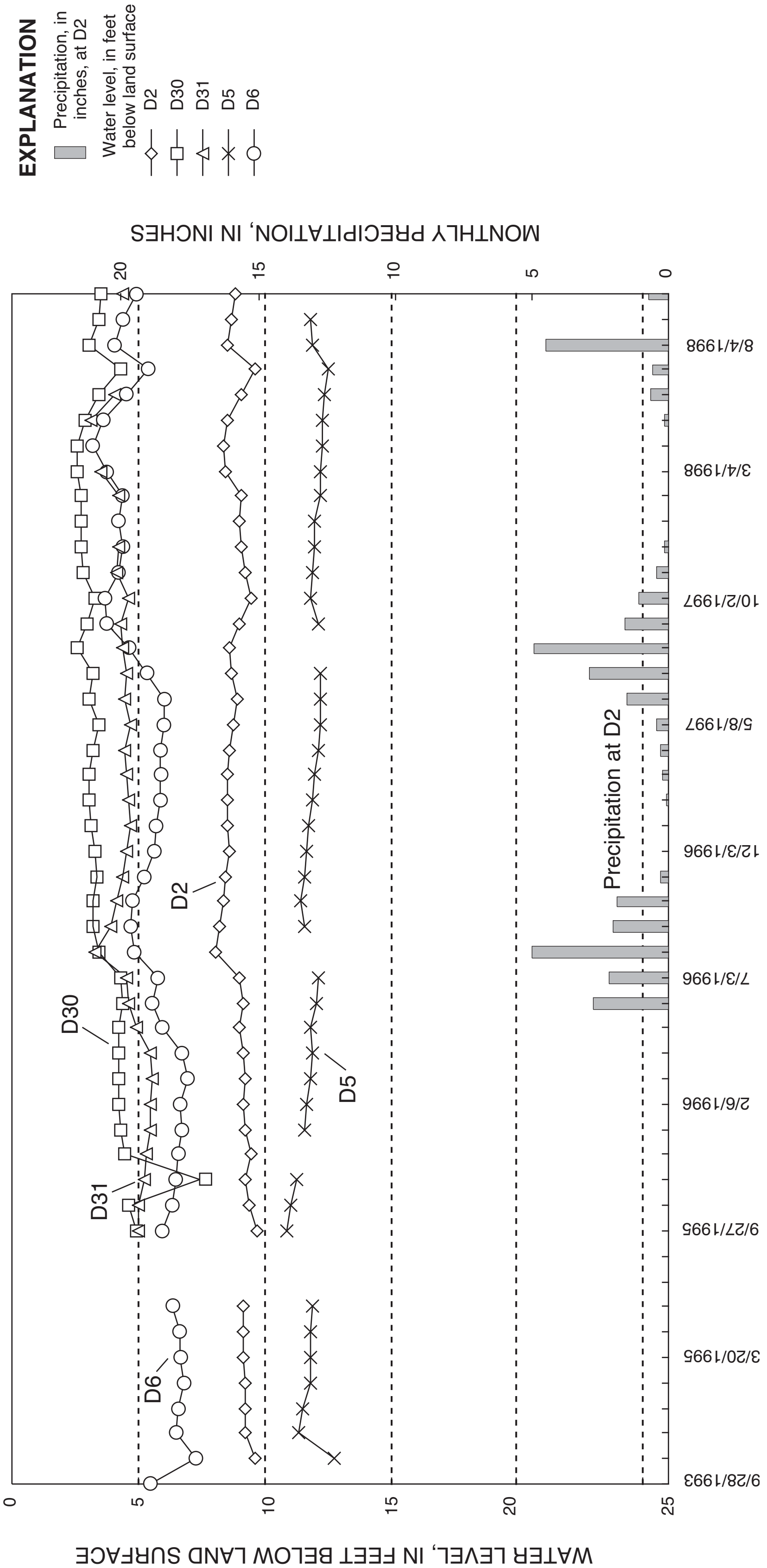


**Figure II.2.** Monthly water levels and precipitation for wells along Cottonwood Creek near Deer Trail, Colorado, 1993–98.

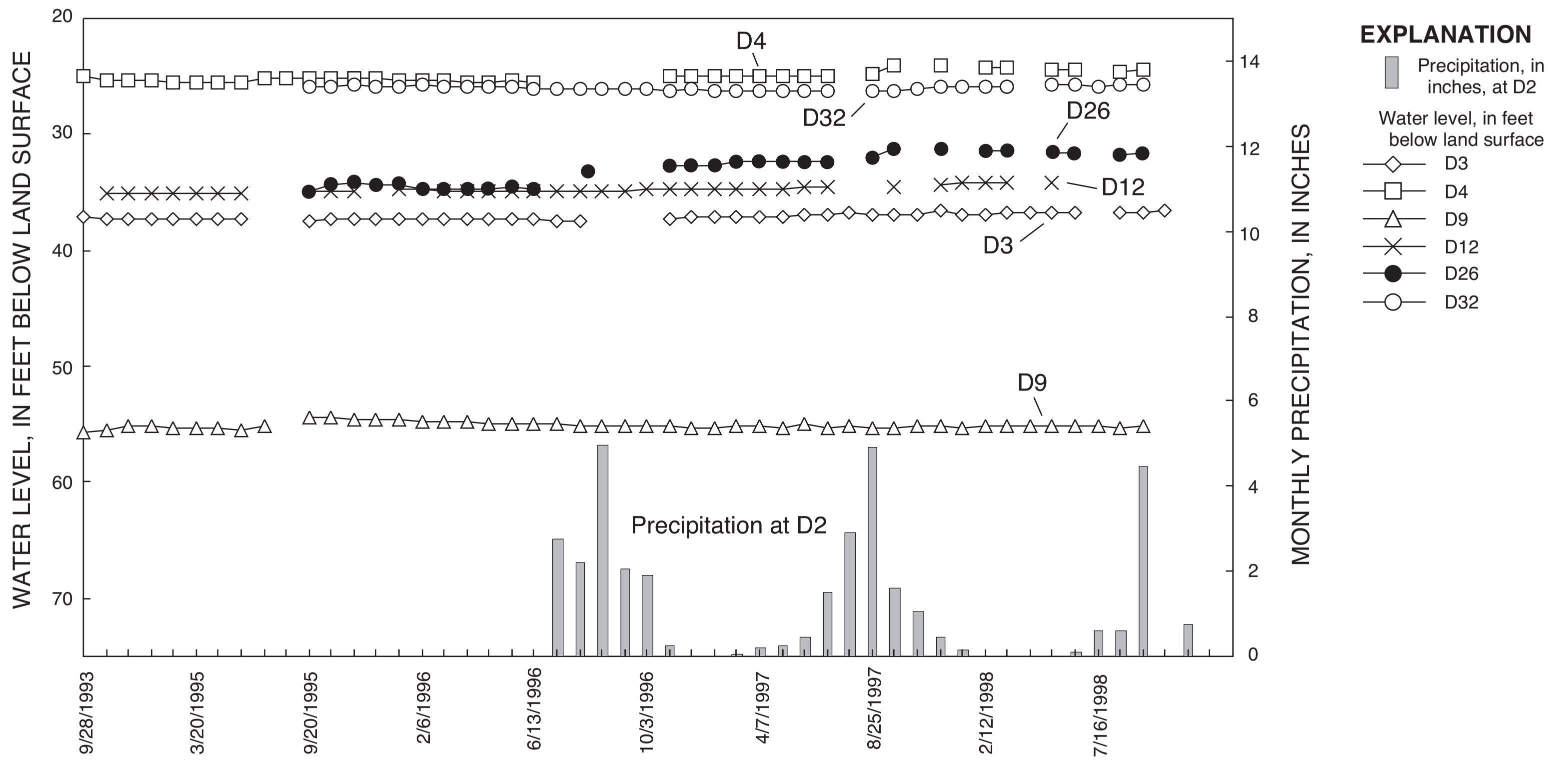


**Figure II.3.** Monthly water levels for deeper wells and precipitation near Deer Trail, Colorado, 1993–98.

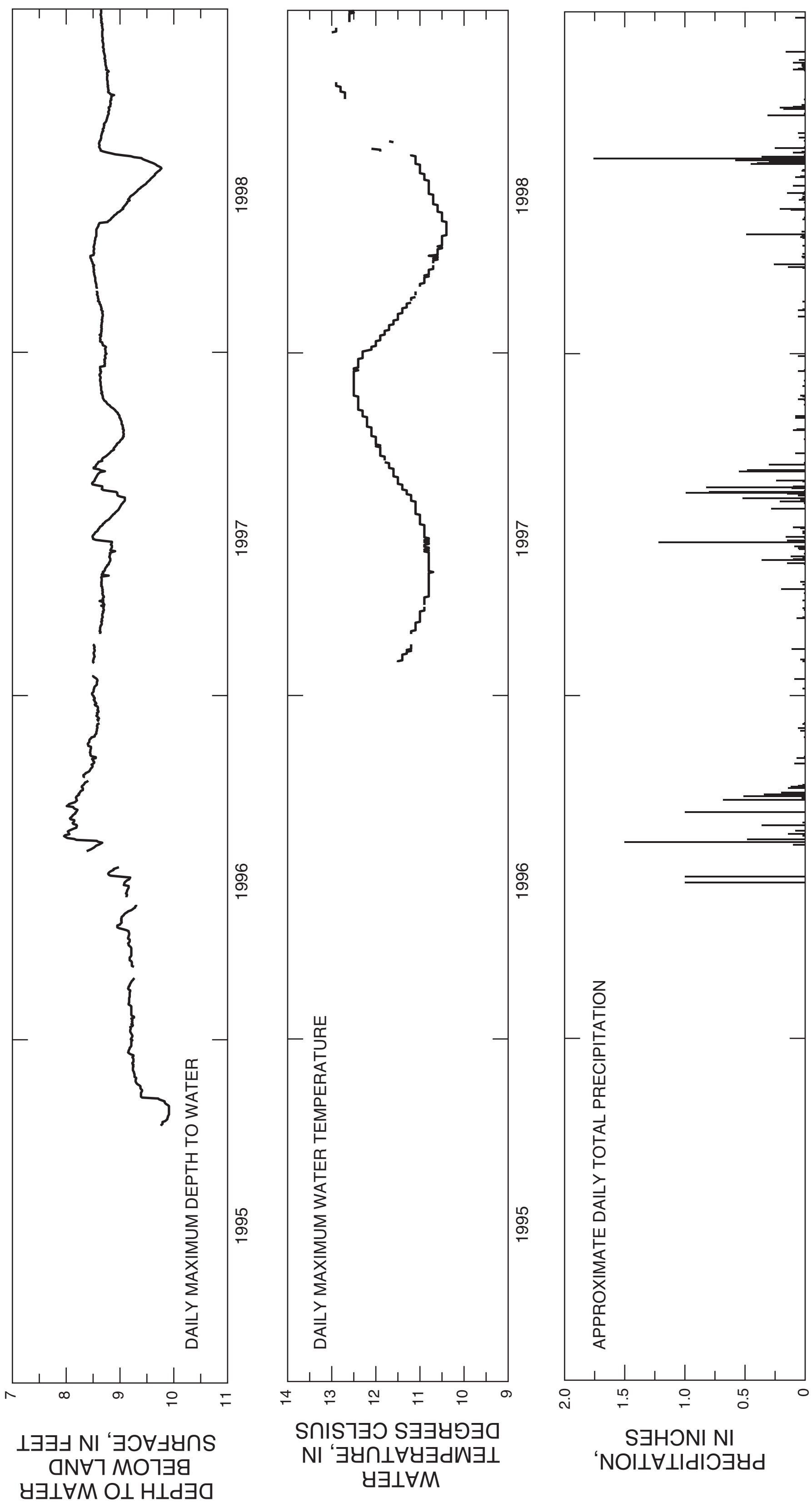


**Figure II.4.** Continuous water-level, ground-water-temperature, and precipitation data for well D2 near Deer Trail, Colorado, 1995–98.

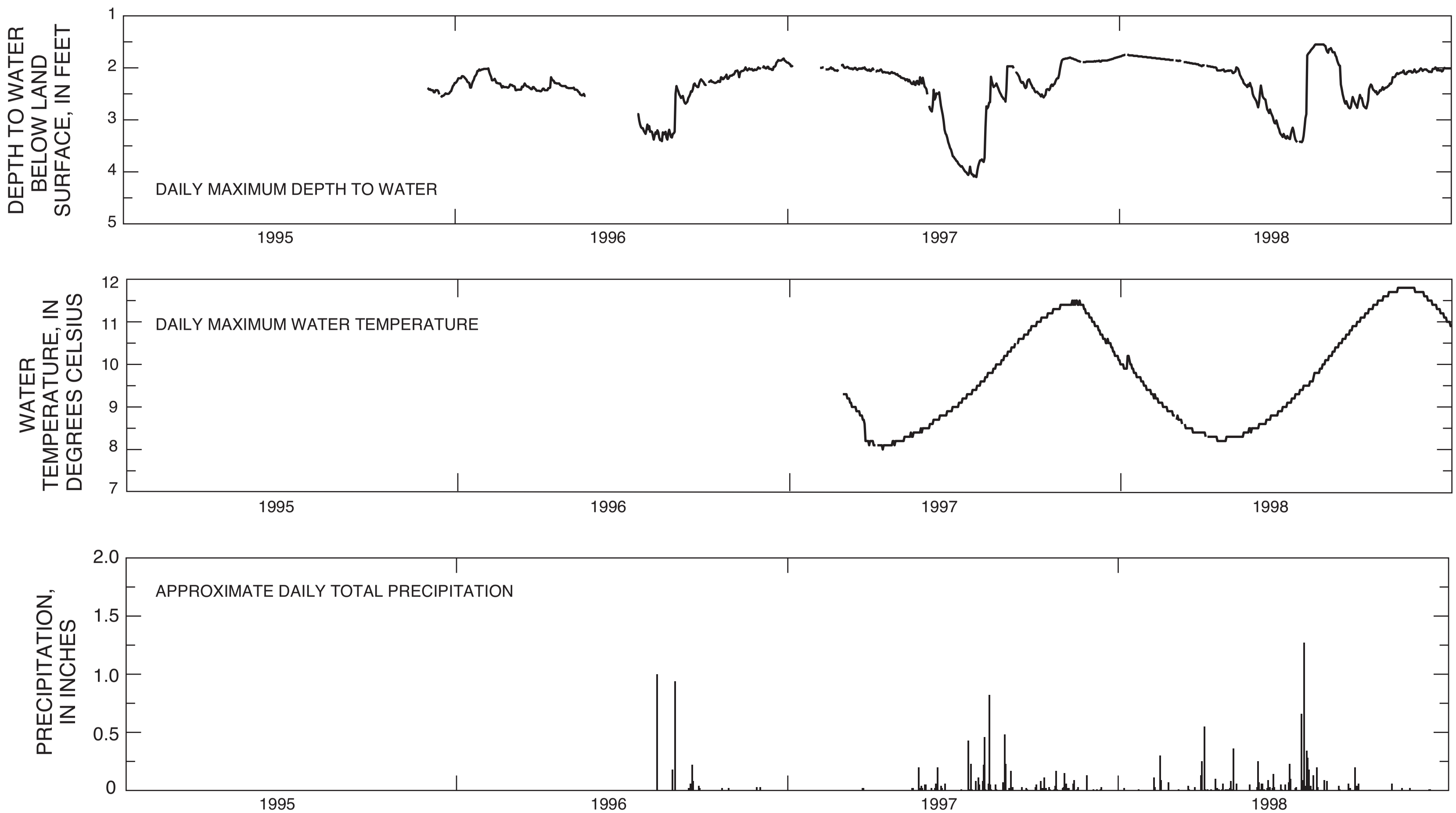


**Figure II.5.** Continuous water-level, ground-water-temperature, and precipitation data for well D23 near Deer Trail, Colorado, 1995–98.

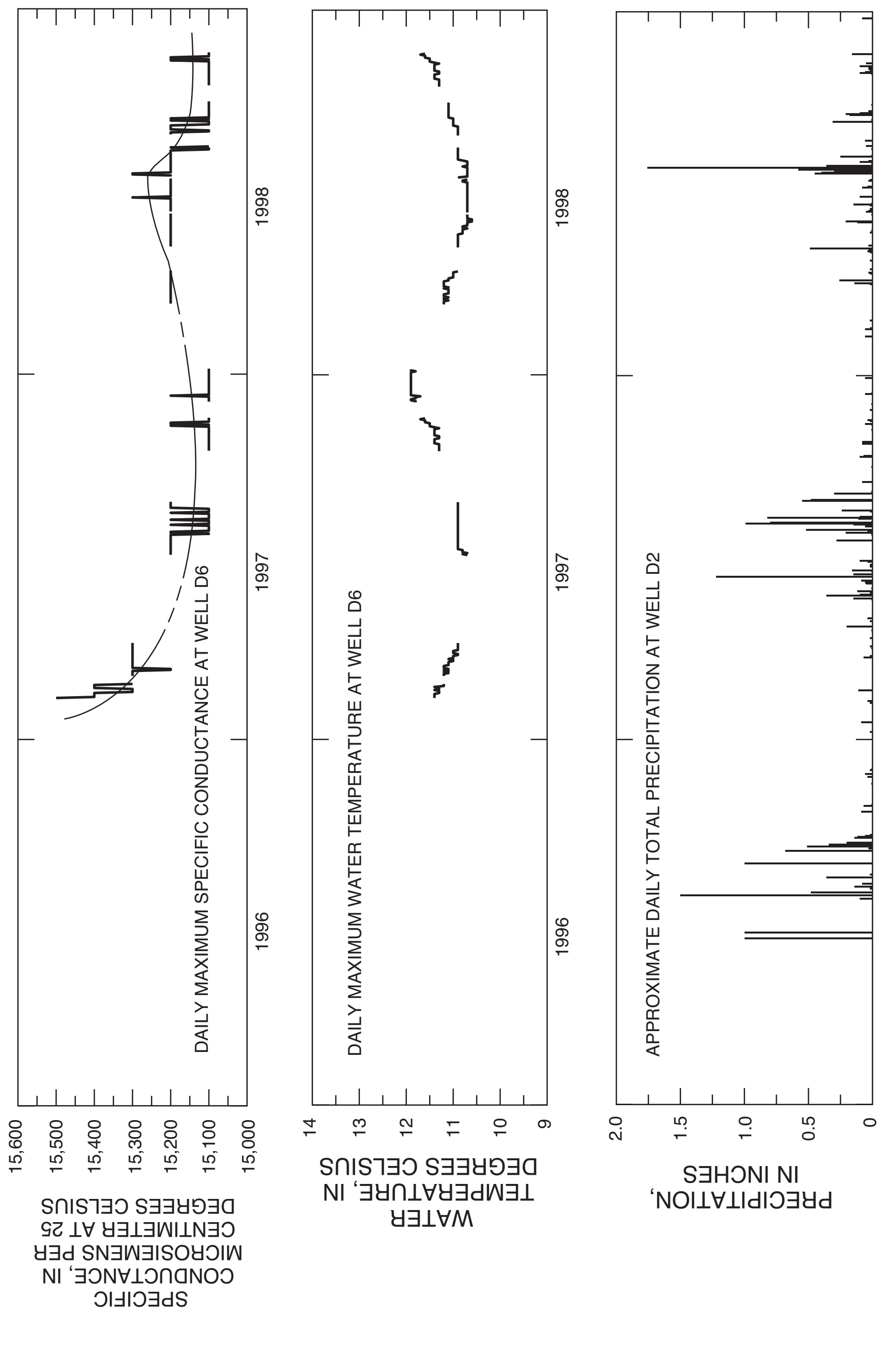


**Figure II.6.** Continuous-recorder specific-conductance and ground-water-temperature data for well D6 and precipitation for well D2 near Deer Trail, Colorado, 1996–98.

**Figure II.7**. Data used to map the Laramie-Fox Hills hydrostratigraphic unit near Deer Trail, Colorado (plates 1 and 2).

[Marker bed, top of D Sandstone member of Pierre Shale; LFH-HU, Laramie-Fox Hills hydrostratigraphic unit;
Format of location, 4-57-35 -- Township 4 South, Range 57 West, Section 35; A, NE l/4; B, NW l/4; C, SW l/4; D, SE l/4;
ft, feet; KB, Kelly Bushing; GL, Ground Level; RP, Reference Point; altitude is in feet above NGVD 29].

DATA FROM GEOPHYSICAL LOGS

| Well ID | Location | GL (ft above NGVD 29) | KB (ft above NGVD 29) | RP | Marker bed depth (ft below RP) | Marker bed altitude (ft above NGVD 29) | Base LFH-HU depth (ft below RP) | Base LFH-HU altitude (ft above NGVD 29) | Top LFH-HU depth (ft below RP) | Top LFH-HU altitude (ft above NGVD29) | Well name |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Klf1 | 5-58-14BA | 5079 | 5090 | KB | 620 | 4470 | 96 | 4994 | | | Jolly "D" |
| Klf2 | 5-58-15AB | 5255 | 5263 | KB | 835 | 4428 | 303 | 4960 | | | UPRR Bixler #1 |
| Klf3 | 5-58-15BB | 5264 | 5277 | KB | 842 | 4435 | 327 | 4950 | | | #1UPRR-Rudolf |
| Klf4 | 5-58-18CC | 5277 | 5287 | KB | 910 | 4377 | 390 | 4897 | 75 | 5212 | Monnahan #1 |
| Klf5 | 5-58-18CD | 5223 | 5232 | KB | 845 | 4387 | 334 | 4898 | 19 | 5213 | Monnahan #24-18 |
| Klf6 | 5-58-19BA | 5233 | 5242 | KB | 840 | 4402 | 340 | 4902 | 25 | 5217 | UPRR Monnahan #1 |
| Klf7 | 5-58-19BC | 5279 | 5289 | KB | 885 | 4404 | 377 | 4912 | 62 | 5227 | UPRR Monnahan #2 |
| Klf8 | 5-58-19BA | 5216 | 5227 | KB | 820 | 4407 | 310 | 4917 | | | #1 Trout |
| Klf9 | 5-58-19AB | 5173 | 5182 | KB | 770 | 4412 | 266 | 4916 | | | UPRR Trout #1 (Tiger) |
| Klf10 | 5-58-19CA | 5220 | 5227 | KB | 800 | 4427 | 305 | 4922 | | | UPRR Trout #1 (Sun) |
| Klf11 | 5-58-19DA | 5206 | 5216 | KB | 770 | 4446 | 280 | 4936 | | | UPRR Trout #1 |
| Klf12 | 5-58-24CD | 5058 | 5068 | KB | 520 | 4548 | 15 | 5053 | | | Wood Yager #1 |
| Klf13 | 5-58-26AA | 5156 | 5167 | KB | 600 | 4567 | 96 | 5071 | | | #1 Mace |
| Klf14 | 5-58-27CC | 5267 | 5278 | KB | 735 | 4543 | 241 | 5037 | | | #1 UPRR Jolly |
| Klf15 | 5-58-27DD | 5283 | 5291 | KB | 740 | 4551 | 243 | 5048 | | | UPRR Jolly B-1 |
| Klf16 | 5-58-29CC | 5268 | 5278 | KB | 775 | 4503 | 292 | 4986 | | | #1 UP Davies |
| Klf17 | 5-58-32DD | 5350 | 5361 | KB | 815 | 4546 | 345 | 5016 | | | #1 Davies |
| Klf18 | 5-58-35AB | 5136 | 5145 | KB | 585 | 4560 | 80 | 5065 | | | #1 UPRR-Jolly |
| Klf19 | 6-58-5DD | 5338 | 5349 | KB | 770 | 4579 | 300 | 5049 | | | #1 UPRR-Davies |
| Klf20 | 6-58-12CC | 5256 | 5265 | KB | 560 | 4705 | 105 | 5160 | | | Jolly #1 |
| Klf22 | 5-59-1BB | 5213 | 5223 | KB | 964 | 4259 | 430 | 4793 | 90 | 5133 | No.1-1 UPRR-Bixler |
| Klf23 | 5-59-5CC | 5264 | 5271 | KB | 1060 | 4211 | 552 | 4719 | 237 | 5034 | No.1-5 UPRR Deter |
| Klf24 | 5-59-5DC | 5214 | 5226 | KB | 1007 | 4219 | 500 | 4726 | 180 | 5046 | No.1-5 Amoco UPRR |
| Klf25 | 5-59-6BB | 5188 | 5198 | KB | 1030 | 4168 | 529 | 4669 | 220 | 4978 | No.1-B Hanks |
| Klf26 | 5-59-7BB | 5278 | 5288 | KB | 1090 | 4198 | 600 | 4688 | 290 | 4998 | UPRR #1 Turecek |
| Klf27 | 5-59-4AA | 5282 | 5292 | KB | 1059 | 4233 | 540 | 4752 | 212 | 5080 | Van Matre #1 |
| Klf28 | 5-59-15CD | 5400 | 5410 | KB | 1112 | 4298 | 620 | 4790 | 298 | 5112 | #1 UPRR Le Valley |
| Klf29 | 5-59-15BB | 5386 | 5396 | KB | 1125 | 4271 | 622 | 4774 | 309 | 5087 | Amoco Le Valley #1 |
| Klf30 | 5-59-18AA | 5331 | 5341 | KB | 1126 | 4215 | 630 | 4711 | 310 | 5031 | Turecek No.1 |
| Klf31 | 5-59-20AA | 5354 | 5364 | KB | 1102 | 4262 | 615 | 4749 | 279 | 5085 | No.1A Turecek et al. |
| Klf32 | 5-59-21DD | 5363 | 5373 | KB | 1055 | 4318 | 571 | 4802 | 252 | 5121 | Henry Deter No.1 |
| Klf33 | 5-59-22DC | 5389 | 5400 | KB | 1074 | 4326 | 590 | 4810 | 270 | 5130 | No.1 Turecek |

**Figure II.7**. Data used to map the Laramie-Fox Hills hydrostratigraphic unit near Deer Trail, Colorado (plates 1 and 2).–Continued

[Marker bed, top of D Sandstone member of Pierre Shale; LFH-HU, Laramie-Fox Hills hydrostratigraphic unit;
Format of location, 4-57-35 -- Township 4 South, Range 57 West, Section 35; A, NE l/4; B, NW l/4; C, SW l/4; D, SE l/4;
ft, feet; KB, Kelly Bushing; GL, Ground Level; RP, Reference Point; altitude is in feet above NGVD 29].

DATA FROM GEOPHYSICAL LOGS

| Well ID | Location | GL (ft above NGVD 29) | KB (ft above NGVD 29) | RP | Marker bed depth (ft below RP) | Marker bed altitude (ft above NGVD 29) | Base LFH-HU depth (ft below RP) | Base LFH-HU altitude (ft above NGVD 29) | Top LFH-HU depth (ft below RP) | Top LFH-HU altitude (ft above NGVD29) | Well name |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Klf34 | 5-59-22CA | 5367 | 5377 | KB | 1060 | 4317 | 572 | 4805 | 252 | 5125 | Okada-Turecek #1 |
| Klf35 | 5-59-24AD | 5277 | 5286 | KB | 890 | 4396 | 384 | 4902 | 84 | 5202 | Trout #1 |
| Klf36 | 5-59-24CC | 5341 | 5348 | KB | 1005 | 4343 | 512 | 4836 | 170 | 5178 | Tom Wall No.1-24 |
| Klf37 | 5-59-22AAA | 5345 | -- | GL | 1011 | 4334 | 522 | 4823 | 208 | 5137 | Deter #1 |
| Klf38 | 5-59-25CC | 5409 | 5419 | KB | 980 | 4439 | 502 | 4917 | 187 | 5232 | #1 UPRR Davies |
| Klf39 | 5-59-27BC | 5425 | 5436 | KB | 1106 | 4330 | 626 | 4810 | 303 | 5133 | Wall-Champlin #1 |
| Klf40 | 5-59-27DB | 5454 | 5463 | KB | 1084 | 4379 | 613 | 4850 | 290 | 5173 | 33-27 Tom Wall |
| Klf41 | 5-59-28A | 5358 | 5369 | KB | 1052 | 4317 | 573 | 4796 | 247 | 5122 | No.1 Wall |
| Klf42 | 5-59-30AA | 5239 | 5246 | KB | 968 | 4278 | 505 | 4741 | 200 | 5046 | Martyn James #1 |
| Klf43 | 5-59-30CC | 5223 | 5233 | KB | 980 | 4253 | 516 | 4717 | 210 | 5023 | No.1 Vest |
| Klf44 | 5-59-31BC | 5272 | 5282 | KB | 1014 | 4268 | 560 | 4722 | 253 | 5029 | UPRR Martyn No.1 |
| Klf45 | 5-59-32CC | 5234 | 5240 | KB | 917 | 4323 | 472 | 4768 | 162 | 5078 | Ballard 1-32 |
| Klf46 | 4-58-1DDD | 4981 | 4991 | KB | 650 | 4341 | 76 | 4915 | | | #1 U.P. Jolly |
| Klf47 | 4-58-1AA | 4944 | 4948 | KB | 627 | 4321 | 45 | 4903 | | | Champlin UPRR #1-1 |
| Klf48 | 4-58-1CC | 5062 | 5070 | KB | 747 | 4323 | 160 | 4910 | | | UPRR Roy #1 |
| Klf49 | 4-58-2AA | 5006 | 5016 | KB | 710 | 4306 | 135 | 4881 | | | Axtell #1 |
| Klf50 | 4-58-3DB | 4883 | 4891 | KB | 597 | 4294 | 20 | 4871 | | | UPRR Jolly #1 |
| Klf51 | 4-58-3CC | 4895 | 4902 | KB | 610 | 4292 | 35 | 4867 | | | UPRR #B-1 |
| Klf52 | 4-58-3DD | 4886 | 4893 | KB | 597 | 4296 | 15 | 4878 | | | #2-B UPRR |
| Klf53 | 4-58-3CB | 4907 | 4917 | KB | 635 | 4282 | 65 | 4852 | | | #1 Jolly Ranch UPRR |
| Klf54 | 4-58-3BBD | 4950 | 4960 | KB | 685 | 4275 | 115 | 4845 | | | #3 UPRR Jolly |
| Klf55 | 4-58-3BA | 4948 | 4958 | KB | 675 | 4283 | 120 | 4838 | | | #4 UPRR Jolly |
| Klf56 | 4-58-4AD | 4975 | 4983 | KB | 710 | 4273 | 140 | 4843 | | | #1 Schultz Assoc. |
| Klf57 | 4-58-8BB | 5093 | 5102 | KB | 847 | 4255 | 305 | 4797 | | | Axtell #1-8 |
| Klf58 | 4-58-6CA | 5165 | 5175 | KB | 930 | 4245 | 390 | 4785 | 25 | 5150 | Angela 6-1 |
| Klf59 | 4-58-9AB | 4921 | 4930 | KB | 635 | 4295 | 80 | 4850 | | | #1 UPRR Jolly |
| Klf60 | 4-58-10BA | 4917 | 4925 | KB | 630 | 4295 | 55 | 4870 | | | Wanda #1 |
| Klf61 | 4-58-10CC | 5018 | 5028 | KB | 715 | 4313 | 148 | 4880 | | | Will Jolly #1 |
| Klf62 | 4-58-10AB | 4925 | 4933 | KB | 623 | 4310 | 53 | 4880 | | | Wanda Jolly #1 |
| Klf63 | 4-58-11BC | 4867 | 4877 | GL | 563 | 4304 | | | | | Union Pacific #1 |
| Klf64 | 4-58-12BD | 5036 | 5047 | KB | 715 | 4332 | 140 | 4907 | | | #22-12 London Co. |
| Klf65 | 4-58-15DD | 4944 | 4949 | KB | 630 | 4319 | 55 | 4894 | | | UPRR Janice #1 |
| Klf66 | 4-58-15BA | 4994 | 5002 | KB | 685 | 4317 | 120 | 4882 | | | Janice UPRR #2 |

**Figure II.7**. Data used to map the Laramie-Fox Hills hydrostratigraphic unit near Deer Trail, Colorado (plates 1 and 2).–Continued

[Marker bed, top of D Sandstone member of Pierre Shale; LFH-HU, Laramie-Fox Hills hydrostratigraphic unit;
Format of location, 4-57-35 -- Township 4 South, Range 57 West, Section 35; A, NE I/4; B, NW I/4; C, SW I/4; D, SE I/4;
ft, feet; KB, Kelly Bushing; GL, Ground Level; RP, Reference Point; altitude is in feet above NGVD 29].

DATA FROM GEOPHYSICAL LOGS

| Well ID | Location | GL (ft above NGVD 29) | KB (ft above NGVD 29) | RP | Marker bed depth (ft below RP) | Marker bed altitude (ft above NGVD 29) | Base LFH-HU depth (ft below RP) | Base LFH-HU altitude (ft above NGVD 29) | Top LFH-HU depth (ft below RP) | Top LFH-HU altitude (ft above NGVD29) | Well name |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Klf67 | 4-58-15AC | 4935 | 4945 | KB | 625 | 4320 | 50 | 4895 | | | Nickell #1 |
| Klf68 | 4-58-16AC | 5049 | 5059 | KB | 770 | 4289 | 195 | 4864 | | | State #1-16 |
| Klf69 | 4-58-16CC | 5088 | 5096 | KB | 800 | 4296 | 235 | 4861 | | | State "A-H" #1 |
| Klf70 | 4-58-18CC | 5211 | 5221 | KB | 992 | 4229 | 445 | 4776 | 80 | 5141 | Bixler #1 |
| Klf71 | 4-58-19CD | 5194 | 5204 | KB | 982 | 4222 | 430 | 4774 | 50 | 5154 | #1-19 UPRR Bixler |
| Klf72 | 4-58-20DB | 5123 | 5132 | KB | 850 | 4282 | 290 | 4842 | | | Dave Jolly #1 |
| Klf73 | 4-58-22BB | 4962 | 4969 | KB | 650 | 4319 | 75 | 4894 | | | #4-22 Jolly |
| Klf74 | 4-58-25DC | 5017 | 5028 | KB | 620 | 4408 | 50 | 4978 | | | #592-1 Juniper UPRR |
| Klf75 | 4-58-26AA | 5093 | 5101 | KB | 745 | 4356 | 155 | 4946 | | | Rhodes "A" #1 |
| Klf76 | 4-58-26CC | 5079 | 5086 | KB | 733 | 4353 | 160 | 4926 | | | Rhodes #1-26 |
| Klf77 | 4-58-30CC | 5221 | 5230 | KB | 965 | 4265 | 422 | 4808 | 57 | 5173 | Lundgren #1-30 |
| Klf78 | 4-58-33BB | 5093 | 5103 | KB | 803 | 4300 | 242 | 4861 | | | #1 UP Jolly |
| Klf79 | 4-58-35DC | 5062 | 5073 | KB | 690 | 4383 | 130 | 4943 | | | 592-1 Pine UPRR |
| Klf80 | 4-58-35DD | 5043 | 5051 | KB | 667 | 4384 | 107 | 4944 | | | UPRR #2 |
| Klf81 | 4-58-36CA | 5025 | 5031 | KB | 635 | 4396 | 75 | 4956 | | | State #2 |
| Klf82 | 4-58-36DD | 4970 | 4979 | KB | 565 | 4414 | 5 | 4974 | | | State #1 |
| Klf83 | 4-58-36CB | 5073 | 5081 | KB | 688 | 4393 | 128 | 4953 | | | #3 State |
| Klf84 | 4-58-36CC | 5004 | 5014 | KB | 622 | 4392 | 62 | 4952 | | | #1 State |
| Klf85 | 4-59-1CC | 5151 | 5161 | KB | 945 | 4216 | 420 | 4741 | 55 | 5106 | UPRR Montgomery 2-1 |
| Klf86 | 4-59-1DD | 5190 | 5200 | KB | 970 | 4230 | 435 | 4765 | 70 | 5130 | UPRR Montgomery 1-1 |
| Klf87 | 4-59-2CB | 5074 | 5080 | KB | 888 | 4192 | 373 | 4707 | 63 | 5017 | #2 Montgomery |
| Klf88 | 4-59-1BD | 5144 | 5154 | KB | 922 | 4232 | 400 | 4754 | 80 | 5074 | 22-1 Downing |
| Klf89 | 4-59-2CD | 5064 | 5070 | KB | 865 | 4205 | 350 | 4720 | 35 | 5035 | #3-2 Montgomery |
| Klf90 | 4-59-2AA | 5133 | 5142 | KB | 946 | 4196 | 426 | 4716 | 61 | 5081 | Linnebur #1-2 |
| Klf91 | 5-59-34BA | 5400 | 5411 | KB | 1044 | 4367 | 582 | 4829 | 257 | 5154 | Tom Wall No.1 |
| Klf92 | 4-59-5DB | 5043 | 5053 | KB | 928 | 4125 | 424 | 4629 | 84 | 4969 | #33-5 UPRR Koepke |
| Klf93 | 4-59-6BD | 5069 | 5079 | KB | 986 | 4093 | 489 | 4590 | | | Mary Healey #2 |
| Klf94 | 6-58-16AA | 5332 | 5338 | KB | 698 | 4640 | 245 | 5093 | | | #1 State |
| Klf95 | 6-58-19DC | 5517 | 5528 | KB | 894 | 4634 | 435 | 5093 | 140 | 5388 | #1UPRR Walter |
| Klf96 | 6-58-22CC | 5352 | 5358 | KB | 651 | 4707 | 214 | 5144 | | | #1 Jolly |

**Figure II.7**. Data used to map the Laramie-Fox Hills hydrostratigraphic unit near Deer Trail, Colorado (plates 1 and 2).–Continued

[Marker bed, top of D Sandstone member of Pierre Shale; LFH-HU, Laramie-Fox Hills hydrostratigraphic unit;
Format of location, 4-57-35 -- Township 4 South, Range 57 West, Section 35; A, NE l/4; B, NW l/4; C, SW l/4; D, SE l/4;
ft, feet; KB, Kelly Bushing; GL, Ground Level; RP, Reference Point; altitude is in feet above NGVD 29].

DATA FROM GEOPHYSICAL LOGS

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|---|---|---|---|---|---|---|---|---|---|---|---|
| Klf97 | 6-58-23CD | 5297 | 5306 | KB | 590 | 4716 | 120 | 5186 | | | #1-A UPRR Jolly |
| Klf98 | 6-58-35DC | 5551 | 5560 | KB | 762 | 4798 | 345 | 5215 | 10 | 5550 | #1-B UPRR, J.B. Jolly |
| Klf99 | 6-59-3CC | 5336 | 5348 | KB | 886 | 4462 | 452 | 4896 | 152 | 5196 | UPRC-So. Deertrail #1 |
| Klf100 | 6-59-4DD | 5361 | 5371 | KB | 929 | 4442 | 490 | 4881 | 190 | 5181 | #1 Blair |
| Klf101 | 6-59-6CC | 5426 | 5434 | KB | 1103 | 4331 | 673 | 4761 | 370 | 5064 | Pisel #6-13 |
| Klf102 | 4-59-2BB | 5063 | 5072 | KB | 889 | 4183 | 375 | 4697 | 65 | 5007 | No. 2-2 Linnebur |
| Klf103 | 4-59-2DB | 5103 | 5109 | KB | 900 | 4209 | 380 | 4729 | 65 | 5044 | EDH Ltd #1 Montgomery |
| Klf105 | 4-59-3AA | 5075 | 5085 | KB | 904 | 4181 | 391 | 4694 | 26 | 5059 | Poncho #19 |
| Klf106 | 4-59-3CB | 5028 | 5038 | KB | 882 | 4156 | 369 | 4669 | | | UPRR #64 Amoco #1 |
| Klf107 | 4-59-3BA | 5023 | 5032 | KB | 864 | 4168 | 356 | 4676 | 56 | 4976 | UPRR Price #4-3 |
| Klf108 | 4-59-3AB | 5058 | 5067 | KB | 892 | 4175 | 378 | 4689 | 78 | 4989 | No.1 Richard Price 31-3 |
| Klf109 | 4-59-3BD | 4992 | 5001 | KB | 838 | 4163 | 327 | 4674 | | | Price No. 3-3 |
| Klf110 | 4-59-3AD | 5075 | 5084 | KB | 903 | 4181 | 387 | 4697 | 22 | 5062 | #2 Rich. Price Jr.#42-3 |
| Klf111 | 4-59-3CD | 4995 | 5003 | KB | 828 | 4175 | 315 | 4688 | | | UPRR-Price #5-3 |
| Klf112 | 4-59-3BB | 4989 | 4997 | KB | 844 | 4153 | 332 | 4665 | | | #1-3 UPRR Price |
| Klf113 | 4-59-4DD | 5056 | 5063 | KB | 904 | 4159 | 393 | 4670 | 88 | 4975 | Noonen et al 1-4x |
| Klf114 | 4-59-4DA | 5009 | 5022 | KB | 861 | 4161 | 358 | 4664 | 58 | 4964 | Poncho #17 |
| Klf115 | 4-59-4CC | 5096 | 5103 | KB | 948 | 4155 | 445 | 4658 | 105 | 4998 | M. Cronk et. al. #1-4 |
| Klf116 | 4-59-4DC | 5039 | 5046 | KB | 880 | 4166 | 374 | 4672 | 69 | 4977 | Cronk No.2-4 |
| Klf117 | 4-59-4DB | 5040 | 5049 | KB | 898 | 4151 | 397 | 4652 | 37 | 5012 | No. 3-4 Cronk |
| Klf118 | 4-59-4AD | 5022 | 5031 | KB | 881 | 4150 | 374 | 4657 | 74 | 4957 | Noonen et. al. #2-4 |
| Klf119 | 4-59-5CB | 5068 | 5081 | KB | 977 | 4104 | 478 | 4603 | 153 | 4928 | UP-Amoco-Koepke 5-12 |
| Klf120 | 4-59-6AA | 5040 | 5050 | KB | 970 | 4080 | 475 | 4575 | 155 | 4895 | Linnebur Bros. #1 |
| Klf121 | 4-59-6AD | 5065 | 5075 | KB | 985 | 4090 | 485 | 4590 | | | Linnebur Bros. #2 |
| Klf122 | 4-59-6BC | 5087 | 5093 | KB | 1007 | 4086 | 510 | 4583 | 200 | 4893 | Healey #1 |
| Klf123 | 4-59-6BB | 5077 | 5087 | KB | 1005 | 4082 | 509 | 4578 | 199 | 4888 | #2 Healey |
| Klf124 | 4-59-6DC | 5054 | 5060 | KB | 960 | 4100 | 460 | 4600 | 145 | 4915 | #1 Amoco Hinch |
| Klf125 | 4-59-6DB | 5041 | 5047 | KB | 957 | 4090 | 460 | 4587 | 150 | 4897 | #1-6 Koepke-Hinch |
| Klf126 | 4-59-6DA | 5076 | 5082 | KB | 990 | 4092 | 491 | 4591 | 181 | 4901 | #1-A-6 Koepke-Hinch |
| Klf127 | 4-59-6AC | 5028 | 5034 | KB | 942 | 4092 | 450 | 4584 | 140 | 4894 | EDH Ltd #1-6 Linnebur |
| Klf128 | 4-59-6BA | 5069 | 5075 | KB | 982 | 4093 | 485 | 4590 | | | Mary Healey #1 |
| Klf129 | 4-59-6CC | 5101 | 5110 | KB | 1011 | 4099 | 510 | 4600 | | | Linnebur #1 |
| Klf130 | 4-59-7BD | 5078 | 5084 | KB | 961 | 4123 | 456 | 4628 | 146 | 4938 | #1-7 Amoco-Koepke |

**Figure II.7**. Data used to map the Laramie-Fox Hills hydrostratigraphic unit near Deer Trail, Colorado (plates 1 and 2).–Continued

[Marker bed, top of D Sandstone member of Pierre Shale; LFH-HU, Laramie-Fox Hills hydrostratigraphic unit;
Format of location, 4-57-35 -- Township 4 South, Range 57 West, Section 35; A, NE l/4; B, NW l/4; C, SW l/4; D, SE l/4;
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DATA FROM GEOPHYSICAL LOGS

| Well ID | Location | GL (ft above NGVD 29) | KB (ft above NGVD 29) | RP | Marker bed depth (ft below RP) | Marker bed altitude (ft above NGVD 29) | Base LFH-HU depth (ft below RP) | Base LFH-HU altitude (ft above NGVD 29) | Top LFH-HU depth (ft below RP) | Top LFH-HU altitude (ft above NGVD29) | Well name |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Klf131 | 4-59-8AAC | 5079 | 5089 | KB | 925 | 4164 | 423 | 4666 | 93 | 4996 | Koepke #1 |
| Klf132 | 4-59-9CB | 5092 | 5100 | KB | 930 | 4170 | 420 | 4680 | 65 | 5035 | UPRR Hanks #1-9 |
| Klf133 | 4-59-9AD | 5049 | 5058 | KB | 881 | 4177 | 365 | 4693 | 65 | 4993 | UPRR Harry Hanks 42-9 |
| Klf134 | 4-59-9BB | 5101 | 5111 | KB | 950 | 4161 | 443 | 4668 | 123 | 4988 | Hanks #2-9 |
| Klf135 | 4-59-9AB | 5055 | 5062 | KB | 889 | 4173 | 377 | 4685 | 77 | 4985 | Champlin H. Hanks 31-9 |
| Klf136 | 6-59-9CA | 5293 | 5297 | KB | 844 | 4453 | 412 | 4885 | 107 | 5190 | UPRR No. 9-1 |
| Klf137 | 6-59-11AA | 5542 | 5553 | KB | 1032 | 4521 | 594 | 4959 | 270 | 5283 | #1 Miller |
| Klf138 | 6-59-12CC | 5516 | 5525 | KB | 975 | 4550 | 547 | 4978 | 237 | 5288 | #12-13 Butter-Purdy |
| Klf139 | 6-59-15BB | 5333 | 5344 | KB | 846 | 4498 | 417 | 4927 | 84 | 5260 | #1UPRR Kellog |
| Klf140 | 6-59-16DD | 5353 | 5365 | KB | 875 | 4490 | 420 | 4945 | 128 | | State # 1-16 |
| Klf141 | 6-59-18BB | 5415 | 5422 | KB | 1032 | 4390 | 580 | 4842 | 310 | 5112 | #1 Wall-State |
| Klf142 | 6-59-23AA | 5378 | 5389 | KB | 810 | 4579 | 379 | 5010 | 69 | 5320 | #1 UPRR-Flack |
| Klf143 | 6-59-24CD | 5427 | 5436 | KB | 839 | 4597 | 377 | 5059 | 90 | 5346 | Butler-Prudy #1 |
| Klf144 | 6-59-28DD | 5414 | 5424 | KB | 858 | 4566 | 410 | 5014 | 130 | 5294 | #1 Hamacher N. Drlg. |
| Klf145 | 6-59-30AA | 5548 | 5558 | KB | 1070 | 4488 | 641 | 4917 | 360 | 5198 | #1 Rector |
| Klf146 | 6-59-31AA | 5587 | 5598 | KB | 1081 | 4517 | 650 | 4948 | 377 | 5221 | #1 UPRR Geesen |
| Klf147 | 6-59-32DD | 5455 | 5464 | KB | 909 | 4555 | 473 | 4991 | 198 | 5266 | Woodard No.1 |
| Klf148 | 6-59-36CC | 5407 | 5415 | KB | 754 | 4661 | 320 | 5095 | 50 | 5365 | #1 State Monks |
| Klf156 | 4-59-25CC | 5084 | 5091 | KB | 859 | 4232 | 321 | 4770 | | | Bixler #1-25 |
| Klf157 | 4-59-25CA | 5146 | 5156 | KB | 920 | 4236 | 378 | 4778 | 14 | 5142 | 25-1 Amoco UPRC Price |
| Klf158 | 4-59-26BBA | 5146 | 5153 | KB | 928 | 4225 | 401 | 4752 | 68 | 5085 | Gould #1 |
| Klf159 | 4-59-28DA | 5259 | 5270 | KB | 1059 | 4211 | 540 | 4730 | 195 | 5075 | Arco N. Deer Trail #1 |
| Klf160 | 4-59-29DD | 5176 | 5186 | KB | 981 | 4205 | 476 | 4710 | | | UPRR #56 Pan Am "C" |
| Klf161 | 4-59-30CC | 5243 | 5253 | KB | 1095 | 4158 | 594 | 4659 | 274 | 4979 | Trustee #1 Deter |
| Klf162 | 4-59-32DC | 5300 | 5306 | KB | 1103 | 4203 | 592 | 4714 | 252 | 5054 | #1 Deter Smith |
| Klf163 | 4-59-33CD | 5273 | 5279 | KB | 1055 | 4224 | 546 | 4733 | 216 | 5063 | EDH Ltd#1 Amoco Hanks |
| Klf164 | 4-59-36BA | 5088 | 5096 | KB | 850 | 4246 | 317 | 4779 | | | Koenig Exeter #1 State |
| Klf165 | 4-57-4AA | 4874 | 4883 | KB | 521 | 4362 | | | | | Cronk No. 1-4 |
| Klf166 | 4-57-8CC | 5016 | 5026 | KB | 659 | 4367 | 84 | 4942 | | | Tiger Oil Co. No.1-8 Lloyd |
| Klf167 | 4-57-9CA | 5000 | 5008 | KB | 638 | 4370 | 63 | 4945 | | | UPRR Cronk #8 |
| Klf168 | 4-57-9AB | 4982 | 4990 | KB | 618 | 4372 | 43 | 4947 | | | UPRR Cronk#1-A |
| Klf169 | 4-57-17DC | 4929 | 4935 | KB | 553 | 4382 | | | | | UPRR Koepke #1 |
| Klf170 | 4-57-18DB | 4956 | 4967 | KB | 603 | 4364 | 28 | 4939 | | | #33-18 Linnebur |

**Figure II.7**. Data used to map the Laramie-Fox Hills hydrostratigraphic unit near Deer Trail, Colorado (plates 1 and 2).–Continued

[Marker bed, top of D Sandstone member of Pierre Shale; LFH-HU, Laramie-Fox Hills hydrostratigraphic unit;
Format of location, 4-57-35 -- Township 4 South, Range 57 West, Section 35; A, NE I/4; B, NW I/4; C, SW I/4; D, SE I/4;
ft, feet; KB, Kelly Bushing; GL, Ground Level; RP, Reference Point; altitude is in feet above NGVD 29].

DATA FROM GEOPHYSICAL LOGS

| Well ID | Location | GL (ft above NGVD 29) | KB (ft above NGVD 29) | RP | Marker bed depth (ft below RP) | Marker bed altitude (ft above NGVD 29) | Base LFH-HU depth (ft below RP) | Base LFH-HU altitude (ft above NGVD 29) | Top LFH-HU depth (ft below RP) | Top LFH-HU altitude (ft above NGVD29) | Well name |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Klf171 | 4-57-19DDD | 4887 | 4894 | KB | 483 | 4411 | | | | | UPRR #A-1 |
| Klf172 | 4-57-20DC | 4908 | 4918 | KB | 498 | 4420 | | | | | #1 Hollingsworth |
| Klf173 | 4-57-20AC | 4901 | 4907 | KB | 506 | 4401 | | | | | Walter Monnahan #1 |
| Klf174 | 4-57-29DD | 4948 | 4957 | KB | 504 | 4453 | | | | | #1 UPRR Hollingsworth |
| Klf175 | 4-57-30DA | 4925 | 4934 | KB | 497 | 4437 | | | | | Rhodes No.1 |
| Klf176 | 4-57-31DD | 5023 | 5032 | KB | 598 | 4434 | 38 | 4994 | | | UPRR Davids Jolly #1 |
| Klf177 | 4-57-32BD | 4958 | 4966 | KB | 530 | 4436 | | | | | Jolly No.1 |
| Klf181 | 4-59-9DD | 5103 | 5111 | KB | 925 | 4186 | 410 | 4701 | 50 | 5061 | UPRR Hanks #4-9 |
| Klf182 | 4-59-9BB | 5101 | 5114 | KB | 953 | 4161 | 446 | 4668 | 116 | 4998 | UP Amoco Hanks 9-4 |
| Klf183 | 4-59-10AB | 5003 | 5011 | KB | 825 | 4186 | 311 | 4700 | | | #1-10 Price |
| Klf184 | 4-59-10ADC | 5013 | 5023 | KB | 820 | 4203 | 302 | 4721 | | | #1 Devon Price |
| Klf185 | 4-59-10CD | 5103 | 5109 | KB | 918 | 4191 | 410 | 4699 | 45 | 5064 | Baughman Farms #2 |
| Klf186 | 4-59-10BB | 5075 | 5085 | KB | 914 | 4171 | 399 | 4686 | 87 | 4998 | Winter #1 |
| Klf187 | 4-59-11CCC | 5029 | 5039 | KB | 839 | 4200 | 320 | 4719 | | | #1 UPRR Noonan |
| Klf188 | 4-59-11BB | 5042 | 5051 | KB | 847 | 4204 | 330 | 4721 | | | #1 Amoco UPRR N. Price |
| Klf189 | 4-59-16BD | 5093 | 5103 | KB | 918 | 4185 | 406 | 4697 | 66 | 5037 | State #16-6 |
| Klf190 | 4-59-16AB | 5072 | 5081 | KB | 900 | 4181 | 385 | 4696 | | | Colorado 16-4-59 |
| Klf191 | 4-59-16ACD | 5090 | 5102 | KB | 917 | 4185 | 405 | 4697 | 79 | 5023 | State Hanks #32-16 |
| Klf192 | 4-59-16DD | 5152 | 5159 | KB | 970 | 4189 | 453 | 4706 | 108 | 5051 | #1 State |
| Klf193 | 4-59-17CB | 5154 | 5164 | KB | 998 | 4166 | 490 | 4674 | 175 | 4989 | #1-17 UPRR Amoco |
| Klf194 | 4-59-18AC | 5170 | 5177 | KB | 1054 | 4123 | 552 | 4625 | 242 | 4935 | Koepke hinch 1-18 |
| Klf195 | 4-59-18BA | 5116 | 5126 | KB | 995 | 4131 | 495 | 4631 | | | Emma Koepke Hinch #1 |
| Klf196 | 4-59-18CA | 5184 | 5194 | KB | 1061 | 4133 | 555 | 4639 | 245 | 4949 | Koepke Hinch #2-18 |
| Klf197 | 4-59-20BB | 5193 | 5202 | KB | 1040 | 4162 | 533 | 4669 | 200 | 5002 | Kalcevic Farms #1-20 |
| Klf198 | 4-59-20CD | 5233 | 5242 | KB | 1064 | 4178 | 556 | 4686 | 225 | 5017 | Kalcevic Farms #3-20 |
| Klf199 | 4-59-20AA | 5164 | 5171 | KB | 993 | 4178 | 488 | 4683 | 162 | 5009 | Kalcevic Farms 2-20 |
| Klf200 | 4-59-20BD | 5230 | 5242 | KB | 1055 | 4187 | 543 | 4699 | 217 | 5025 | Kalcevic 22-20 |
| Klf201 | 5-58-1DA | 5071 | 5082 | KB | 650 | 4432 | 105 | 4977 | | | #1-1 UPRR |
| Klf202 | 5-58-1BB | 5057 | 5063 | KB | 664 | 4399 | 109 | 4954 | | | #1 UPRR |
| Klf203 | 5-58-2AB | 5146 | 5158 | KB | 766 | 4392 | 210 | 4948 | | | #1 Blackburn-Jolly |
| Klf204 | 5-58-3DA | 5213 | 5222 | KB | 842 | 4380 | 291 | 4931 | | | UPRR Jolly #1 |
| Klf205 | 5-58-6DB | 5164 | 5174 | KB | 874 | 4300 | 330 | 4844 | | | Weisensee 33-6 |
| Klf206 | 5-58-6CC | 5151 | 5162 | KB | 878 | 4284 | 340 | 4822 | | | Weisnee #1 |
| Klf207 | 5-58-13DD | 4965 | 4975 | KB | 450 | 4525 | | | | | #1-A UPRR Jolly |

**Figure II.7**. Data used to map the Laramie-Fox Hills hydrostratigraphic unit near Deer Trail, Colorado (plates 1 and 2).–Continued

[Marker bed, top of D Sandstone member of Pierre Shale; LFH-HU, Laramie-Fox Hills hydrostratigraphic unit;
Format of location, 4-57-35 -- Township 4 South, Range 57 West, Section 35; A, NE l/4; B, NW l/4; C, SW l/4; D, SE l/4;
ft, feet; KB, Kelly Bushing; GL, Ground Level; RP, Reference Point; altitude is in feet above NGVD 29].

DATA FROM GEOPHYSICAL LOGS

| Well ID | Location | GL (ft above NGVD 29) | KB (ft above NGVD 29) | RP | Marker bed depth (ft below RP) | Marker bed altitude (ft above NGVD 29) | Base LFH-HU depth (ft below RP) | Base LFH-HU altitude (ft above NGVD 29) | Top LFH-HU depth (ft below RP) | Top LFH-HU altitude (ft above NGVD29) | Well name |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Klf208 | 5-57-5CD | 4956 | 4966 | KB | 470 | 4496 | | | | | #1 UPRR Jolly |
| Klf209 | 5-57-18AB | 4947 | 4958 | KB | 423 | 4535 | | | | | Jolly "E" #1 |
| Klf210 | 5-57-31BB | 5020 | 5029 | KB | 412 | 4617 | | | | | A-1 David Jolly |
| Klf243 | 7-58-5AA | 5540 | 5551 | KB | 820 | 4731 | 380 | 5171 | 92 | 5459 | #1 UPRR Butler |
| Klf244 | 7-58-7AB | 5468 | 5477 | KB | 751 | 4726 | 316 | 5161 | 38 | 5439 | Peppel #31 x-7 |
| Klf245 | 7-59-4DD | 5527 | 5534 | KB | 928 | 4606 | 500 | 5034 | 222 | 5312 | No.1 Geesen State |
| Klf247 | 7-59-5CC | 5636 | 5646 | KB | 1096 | 4550 | 669 | 4977 | 400 | 5246 | #1-5 Champlin-Geesen |
| Klf249 | 7-59-8DD | 5609 | 5618 | KB | 1030 | 4588 | 610 | 5008 | 335 | 5283 | State #44-8 |
| Klf250 | 7-59-14CC | 5430 | 5440 | KB | 748 | 4692 | 330 | 5110 | 55 | 5385 | #1-14 Monks |
| Klf251 | 7-58-24AA | 5427 | 5435 | KB | 511 | 4924 | 80 | 5355 | | | Butler State #1 |
| Klf252 | 7-58-21DD | 5682 | 5691 | KB | 840 | 4851 | 415 | 5276 | 135 | 5556 | UPRR No.44-21 |
| Klf301 | 4-57-29BB | 4911 | 4919 | KB | 502 | 4417 | | | | | Hollingsworth UPRR #1 |
| Klf302 | 4-57-30BD | 4944 | 4956 | KB | 532 | 4424 | | | | | 22-30 Kalcevick |
| Klf303 | 4-57-31AB | 4993 | 5003 | KB | 567 | 4436 | | | | | #1 UPRR Jolly |
| Klf304 | 4-57-32ADB | 4927 | 4936 | KB | 490 | 4446 | | | | | Jolly No.1 |
| Klf305 | 5-57-17DDD | 4991 | 5002 | KB | 433 | 4569 | | | | | #1 UP David Jolly |
| Klf306 | 5-57-31BD | 5017 | 5028 | KB | 394 | 4634 | | | | | #1 Wootten-Champlin 6-31 |
| Klf307 | 6-57-34BD | 5163 | 5169 | KB | 270 | 4899 | | | | | Jolly #J-1 |
| Klf309 | 7-57-24AA | 5470 | 5479 | KB | 393 | 5086 | | | | | 1-B Higgins |
| Klf310 | 7-57-34AD | 5871 | 5880 | KB | 830 | 5050 | 378 | 5502 | 108 | 5772 | Higgins #42-34 |
| Klf311 | 7-58-18AA | 5497 | 5507 | KB | 740 | 4767 | 309 | 5198 | 30 | 5477 | #1 Engel |
| Klf312 | 7-58-22DA | 5487 | 5496 | KB | 646 | 4850 | 216 | 5280 | | | State #43-22 |
| Klf313 | 7-58-26BA | 5555 | 5563 | KB | 668 | 4895 | 242 | 5321 | | | State Beaver #26-21 |
| Klf314 | 7-58-36CD | 5621 | 5630 | KB | 671 | 4959 | 251 | 5379 | | | State #24-36 |
| Klf315 | 7-59-16CC | 5611 | 5619 | KB | 983 | 4636 | 572 | 5047 | 300 | 5319 | #1 Geesen State |
| Klf316 | 7-59-25DD | 5489 | 5496 | KB | 760 | 4736 | 345 | 5151 | 54 | 5442 | #1-25 Champlin-Williams |
| Klf317 | 7-59-27DD | 5487 | 5497 | KB | 800 | 4697 | 394 | 5103 | 110 | 5387 | UPRR Mathews #1 |
| Klf318 | 7-60-23DD | 5704 | 5711 | KB | 1164 | 4547 | 750 | 4961 | 489 | 5222 | Kickapoo Land Co. 44-23 |
| Klf329 | 5-57-3AA | 4851 | 4860 | KB | 334 | 4526 | | | | | UPRR Frasier Farms 1-3 |
| Klf330 | 5-57-10AA | 4891 | 4901 | KB | 325 | 4576 | | | | | #1 Frasier Farms |
| Klf331 | 5-57-12CC | 4909 | 4918 | KB | 282 | 4636 | | | | | Frasier Farms No.1 |
| Klf332 | 5-57-20DA | 4993 | 5003 | KB | 378 | 4625 | | | | | Jolly #1 |

**Figure II.7**. Data used to map the Laramie-Fox Hills hydrostratigraphic unit near Deer Trail, Colorado (plates 1 and 2).–Continued

[Marker bed, top of D Sandstone member of Pierre Shale; LFH-HU, Laramie-Fox Hills hydrostratigraphic unit;
Format of location, 4-57-35 -- Township 4 South, Range 57 West, Section 35; A, NE l/4; B, NW l/4; C, SW l/4; D, SE l/4;
ft, feet; KB, Kelly Bushing; GL, Ground Level; RP, Reference Point; altitude is in feet above NGVD 29].

DATA FROM GEOPHYSICAL LOGS

| Well ID | Location | GL (ft above NGVD 29) | KB (ft above NGVD 29) | RP | Marker bed depth (ft below RP) | Marker bed altitude (ft above NGVD 29) | Base LFH-HU depth (ft below RP) | Base LFH-HU altitude (ft above NGVD 29) | Top LFH-HU depth (ft below RP) | Top LFH-HU altitude (ft above NGVD29) | Well name |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Klf333 | 5-57-27AA | 4999 | 5008 | KB | 325 | 4683 | | | | | #2 UPRR Jolly |
| Klf334 | 5-57-28BC | 4973 | 4982 | KB | 327 | 4655 | | | | | Dave Jolly Jr. #1 |
| Klf335 | 5-57-35CC | 5036 | 5045 | KB | 260 | 4785 | | | | | #1 James "B" Jolly |
| Klf336 | 5-57-36AA | 4997 | 5006 | KB | 224 | 4782 | | | | | State No.1 |
| Klf338 | 4-57-1BA | 4833 | 4840 | KB | 433 | 4407 | | | | | UPRR Miller #1 |
| Klf339 | 4-57-2AA | 4878 | 4887 | KB | 503 | 4384 | | | | | Jolly #4 |
| Klf340 | 4-57-2BC | 4943 | 4955 | KB | 572 | 4383 | | | | | Bohan #12-2 |
| Klf341 | 4-57-3DB | 4937 | 4947 | KB | 568 | 4379 | | | | | UPRC Linnebur 33-3 |
| Klf342 | 4-57-3BD | 4898 | 4904 | KB | 538 | 4366 | | | | | UPRR Jolly #2-3 |
| Klf343 | 4-57-3DDD | 4930 | 4939 | KB | 540 | 4399 | | | | | UPRR #1 |
| Klf344 | 4-57-12CC | 4811 | 4821 | KB | 381 | 4440 | | | | | #12-13 Davison |
| Klf345 | 4-57-14BB | 4849 | 4859 | KB | 420 | 4439 | | | | | #1 Wagner |
| Klf346 | 4-57-15CB | 4927 | 4937 | KB | 518 | 4419 | | | | | Amoco Champlin 1-15 |
| Klf347 | 4-57-16BC | 4903 | 4909 | KB | 531 | 4378 | | | | | State of Colorado No.1 |
| Klf348 | 4-57-21CC | 4901 | 4911 | KB | 476 | 4435 | | | | | #1 U.P. Railroad |
| Klf349 | 4-57-22AB | 4845 | 4853 | KB | 400 | 4453 | | | | | D.M. Hand #1 |
| Klf350 | 4-57-27DD | 4844 | 4852 | KB | 375 | 4477 | | | | | UPRR Cronk No. 27-2 |
| Klf351 | 4-57-34CB | 4883 | 4891 | KB | 415 | 4476 | | | | | Jolly No. 34-1 |
| Klf352 | 4-57-35BD | 4823 | 4832 | KB | 316 | 4516 | | | | | UPRR Frasier Farms 1 |
| DTX8 | 4-59-25BB | 5071 | | GL | | | | | | | USGS monitoring well DTX8 |

Source: Colorado Oil and Gas Conservation Commission except for DTX8, which is from U.S. Geological Survey

**Figure II.7**. Data used to map the Laramie-Fox Hills hydrostratigraphic unit near Deer Trail, Colorado (plates 1 and 2).–Continued

[Marker bed, top of D Sandstone member of Pierre Shale; LFH-HU, Laramie-Fox Hills hydrostratigraphic unit; Format of location, 4-57-35 -- Township 4 South, Range 57 West, Section 35; A, NE l/4; B, NW l/4; C, SW l/4; D, SE l/4; ft, feet; KB, Kelly Bushing; GL, Ground Level; RP, Reference Point; altitude is in feet above NGVD 29].

**Data from various lithologic logs and field inspection**

| ID | Location | GL (ft above NGVD 29) | Top LFH-HU altitude (ft above NGVD 29) | Source |
|---|---|---|---|---|
| Klf353 | 4-59-4AAB | 5020 | 4992 | Lithologic log |
| Klf354 | 4-59-9AAA | 5060 | 5041 | Lithologic log |
| Klf355 | 4-59-10CBB | 5080 | 5062 | Lithologic log |
| Klf356 | 4-59-10CC | 5095 | 5058 | Lithologic log |
| Klf357 | 4-58-20BBB | 5230 | 5203 | Lithologic log |
| Klf358 | 4-58-19DBA | 5225 | 5164 | Lithologic log |
| Klf360 | 4-59-4DA | 5030 | 5030 | Field inspection |
| Klf361 | 4-59-9ADD | 5055 | 5055 | Field inspection |
| Klf362 | 4-59-23CDD | 5120 | 5120 | Field inspection |
| Klf363 | 4-59-26BAB | 5120 | 5120 | Field inspection |
| Klf364 | 4-59-24CDD | 5140 | 5140 | Field inspection |
| Klf365 | 4-59-25BDB | 5140 | 5140 | Field inspection |
| Klf366 | 4-58-31CCB | 5170 | 5170 | Field inspection |
| Klf367 | 5-58-7CCD | 5200 | 5200 | Field inspection |
| Klf368 | 5-58-8CCD | 5220 | 5220 | Field inspection |
| Klf369 | 5-58-18ACB | 5220 | 5220 | Field inspection |
| Klf370 | 5-58-20CDB | 5280 | 5280 | Field inspection |
| Klf371 | 5-58-29BBA | 5280 | 5280 | Field inspection |
| Klf372 | 5-58-29DCB | 5320 | 5320 | Field inspection |
| Klf374 | 6-58-5BA | 5360 | 5360 | Field inspection |
| Klf375 | 6-58-27CAB | 5500 | 5500 | Field inspection |
| Klf376 | 6-58-27CDB | 5500 | 5500 | Field inspection |
| Klf377 | 6-58-34BBC | 5490 | 5490 | Field inspection |
| Klf378 | 6-58-27BCA | 5480 | 5480 | Field inspection |

**Table II.1.** Information for U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1993–98.

[Latitude and longitude are in the format degrees minutes seconds referenced to NAD 83; HUC, hydrologic unit code in the format 101900XX; Metro, Metro Wastewater Reclamation District; stickup, height of measuring point on well casing above land surface; ft., feet; bmp, below measuring point (stickup); in., inches; <, less than; km, kilometer; --, no data; altitude is in feet above NGVD 29; JRE, professional survey that used levels to benchmarks and high-accuracy global positioning system; DEM, digital elevation map; TDS, total data station that the USGS used to run levels; GPS, global positioning system]

| Well | Latitude | Longitude | County | HUC | Property owner | Date drilled | Stickup, ft. | Total depth, ft. bmp, from Drillers' notes | Screened interval: Top, ft. bmp, from Drillers' notes | Screened interval: Bottom, ft. bmp, from Drillers' notes | Screen length, ft., from Drillers' notes | Screen opening, in. | Sump length, ft | Effective total depth, measured 12/95-2/96, ft bmp | Altitude of measuring point (top of stickup), ft. | Altitude of land surface, ft. | Altitude of land surface, km | Source of position and altitude data |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D1 | 39 36 57.80671N | 103 52 36.00105W | ARAPAHOE | 13 | Metro | 9/7/93 | 2.09 | 17 | 12 | 17 | 5 | hand slotted | < 1 | 17.15 | 5226.90 | 5224.81 | 1.59 | JRE |
| [1]D2 | 39 36 46.91675N | 103 51 58.93608W | ARAPAHOE | 13 | Metro | 9/7/93 | 3.29 | 25 | 15 | 25 | 10 | 0.010 | < 1 | 24.50 | 5170.19 | 5166.90 | 1.57 | JRE |
| D3 | 39 37 20.89342N | 103 54 31.35544W | ARAPAHOE | 11 | Metro | 9/11/93 | 2.83 | 46 | 36 | 46 | 10 | 0.010 | < 1 | 47.28 | 5188.59 | 5185.76 | 1.58 | JRE |
| D4 | 39 36 40.77561N | 103 53 51.02474W | ARAPAHOE | 11 | Metro | 9/10/93 | 2.11 | 34 | 24 | 34 | 10 | 0.010 | < 1 | 33.41 | 5209.81 | 5207.70 | 1.59 | JRE |
| D5 | 39 36 18.96329N | 103 51 55.40047W | ARAPAHOE | 13 | Metro | 9/11/93 | 3.45 | 30 | 20 | 30 | 10 | 0.010 | < 1 | 29.21 | 5195.59 | 5192.14 | 1.58 | JRE |
| [2]D6 | 39 36 32.92243N | 103 51 22.41861W | ARAPAHOE | 13 | Metro | 9/12/93 | 2.65 | 26 | 16 | 26 | 10 | 0.010 | < 1 | 25.10 | 5126.08 | 5123.43 | 1.56 | JRE |
| D7 | 39 36 00.91012N | 103 53 56.45627W | ARAPAHOE | 11 | Metro | 9/10/93 | 2.62 | 25 | 15 | 25 | 10 | 0.010 | < 1 | 23.77 | 5220.58 | 5217.96 | 1.59 | JRE |
| D8 | 39 36 36.96236N | 103 54 21.56186W | ARAPAHOE | 11 | Metro | 9/10/93 | 2.79 | 20 | 10 | 20 | 10 | 0.010 | < 1 | 19.15 | 5186.44 | 5183.65 | 1.58 | JRE |
| D9 | 39 37 27.90764N | 103 52 57.05224W | ARAPAHOE | 12 | Metro | 9/12/93 | 2.37 | 61 | 51 | 61 | 10 | 0.010 | < 1 | 62.00 | 5217.90 | 5215.53 | 1.59 | JRE |
| D10 | 39 36 07.67740N | 103 51 49.94923W | ARAPAHOE | 13 | Metro | 9/11/93 | 2.40 | 20 | 10 | 20 | 10 | 0.010 | < 1 | 19.19 | 5197.09 | 5194.69 | 1.58 | JRE |
| [3]D11 | 39 36 38N | 103 53 13W | ARAPAHOE | 11 | Metro | 9/12/93 | 3.50 | 17 | 7 | 17 | 10 | 0.010 | < 1 | -- | 5264 | 5260 | 1.60 | DEM |
| D11a | 39 33 45N | 103 54 23W | ELBERT | 11 | Metro | 10/23/97 | 2.46 | 143.03 | 112.65 | 122.65 | 10 | 0.010 | 20.38 | -- | 5374 | 5372 | 1.64 | Map, TDS, DEM |
| D12 | 39 37 01.56726N | 103 52 18.76732W | ARAPAHOE | 13 | Metro | -- | 0.62 | -- | -- | -- | -- | -- | -- | 55.48 | 5191.33 | 5190.71 | 1.58 | JRE |
| D13 | 39 34 41.52701N | 103 54 37.51467W | ARAPAHOE | 11 | Metro | 4/4/94 | 1.81 | 17 | 7 | 17 | 10 | 0.010 | < 1 | 16.15 | 5232.63 | 5230.82 | 1.59 | JRE |
| D14 | 39 34 28.76792N | 103 54 03.29046W | ARAPAHOE | 11 | Metro | 4/4/94 | 1.39 | 24 | 14 | 24 | 10 | 0.010 | < 1 | 24.00 | 5269.43 | 5268.04 | 1.61 | JRE |
| D15 | 39 33 58.75763N | 103 54 54.24674W | ELBERT | 11 | Private | 4/7/94 | 1.86 | 25 | 15 | 25 | 10 | 0.010 | < 1 | 24.06 | 5244.07 | 5242.21 | 1.60 | JRE |
| D16 | 39 33 06N | 103 54 56W | ELBERT | 11 | Private | 4/7/94 | 1.88 | 25 | 15 | 25 | 10 | 0.010 | < 1 | 24.06 | 5279 | 5277 | 1.61 | GPS, DEM |
| D17 | 39 33 34.44687N | 103 54 36.41899W | ELBERT | 11 | Metro | 4/5/94 | 1.90 | 22 | 12 | 22 | 10 | 0.010 | < 1 | 20.89 | 5275.03 | 5273.13 | 1.61 | JRE |
| D18 | 39 33 29N | 103 55 20W | ELBERT | 11 | Private | 4/16/94 | 2.50 | 15 | 10 | 15 | 5 | 0.010 | < 1 | 14.90 | 5298 | 5296 | 1.61 | GPS, DEM |

**Table II.1.** Information for U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1993–98.

[Latitude and longitude are in the format degrees minutes seconds referenced to NAD 83; HUC, hydrologic unit code in the format 101900XX; Metro, Metro Wastewater Reclamation District; stickup, height of measuring point on well casing above land surface; ft., feet; bmp, below measuring point (stickup); in., inches; <, less than; km, kilometer; --, no data; altitude is in feet above NGVD 29; JRE, professional survey that used levels to benchmarks and high-accuracy global positioning system; DEM, digital elevation map; TDS, total data station that the USGS used to run levels; GPS, global positioning system]

| | | | | | | | | | Screened interval | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Well | Latitude | Longitude | County | HUC | Property owner | Date drilled | Stickup, ft. | Total depth, ft. bmp, from Drillers' notes | Top, ft. bmp, from Drillers' notes | Bottom, ft. bmp, from Drillers' notes | Screen length, ft., from Drillers' notes | Screen opening, in. | Sump length, ft | Effective total depth, measured 12/95-2/96, ft bmp | Altitude of measuring point (top of stickup), ft. | Altitude of land surface, ft. | Altitude of land surface, km | Source of position and altitude data |
| D19 | 39 33 16.97000N | 103 54 18.09956W | ELBERT | 11 | Metro | 4/5/94 | 1.69 | 30 | 20 | 30 | 10 | 0.010 | < 1 | 29.00 | 5301.54 | 5299.85 | 1.62 | JRE |
| D20 | 39 32 46N | 103 54 42W | ELBERT | 11 | Private | 4/6/94 | 2.27 | 22 | 12 | 22 | 10 | 0.010 | < 1 | [5]-- | 5282 | 5280 | 1.61 | GPS, DEM |
| D21 | 39 32 09N | 103 54 46W | ELBERT | 11 | Private | 4/5/94 | 1.71 | 20 | 10 | 20 | 10 | 0.010 | < 1 | 19.12 | 5319 | 5317 | 1.62 | GPS, DEM |
| D22 | 39 33 07.54597N | 103 52 00.42522W | ELBERT | 13 | Metro | 4/8/94 | 3.58 | 41 | 31 | 41 | 10 | 0.010 | < 1 | 39.30 | 5154.96 | 5151.38 | 1.57 | JRE |
| [4]D23 | 39 33 42.2N | 103 55 1.1W | ELBERT | 11 | Private | 4/8/94 | 2.54 | 15 | 10 | 15 | 5 | 0.010 | < 1 | 15.00 | 5253.4 | 5250.81 | 1.60 | JRE |
| D24 | 39 37 24.35652N | 103 53 51.56324W | ARAPAHOE | 11 | Metro | 5/10/95 | 2.31 | 60 | 20 | 50 | 30 | 0.010 | 10 | 59.50 | 5242.30 | 5239.99 | 1.60 | JRE |
| D25 | 39 37 02.36429N | 103 54 41.77998W | ARAPAHOE | 11 | Metro | 5/1/95 | 2.23 | 25 | 15 | 25 | 10 | 0.010 | < 1 | 22.93 | 5164.43 | 5162.20 | 1.57 | JRE |
| D26 | 39 36 39.48726N | 103 53 30.23390W | ARAPAHOE | 11 | Metro | 5/3/95 | 2.44 | 44 | 34 | 44 | 10 | 0.010 | < 1 | 43.50 | 5230.64 | 5228.20 | 1.59 | JRE |
| D27 | 39 36 20.63663N | 103 54 09.06578W | ARAPAHOE | 11 | Metro | 5/2/95 | 2.77 | 26 | 16 | 26 | 10 | 0.010 | < 1 | 23.96 | 5204.50 | 5201.73 | 1.59 | JRE |
| D28 | 39 35 44.79713N | 103 53 40.17959W | ARAPAHOE | 11 | Metro | 5/2/95 | 2.12 | 30 | 20 | 30 | 10 | 0.010 | < 1 | 28.38 | 5236.41 | 5234.29 | 1.60 | JRE |
| D29 | 39 36 41N | 103 52 48W | ARAPAHOE | 13 | Metro | 11/4/97 | 2.38 | 183.19 | 147.81 | 157.81 | 10 | 0.010 | 25.38 | -- | 5369 | 5366 | 1.64 | Map, TDS, DEM |
| D30 | 39 36 54.59463N | 103 51 22.26453W | ARAPAHOE | 13 | Metro | 5/5/95 | 1.98 | 21 | 11 | 21 | 10 | 0.010 | < 1 | 18.99 | 5093.73 | 5091.75 | 1.55 | JRE |
| D31 | 39 36 55.75641N | 103 51 38.57257W | ARAPAHOE | 13 | Metro | 5/4/95 | 1.84 | 26 | 11 | 21 | 10 | 0.010 | 5 | 23.94 | 5117.06 | 5115.22 | 1.56 | JRE |
| D32 | 39 36 09.10353N | 103 51 25.51780W | ARAPAHOE | 13 | Metro | 5/9/95 | 1.99 | 40 | 30 | 40 | 10 | 0.010 | < 1 | 39.00 | 5186.23 | 5184.24 | 1.58 | JRE |
| D33 | 39 35 56.05290N | 103 51 53.08219W | ARAPAHOE | 13 | Metro | 5/5/95 | 1.73 | 25 | 10 | 20 | 10 | 0.010 | 5 | 24.19 | 5226.38 | 5224.65 | 1.59 | JRE |

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

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

[3] Well was closed on 09/07/1995.

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

[5] Accurate depth measurement not obtained because well seems to have an object immersed in the well since before October 1995 (possibly a bailer).

**Table II.2.** Lithologic descriptions for U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1993–98.

### Well D1

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Top soil is light-brown clay mixed with silt. |
| 3 – 8 feet | Surficial drill cuttings | Very hard, silty, dry clay. |
| 8 – 13 feet | Surficial drill cuttings | Same material. |
| 13 – 15 feet | Surficial drill cuttings | Little easier drilling from 11.5 to 13 feet; otherwise same material. |

### Well D2

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Top soil is light-brown clay mixed with silt. |
| 3 – 8 feet | Surficial drill cuttings | Soft clay at 3 feet. |
| 8 – 13 feet | Surficial drill cuttings | Same material. |
| 13 – 18 feet | Surficial drill cuttings | Very easy drilling; water at 14–15 feet. |
| 18 – 23 feet | Surficial drill cuttings | No change; saturated silty clay. |

### Well D3

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Medium-brown, dry, silty clay. |
| 3 – 8 feet | Surficial drill cuttings | Tighter at 4 feet; same material; a little damp. |
| 8 – 13 feet | Surficial drill cuttings | Hard, dry, silty clay; darker brown color. |
| 13 – 18 feet | Surficial drill cuttings | At 15.5 feet, getting harder–more silt. |
| 18 – 23 feet | Surficial drill cuttings | Soft at 18.5–19 feet; a little perched-water zone. |
| 23 – 28 feet | Surficial drill cuttings | Tighter at 23.5 feet; a little silty clay; damp. |
| 28 – 33 feet | Surficial drill cuttings | Moist, fine-grained sand; very hard at 28 feet; loose at 31 feet. |
| 33 – 38 feet | Surficial drill cuttings | Soft, moist, fine-grained sand; very loose; water at 35–35.5 feet. |
| 38 – 43 feet | Surficial drill cuttings | Saturated fine sand. |
| 43 – 48 feet | Surficial drill cuttings | No change. |

### Well D4

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Topsoil is a light-brown, silty clay. |
| 3 – 8 feet | Surficial drill cuttings | Bone-white clay; very dry and hard. |
| 8 – 13 feet | Surficial drill cuttings | Soft, dry, silty clay grades to sand or fine-grained sand; light-brown and dark-yellow color. |
| 13 – 18 feet | Surficial drill cuttings | Hard clay; return of a lot of fine-grained yellow and light-brown sand. |
| 18 – 23 feet | Surficial drill cuttings | Same material. |
| 23 – 28 feet | Surficial drill cuttings | No change. |
| 28 – 32 feet | Surficial drill cuttings | Softer from 29–31; water at 31 to 32 feet; hard, black clay at bottom. |

**Table II.2.** Lithologic descriptions for U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

### Well D5

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Dry, tan, silty, powdery clay. |
| 3 – 8 feet | Surficial drill cuttings | Silty clay; moist at 7 feet. |
| 8 – 13 feet | Surficial drill cuttings | Very moist; soft, silty clay. |
| 13 – 18 feet | Surficial drill cuttings | Water at 15 feet; saturated silty to sandy clay. |
| 18 – 23 feet | Surficial drill cuttings | Saturated sandy silt. |
| 23 – 27 feet | Surficial drill cuttings | Same material. |

### Well D6

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Dry, silty, powdery, light-brown clay. |
| 3 – 8 feet | Surficial drill cuttings | Silty clay; moister at 7 feet. |
| 8 – 13 feet | Surficial drill cuttings | Water at 10 to 11 feet; wet silty clay. |
| 13 – 23 feet | Surficial drill cuttings | Saturated, silty, sandy clay. |

### Test Borehole About 15 Feet Southeast of Well D6

(Description from geologist's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0—27.5 feet | Core | Damp, brown clayey loam or loamy clay with thin zones of wet, clay-rich, medium-brown silt containing a few small pebbles, coal fragments, or semi-lithified shale fragments; stiff, plastic, moist, brown clay at about 13 feet. More wet at about 13.8, 14, and 18 feet. Many sugary white crystal pods throughout. |
| 27.5—28 feet | Core | Wet, brown-gray-orange-white angular to subrounded gravel and sand in brown loam. |
| 28—28.5 feet | Core | Dry, gray, interbedded silt and shale. |
| 28.5—30 feet | Core | Dry, dark-gray shale. |

### Well D7

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Dry, tan, silty clay. |
| 3 – 8 feet | Surficial drill cuttings | Same material; at 7.5 feet changes to moist silty clay. |
| 8 – 13 feet | Surficial drill cuttings | Very easy drilling; water at 9–10 feet; saturated silty clay and fine sand. |
| 13 – 18 feet | Surficial drill cuttings | Same material. |
| 18 – 23 feet | Surficial drill cuttings | Saturated silty clay and fine-grained sand. |

**Table II.2.** Lithologic descriptions for U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

**Well D8**

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 2.5 feet | Surficial drill cuttings | Tan, dry, silty clay. |
| 2.5 – 7.5 feet | Surficial drill cuttings | A little moist at 6.5 feet; turning to a black silty clay. |
| 7.5 – 12.5 feet | Surficial drill cuttings | Water at 8–8.5 feet water; saturated fine silty clay and sand. |
| 12.5 – 17.5 feet | Surficial drill cuttings | Saturated silty clay to fine sand. |
| 17.5 – 22 feet | Surficial drill cuttings | Same material. |

**Well D9**

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Moist topsoil of silty clay. |
| 3 – 8 feet | Surficial drill cuttings | Drier silty clay. |
| 8 – 13 feet | Surficial drill cuttings | More fine sand and clay, less silt; moist at 8.5 feet. |
| 13 – 18 feet | Surficial drill cuttings | Same material as above. |
| 18 – 33 feet | Surficial drill cuttings | Less clay; finer sand. |
| 33 – 43 feet | Surficial drill cuttings | Fine sand, little clay. |
| 43 – 48 feet | Surficial drill cuttings | Tighter at 45 feet; hard, fine, sandy clay. |
| 48 – 53 feet | Surficial drill cuttings | Moist, fine sand. |
| 53 – 58 feet | Surficial drill cuttings | Water at 55 feet; wet, fine, silty sand. |
| 58 – 63 feet | Surficial drill cuttings | Harder drilling beginning at 62 feet. |

Test Borehole About 15 Feet Northeast of Well D9

(Description from geologist's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 19 feet | Core | Dry, brown silty loam or very fine-grained sand with some thin clay-rich zones. |
| 19 – 24 feet | Core | Damp, brown clayey loam containing a few small sandstone pebbles at the top and grading downward into more clay. Semi-lithified clay at about 24 feet. |
| 24 – 48.5 feet | Core | Damp, brown clayey loam or loamy silt containing tiny coal fragments and thin coal layers at 32–34 feet. Some sugary white crystal pods at 29 feet. Some semi-lithified sandstone pebbles at about 36 and 48 feet. Generally more sandy at about 48 feet. Outside of core barrel wet from 27.5–28.5 foot interval. |
| 48.5 – 53.5 feet | | Damp, brown, fine-grained sand and silt grade into gray silt that contains many large smears of black at 50–51 feet and orange at 51.5–53.5 feet. Contains large, hard, sub-angular siltstone fragments and softer rounded sandstone fragments. |
| 53.5 – 57.5 feet | Core | Damp, soft, loamy sand with sandstone pebbles at 54–55 feet. Colors are gray, brown, yellow, black, and orange in a striped or smeared pattern. |
| 57.5 – 60.5 feet | Core | Dry, crumbly, interbedded silt, clay, and shale. Colors are gray, brown, yellow, black, and orange in a striped pattern. |

**Table II.2.** Lithologic descriptions for U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

### Well D10

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Dry; tannish silty clay. |
| 3 – 8 feet | Surficial drill cuttings | Same material; very soft, moist, silty clay at 6 feet; water at 7 – 7.5 feet. |
| 8 – 13 feet | Surficial drill cuttings | Saturated fine sandy silt. |
| 13 – 18 feet | Surficial drill cuttings | Saturated fine sandy silt. |

### Well D11

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Powdery, light-brown, silty clay. |
| 3 – 8 feet | Surficial drill cuttings | No change; same material, but a little tighter and harder at 6 feet. |
| 8 – 13 feet | Surficial drill cuttings | A little moist; silty clay at 11 feet. |
| 13 – 13.5 feet | Surficial drill cuttings | Hard drilling at 13 feet. |

### Well D11a

(Description from geologist's notes; <, less than; %, percent)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 35 feet | Air rotary cuttings | Fine-grained, beige, friable, calcareous quartz sandstone with few small (<1/4 inch) iron concretions; calcareous bioturbations. |
| 35 – 75 feet | Air rotary cuttings | Fine-grained sandstone (same as above) with 20 – 80% clay in drill cuttings; brown. |
| 75 – 100 feet | Air rotary cuttings | Fine-grained, soft, beige, friable, sandstone and silt. |
| 100 – 120 feet | Air rotary cuttings | Beige to orange, soft, friable sandstone; water near 120 feet. |
| 120 – 140 feet | Air rotary cuttings | Gray to dark-gray shale with some tiny anhedral pyrite crystals near 125 feet; denser shale at 134 – 140 feet. |

### Well D12

Windmill well drilled by landowners before 1993: U.S. Geological Survey pulled pump and cables from this well in 1993 before sampling. No lithologic information available.

### Well D13

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Silty, powdery clay; moist at 1.5 feet with black and dark-brown fine sand; light-gray fine sand at 3 feet. |
| 3 – 8 feet | Surficial drill cuttings | Saturated, fine-grained sand; water at 4.5 to 5 feet. |
| 8 – 15 feet | Surficial drill cuttings | Same material as above. |

**Table II.2.** Lithologic descriptions for U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

### Well D14

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Dry, fine, silty sand. |
| 3 – 8 feet | Surficial drill cuttings | Trace of clay at 3.5 feet; moist at 5 feet; more silty clay at 6 feet, then sandy clay. |
| 8 – 13 feet | Surficial drill cuttings | Saturated fine sand; water table at 10 – 11 feet. |
| 13 – 18 feet | Surficial drill cuttings | Same material. |
| 18 – 23 feet | Surficial drill cuttings | No change; saturated fine sand. |

### Well D15

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Dark-brown, silty sand; moist at 1 feet; dark clay at 1.5 feet; hard dry clay at 2 feet; moist clay at 3 feet. |
| 3 – 8 feet | Surficial drill cuttings | Moist, silty clay; dark brown clay at 4 feet. |
| 8 – 13 feet | Surficial drill cuttings | Medium-brown silty clay; water table at 12 – 13 feet. |
| 13 – 18 feet | Surficial drill cuttings | Saturated, dark-gray silty sand with little clay. |
| 18 – 23 feet | Surficial drill cuttings | Same material. |

### Well D16

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Dry, silty clay balls; moist at 3 feet. |
| 3 – 8 feet | Surficial drill cuttings | Very moist clay; silty at 5 feet with a little perched-water zone. |
| 8 – 13 feet | Surficial drill cuttings | Medium-brown silty clay with a hard clay bed at 9.5 feet. |
| 13 – 18 feet | Surficial drill cuttings | Saturated, fine-grained sand; water at 13 feet. |
| 18 – 23 feet | Surficial drill cuttings | Wet, fine-grained sand; trace of clay lenses. |

### Well D17

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Black silty sand; more clay at 1.5 feet grading into light-brown fine sand at 2 feet. |
| 3 – 8 feet | Surficial drill cuttings | Trace of gravel at 6.5 feet; moist, fine sand from 7–7.5 feet. |
| 8 – 13 feet | Surficial drill cuttings | Saturated, fine-grained sand; water at 10 feet. |
| 13 – 20 feet | Surficial drill cuttings | Same material as above. |

**Table II.2.** Lithologic descriptions for U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

### Well D18

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Dry, silty, clay balls. |
| 3 – 8 feet | Surficial drill cuttings | Fragments of yellow sandstone at 4 – 6 feet; very thin layers. |
| 8 – 12.5 feet | Surficial drill cuttings | Tighter at 10 feet; medium brown clay getting moist at 11.5 feet; hard drilling at 12 feet. |

### Well D19

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Black fine-grained sand; trace of clay at 2 feet; light-brown sand at 2.5 feet. |
| 3 – 8 feet | Surficial drill cuttings | Same material as above; moist at 8 feet. |
| 8 – 13 feet | Surficial drill cuttings | Trace of gravel at 8.5 feet; black stringer of fine-grained sand at about 11–12 feet, then back to light brown fine sand. |
| 13 – 18 feet | Surficial drill cuttings | Clay bed at 14 feet; dark silty clay balls. |
| 18 – 23 feet | Surficial drill cuttings | Saturated fine sand; water at 17–18 feet. |
| 23 – 28 feet | Surficial drill cuttings | Same material as above. |

### Well D20

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Medium-brown silty sand to dark-brown sand; clay balls at 2 feet. |
| 3 – 8 feet | Surficial drill cuttings | Moist, silty, sandy clay at 3.5 feet; a trace of gravel at 5 feet; very soft gray clay at about 8 feet. |
| 8 – 13 feet | Surficial drill cuttings | Saturated sand with a little gravel; water at 9 – 10 feet; same material. |
| 13 – 20 feet | Surficial drill cuttings | Silty sand with a little gravel; saturated. |

### Well D21

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Silty powdery clay and sand. |
| 3 – 8 feet | Surficial drill cuttings | Light-brown fine-grained sand with clay; moist clay and a trace of gravel at 6 feet; very moist at 7 feet. |
| 8 – 13 feet | Surficial drill cuttings | Gray silty sand with water at 8–8.5 feet; saturated fine sand at 10 feet. |
| 13 – 18 feet | Surficial drill cuttings | Stringers of clay and sand; black organics at 15–18 feet (black as coal) which have no smell. |

**Table II.2.** Lithologic descriptions for U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

### Well D22

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Medium-brown silty sand; light tan silt. |
| 3 – 8 feet | Surficial drill cuttings | Gravel at 5 feet; moist silty clay at 7 feet. |
| 8 – 13 feet | Surficial drill cuttings | Moist, dark-brown silty clay; trace of gravel at 11.5–12 feet. |
| 13 – 18 feet | Surficial drill cuttings | Medium-brown clay. |
| 18 – 23 feet | Surficial drill cuttings | Silty clay and fine-grained sand; gravel at 19 feet. |
| 23 – 28 feet | Surficial drill cuttings | Fine sand and clay getting drier and tighter. |
| 28 – 33 feet | Surficial drill cuttings | Very dark-gray to black, dry clay. |
| 33 – 37 feet | Surficial drill cuttings | Hard drilling at 37 feet. |

### Well D23

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Hard, dry, silty clay; moist silty clay at 2 feet. |
| 3 – 8 feet | Surficial drill cuttings | Moist, dark-gray silty clay. |
| 8 – 13.5 feet | Surficial drill cuttings | Silty, sandy clay; water at 8.5 – 9 feet. |

### Well D24

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Sandy silt. |
| 3 – 41 feet | Surficial drill cuttings | Sandy clay. |
| 41 – 58 feet | Surficial drill cuttings | Clayey sand. |

### Well D25

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3.5 feet | Surficial drill cuttings | Sandy silt. |
| 3.5 – 23 feet | Surficial drill cuttings | Clayey sand; water at 15 feet. |

### Test Borehole About 15 Feet South of Well D25

(Description from geologist's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 7 feet | Core | Damp, medium-brown, silty loam with some fine-grained sand grains; more clay at about 1 foot and 5–6 feet. |
| 7—8.5 feet | Core | Wet, dark-brown loamy clay with some grains of coarse sand becoming drier and more mottled after about 7.5 feet. |

**Table II.2.** Lithologic descriptions for U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

### Test Borehole About 15 Feet South of Well D25—Continued

(Description from geologist's notes)

| | | |
|---|---|---|
| 8.5—14 feet | Core | Damp, brown clayey loam with thin zones of wet, clay-rich, medium-brown silt containing a few small pebbles, coal fragments, or semi-lithified shale fragments. |
| 14—19.8 feet | Core | Wet, medium-brown clay loam grading downward into loamy sand that contains angular and sub-angular rock fragments. |
| 19.8—23.5 feet | Core | Damp, gray, well-sorted fine-grained sand and silt having distinct orange horizontal banding. |

### Well D26

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 12 feet | Surficial drill cuttings | Sandy silt. |
| 12 – 42 feet | Surficial drill cuttings | Clayey sand. |

### Well D27

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 6 feet | Surficial drill cuttings | Sandy silt. |
| 6 – 23 feet | Surficial drill cuttings | Clayey sand. |

### Well D28

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 5 feet | Surficial drill cuttings | Sandy silt. |
| 5 – 28 feet | Surficial drill cuttings | Clayey sand. |

### Well D29

(Description from geologist's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 5 feet | Air rotary cuttings | Uniform brown sandy loam. |
| 5 – 15 feet | Air rotary cuttings | Brown, fine-grained loamy sand with soft chunks of friable, beige sandstone. |
| 15 – 25 feet | Air rotary cuttings | Beige, fine-grained, friable sandstone; calcareous with chunks of bioturbated sandstone near 15 feet and brownish-orange lithified sandstone near 20 feet. |
| 25 – 30 feet | Air rotary cuttings | Hard, dark, gray-brown shale. |
| 30 – 75 feet | Air rotary cuttings | Interbedded beige, soft, friable sandstone with orange-brown and harder red-brown sandstone; friable dark brown shale from 35–38 feet. |
| 75 – 85 feet | Air rotary cuttings | Black friable shale and gray clay. |

**Table II.2.** Lithologic descriptions for U.S. Geological Survey monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

### Well D29—Continued

(Description from geologist's notes)

| | | |
|---|---|---|
| 85 – 125 feet | Air rotary cuttings | Inter-bedded beige friable sandstone and gray clay with shale fragments. |
| 125 – 153 feet | Air rotary cuttings | Inter-bedded soft, orange, silty sandstone with gray clay and gray-black shale; formation has water somewhere in this zone. |
| 153 – 180 feet | Air rotary cuttings | Gray-black shale. |

### Well D30

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 1 feet | Surficial drill cuttings | Sandy silt. |
| 1 – 9 feet | Surficial drill cuttings | Clayey sand; wet at 8 feet. |
| 9 – 19 feet | Surficial drill cuttings | Sandy clay. |

### Well D31

(Description from geologist's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 4.5 feet | Core | Dark-brown, clay loam with angular sand grains; some bedding and sub-angular to rounded grains near 4.5 feet. |
| 4.5 – 9 feet | Core | Water at 8.5–9 feet; medium-brown clay loam with some black organic-rich streaks; no strong sulfide smell; fairly well-sorted; anhedral gypsum. |
| 9 – 14 feet | Core | Wet, clay-rich, medium-brown silty loam; black reducing organics; some sub-angular granitic sand grains and rounded pebbles from 12-14 feet. |
| 14 – 19 feet | Core | Wet, medium-brown clay loam with angular sand fragments to loamy sand. |
| 19 – 24 feet | Core | Wet, medium-brown clay loam with pebbles grading into dry gray and black clay. |

### Well D32

(Description from driller's notes)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 3 feet | Surficial drill cuttings | Sandy silt |
| 3 – 21 feet | Surficial drill cuttings | Clay |
| 21 – 38 feet | Surficial drill cuttings | Clayey sand |

### Well D33

(Description from geologist's notes; <, less than)

| Depth Below Land Surface | Source | Description of Material |
|---|---|---|
| 0 – 4 feet | Core | Dry, medium-brown sandy loam with abundant white roots at surface and coarse sand at about 1 foot. |
| 4 – 8 feet | Core | Dry, dark-gray, fine-grained sandy loam with some hard clay. |
| 8 – 13 feet | Core | Dry, light-brown clay loam with thin (<1 inch) sandy beds interlayered; fine-grained sandy loam with sub-angular grains; wet granitic sands at 12-13 feet. |
| 13 – 18 feet | Core | Wet, medium-brown sandy loam; sub-angular granitic grains and clay-rich zones with black organic debris. |
| 18 – 23 feet | Core | Very wet, fine-grained clay-rich silty loam. |

**Table II.3** Monthly water-level and precipitation data for monitoring wells near Deer Trail, Colorado, 1993–98.

[Date includes time of measurement if that information is available and is of the format *month/day/year military time*; ft. bmp, feet below measuring point; Precip., monthly precipitation as measured in a plastic collection-type gage; --, not measured]

| Well D1 | | Well D2 | | | Well D3 | | Well D4 | | Well D5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Precip., inches | Date | Water Level, ft.bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp |
| | | | | | 9/28/93 | 40.00 | 9/28/93 | 27.00 | 10/1/93 | 7.40 |
| 10/4/94 1220 | dry | 10/4/94 1418 | 12.93 | -- | 9/29/94 0930 | 40.13 | 9/29/94 1449 | 27.41 | 10/3/94 1408 | 16.20 |
| 11/25/94 1400 | dry | 11/25/94 1340 | 12.53 | -- | 11/25/94 0815 | 40.19 | 11/25/94 0854 | 27.43 | 11/25/94 1320 | 14.77 |
| 12/12/94 1505 | dry | 12/12/94 1450 | 12.55 | -- | 12/12/94 1105 | 40.16 | 12/12/94 1124 | 27.50 | 12/12/94 1441 | 14.93 |
| 1/30/95 | dry | 1/30/95 | 12.57 | -- | 1/30/95 | 40.14 | 1/30/95 | 27.55 | 1/30/95 | 15.26 |
| 3/20/95 | dry | 3/20/95 | 12.44 | -- | 3/20/95 | 40.16 | 3/20/95 | 27.61 | 3/20/95 | 15.28 |
| 4/11/95 | dry | 5/1/95 | 12.42 | -- | 4/11/95 | 40.15 | 4/11/95 | 27.60 | 4/11/95 | 15.28 |
| 5/1/95 | -- | 5/1/95 | 12.42 | -- | 5/1/95 | 40.17 | 5/1/95 | 27.66 | 5/1/95 | 15.39 |
| 6/22/95 | -- | 6/22/95 | -- | -- | 6/22/95 | -- | 6/22/95 | 27.35 | 6/22/95 | -- |
| 7/12/95 | -- | 7/12/95 | -- | -- | 7/12/95 | -- | 7/12/95 | 27.25 | 7/12/95 | -- |
| 9/20/95 | -- | 9/27/95 1400 | 12.98 | -- | 9/20/95 0930 | 40.25 | 9/22/95 1300 | 27.30 | 9/27/95 1111 | 14.37 |
| 10/30/95 1259 | dry | 10/30/95 1154 | 12.71 | -- | 10/30/95 0840 | 40.20 | 10/30/95 0922 | 27.34 | 10/30/95 1121 | 14.51 |
| 11/30/95 1457 | dry | 11/30/95 1537 | 12.52 | -- | 11/30/95 0745 | 40.17 | 11/30/95 0910 | 27.32 | 11/30/95 1409 | 14.73 |
| 12/13/95 | dry | 12/13/95 1135 | 12.75 | -- | 12/14/95 1308 | 40.16 | 12/13/95 1350 | 27.35 | 12/13/96 | -- |
| 1/25/96 1135 | dry | 1/25/96 1150 | 12.50 | -- | 1/25/96 1425 | 40.12 | 1/25/96 1450 | 27.36 | 1/25/96 1220 | 15.04 |
| 2/6/96 1435 | dry | 2/6/96 1446 | 12.46 | -- | 2/6/96 1205 | 40.17 | 2/6/96 1140 | 27.42 | 2/6/96 1505 | 15.11 |
| 2/21/96 0734 | -- | 2/22/96 0756 | 12.54 | -- | 2/21/96 0734 | 40.17 | 2/21/96 0833 | 27.46 | 2/22/96 1040 | 15.19 |
| 3/5/96 | -- | 3/7/96 1235 | 12.56 | -- | 3/6/96 1215 | 40.18 | 3/6/96 1020 | 27.55 | 3/8/96 0808 | 15.31 |
| 4/4/96 0945 | dry | 4/4/96 0955 | 12.47 | -- | 4/4/96 1210 | 40.17 | 4/4/96 1225 | 27.54 | 4/4/96 1005 | 15.39 |
| 5/2/96 | dry | 5/2/96 | 12.28 | -- | 5/2/96 | 40.19 | 5/2/96 | 27.48 | 5/2/96 | 15.31 |
| 6/13/96 | -- | 6/12/96 0808 | 12.44 | 2.75 | 6/13/96 1242 | 40.21 | 6/14/96 0815 | 27.57 | 6/13/96 1305 | 15.50 |
| 7/3/96 1005 | dry | 7/3/96 1036 | 12.27 | 2.2 | 7/3/96 1350 | 40.22 | 7/3/96 | -- | 7/3/96 1105 | 15.59 |
| 8/7/96 | -- | 8/7/96 1617 | 11.33 | 4.98 | 8/7/96 1430 | 40.23 | 8/7/96 1415 | -- | 8/7/96 1750 | -- |
| 8/21/96 | -- | 8/21/96 1356 | 11.43 | -- | 8/21/96 | -- | 8/20/96 | -- | 8/22/96 1110 | 15.19 |
| 9/11/96 1015 | dry | 9/11/96 1035 | 11.49 | 2.05 | 9/11/96 | -- | 9/11/96 | -- | 9/11/96 1110 | 15.03 |
| 10/3/96 | -- | 10/3/96 0810 | 11.67 | 1.9 | 10/3/96 | -- | 10/3/96 | -- | 10/3/96 1105 | 14.90 |
| 11/7/96 | -- | 11/7/96 1105 | 11.76 | 0.26 | 11/8/96 | -- | 11/8/96 | -- | 11/8/96 900 | 15.02 |

**Table II.3** Monthly water-level and precipitation data for monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

[Date includes time of measurement if that information is available and is of the format *month/day/year military time*; ft. bmp, feet below measuring point; Precip., monthly precipitation as measured in a plastic collection-type gage; --, not measured]

| Well D1 | | Well D2 | | | Well D3 | | Well D4 | | Well D5 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Precip., inches | Date | Water Level, ft.bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp |
| 12/3/96 915 | dry | 12/3/96 950 | 11.90 | -- | 12/3/96 1205 | 40.07 | 12/3/96 1242 | 27.08 | 12/3/96 1027 | 15.09 |
| 1/7/97 942 | dry | 1/7/97 1002 | 11.80 | -- | 1/7/97 1157 | 40.01 | 1/7/97 1247 | 27.03 | 1/7/97 1049 | 15.16 |
| 2/4/97 1118 | dry | 2/4/97 1023 | 11.81 | 0.07 | 2/4/97 1249 | 39.98 | 2/4/1997 1537 | 27.09 | 2/4/97 1136 | 15.36 |
| 3/6/97 941 | dry | 3/6/97 1000 | 11.82 | 0.19 | 3/6/97 1448 | 39.95 | 3/6/97 1127 | 27.08 | 3/6/97 1031 | 15.43 |
| 4/7/97 1135 | dry | 4/7/97 1117 | 11.91 | 0.27 | 4/7/97 1235 | 39.93 | 4/7/97 1410 | 27.08 | 4/8/97 1221 | 15.55 |
| 5/8/97 1059 | -- | 5/8/97 1059 | 12.08 | 0.46 | 5/8/97 1352 | 39.91 | 5/8/97 1300 | 27.15 | 5/8/97 1122 | 15.65 |
| 6/3/97 0758 | -- | 6/3/97 0758 | 12.20 | 1.50 | 6/3/97 1348 | 39.82 | 6/3/97 1308 | 27.09 | 6/2/97 1302 | 15.67 |
| 7/2/97 0913 | dry | 7/2/97 0846 | 11.98 | 2.9 | 7/2/97 1525 | 39.67 | 7/2/97 1135 | 27.04 | 7/2/97 0941 | 15.64 |
| 8/7/97 1300 | -- | 8/7/97 1300 | 11.88 | 4.9 | 8/7/97 1625 | 39.66 | 8/7/97 1200 | -- | 8/7/97 1200 | -- |
| 8/27/97 0833 | -- | 8/27/97 0833 | 11.87 | 1.59 | 8/25/97 0815 | 39.76 | 8/26/97 1025 | 26.84 | 8/26/97 0822 | 15.58 |
| 10/02/97 1003 | -- | 10/02/97 1003 | 12.32 | 1.05 | 10/02/97 1405 | 39.76 | 10/02/97 1320 | 26.10 | 10/02/97 1041 | 15.30 |
| 11/19/97 0815 | -- | 11/19/97 0815 | 11.86 | 0.45 | 11/17/97 1235 | 39.70 | 11/17/97 0800 | -- | 11/18/97 1310 | 15.35 |
| 12/17/97 1015 | dry | 12/17/97 1031 | 11.88 | 0.14 | 12/17/97 1216 | 39.42 | 12/17/97 1350 | 26.18 | 12/17/97 1113 | 15.46 |
| 1/8/98 1504 | dry | 1/07/98 1025 | 11.86 | -- | 1/6/98 1207 | 39.71 | 1/6/98 1200 | -- | 1/8/98 1257 | 15.42 |
| 2/12/98 0826 | dry | 2/12/98 0854 | 11.88 | -- | 2/12/98 1130 | 39.67 | 2/12/98 1243 | 26.36 | 2/12/98 0944 | 15.65 |
| 3/4/98 0719 | dry | 3/4/98 0739 | 11.78 | -- | 3/4/98 1102 | 39.64 | 3/4/98 1206 | 26.38 | 3/4/98 0937 | 15.65 |
| 4/14/98 1200 | -- | 4/14/98 1040 | 11.70 | -- | 4/16/98 0724 | 39.63 | 4/16/98 1200 | -- | 4/15/98 1038 | 15.72 |
| 5/5/98 1656 | -- | 5/5/98 1656 | 11.82 | 0.11 | 5/5/98 1727 | 39.58 | 5/5/98 1146 | 26.47 | 5/5/98 1610 | 15.73 |
| 6/11/98 0855 | -- | 6/11/98 0855 | 12.38 | 0.62 | 6/11/98 1644 | 39.55 | 6/11/98 1402 | 26.50 | 6/11/98 1204 | 15.84 |
| 7/16/98 0830 | -- | 7/16/98 0830 | 12.96 | 0.6 | 7/16/98 1200 | -- | 7/15/98 1200 | -- | 7/15/98 1247 | 15.99 |
| 8/4/98 0843 | -- | 8/4/98 0843 | 11.86 | 4.45 | 8/4/98 1045 | 39.51 | 8/4/98 1119 | 26.64 | 8/4/98 0905 | 15.35 |
| 9/1/98 0940 | -- | 9/1/98 0940 | 11.99 | -- | 9/1/98 1115 | 39.49 | 9/1/98 1136 | 26.60 | 9/1/98 1012 | 15.29 |
| 10/1/98 1037 | dry | 10/1/98 1056 | 12.17 | 0.75 | 10/1/98 1453 | 39.47 | 10/1/98 1200 | -- | 10/1/98 1200 | -- |
| | | Min | 11.33 | | Min | 39.42 | Min | 26.10 | Min | 7.40 |
| | | Median | 12.17 | | Median | 40.04 | Median | 27.30 | Median | 15.35 |
| | | Max | 12.98 | | Max | 40.25 | Max | 27.66 | Max | 16.20 |

**Table II.3** Monthly water-level and precipitation data for monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

[Date includes time of measurement if that information is available and is of the format *month/day/year time*; ft. bmp, feet below measuring point; Precip., monthly precipitation as measured in a plastic collection-type gage; --, not measured]

| Well D6 | | Well D7 | | Well D8 | | Well D9 | | Well D10 | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp |
| 10/1/93 | 8.10 | 9/28/93 | 13.00 | 9/28/93 | 9.00 | 10/5/93 | 58.00 | 10/1/93 | 11.94 |
| 10/3/94 1735 | 9.90 | 9/29/94 1607 | 13.29 | 9/29/94 1212 | 10.96 | 10/4/94 0950 | 57.91 | 10/3/94 1605 | 11.95 |
| 11/25/94 1314 | 9.16 | 11/25/94 0900 | 13.40 | 11/25/94 0845 | 10.61 | 11/25/94 1430 | 57.49 | 11/25/94 1259 | 11.85 |
| 12/12/94 1428 | 9.26 | 12/12/94 1138 | 13.42 | 12/12/94 1115 | 10.64 | 12/12/94 1527 | 57.52 | 12/12/94 1416 | 11.89 |
| 1/30/95 | 9.43 | 1/30/95 | 13.42 | 1/30/95 | 10.65 | 1/30/95 | 57.63 | 1/30/95 | 11.95 |
| 3/20/95 | 9.30 | 3/20/95 | 13.38 | 3/20/95 | 10.65 | 3/20/95 | 57.72 | 3/20/95 | 11.90 |
| 4/11/95 | 9.30 | 4/11/95 | 13.38 | 4/11/95 | 10.60 | 4/11/95 | 57.72 | 4/11/95 | 11.86 |
| 5/1/95 | 9.00 | 5/1/95 | 13.27 | 5/1/95 | 10.66 | 5/1/95 | 57.80 | 5/1/95 | 11.77 |
| 6/22/95 | -- | 6/22/95 | 12.82 | 6/22/95 | 10.34 | 6/22/95 | 57.46 | 6/22/95 | -- |
| 7/12/95 | -- | 7/12/95 | 12.67 | 7/12/95 | 10.47 | 7/12/95 | -- | 7/12/95 | -- |
| 9/20/95 1430 | 8.63 | 9/22/95 | -- | 9/22/95 1100 | 10.74 | 9/28/95 1305 | 56.76 | 9/27/95 1003 | 11.76 |
| 10/30/95 1039 | 9.02 | 10/30/95 | -- | 10/30/95 0914 | 10.53 | 10/30/95 1311 | 56.83 | 10/30/95 1023 | 11.81 |
| 11/30/95 1420 | 9.13 | 11/30/95 | -- | 11/30/95 0845 | 10.56 | 11/30/95 1707 | 56.88 | 11/30/95 1400 | 11.80 |
| 12/13/95 1120 | 9.20 | 12/13/95 | -- | 12/13/95 1102 | 10.59 | 12/15/95 1505 | 56.93 | 12/12/95 1310 | 11.79 |
| 1/25/96 1040 | 9.37 | 1/25/96 | -- | 1/25/96 1445 | 10.57 | 1/25/96 1410 | 57.01 | 1/25/96 1010 | 11.84 |
| 2/6/96 1405 | 9.33 | 2/7/96 0935 | 12.51 | 2/6/96 1135 | 10.61 | 2/6/96 1220 | 57.06 | 2/6/96 1345 | 11.83 |
| 2/22/96 0916 | 9.43 | 2/21/96 | -- | 2/21/96 0818 | 10.59 | 2/22/96 1105 | 57.05 | 2/22/96 1017 | 11.86 |
| 3/7/96 1105 | 9.60 | 3/5/96 | -- | 3/5/96 0815 | 10.58 | 3/7/96 0745 | 57.19 | 3/8/96 1015 | 11.82 |
| 4/4/96 1035 | 9.35 | 4/4/96 1255 | 12.53 | 4/4/96 1220 | 10.47 | 4/4/96 0915 | 57.24 | 4/4/96 1025 | 11.83 |
| 5/2/96 | 8.57 | 5/2/96 | -- | 5/2/96 | 10.44 | 5/2/96 | 57.25 | 5/2/96 | 11.80 |
| 6/11/96 1105 | 8.24 | 6/13/96 | -- | 6/11/96 0907 | 10.63 | 6/14/96 0822 | 57.40 | 6/12/96 1225 | 11.80 |
| 7/3/96 1115 | 8.42 | 7/3/96 | -- | 7/3/96 | -- | 7/3/96 0935 | 57.40 | 7/3/96 1220 | 11.83 |
| 8/7/96 1649 | 7.49 | 8/7/96 1322 | 11.92 | 8/7/96 1415 | -- | 8/7/96 1740 | 57.48 | 8/7/96 1752 | 11.79 |
| 8/22/96 0830 | 7.78 | 8/20/96 0900 | 12.09 | 8/20/96 | -- | 8/21/96 0800 | 57.47 | 8/22/96 1000 | 11.70 |
| 9/11/96 1055 | 7.33 | 9/11/96 1555 | 12.00 | 9/11/96 1605 | 8.58 | 9/11/96 0955 | 57.55 | 9/11/96 1100 | 11.54 |
| 10/3/96 0957 | 7.44 | 10/4/96 1141 | 11.84 | 10/3/96 | -- | 10/3/96 1135 | 57.53 | 10/3/96 1049 | 11.45 |
| 11/7/96 1245 | 7.90 | 11/7/96 1011 | 11.73 | 11/7/96 | -- | 11/6/96 1425 | 57.52 | 11/7/96 1410 | 11.48 |

**Table II.3** Monthly water-level and precipitation data for monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

[Date includes time of measurement if that information is available and is of the format *month/day/year time*; ft. bmp, feet below measuring point; Precip., monthly precipitation as measured in a plastic collection-type gage; --, not measured]

| Well D6 | | Well D7 | | Well D8 | | Well D9 | | Well D10 | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp |
| 12/3/96 1043 | 8.25 | 12/3/96 1438 | 11.68 | 12/3/96 1222 | 9.10 | 12/3/96 1147 | 57.58 | 12/3/96 1032 | 11.46 |
| 1/7/97 1035 | 8.40 | 1/7/97 1222 | 11.72 | 1/7/97 1228 | 9.15 | 1/7/97 930 | 57.62 | 1/7/97 1041 | 11.50 |
| 2/4/97 1124 | 8.54 | 2/4/97 1516 | 11.79 | 2/4/97 1523 | 9.09 | 2/4/97 1238 | 57.65 | 2/4/97 1129 | 11.49 |
| 3/6/97 1049 | 8.49 | 3/6/97 1155 | 11.84 | 3/6/97 1134 | 9.20 | 3/6/97 922 | 57.48 | 3/6/97 1036 | 11.52 |
| 4/8/97 1159 | 8.56 | 4/7/97 1354 | 11.87 | 4/7/97 1420 | 9.32 | 4/8/97 1237 | 57.55 | 4/8/97 1210 | 11.53 |
| 5/8/97 1139 | 8.69 | 5/8/97 1604 | 11.90 | 5/8/97 1309 | 9.46 | 5/8/97 1027 | 57.62 | 5/8/97 1128 | 11.53 |
| 6/2/97 1315 | 8.68 | 6/3/97 0823 | 11.92 | 6/3/97 1200 | -- | 6/3/97 1151 | 57.58 | 6/2/97 1324 | 11.51 |
| 7/2/97 1008 | 8.00 | 7/2/97 1200 | -- | 7/2/97 1200 | -- | 7/2/97 1057 | 57.62 | 7/2/97 1021 | 11.57 |
| 8/7/97 1400 | 7.25 | 8/7/97 1200 | -- | 8/7/97 1200 | -- | 8/7/97 1450 | 57.58 | 8/7/97 1200 | -- |
| 8/27/97 1240 | 6.39 | 8/27/97 1200 | -- | 8/27/97 1200 | -- | 8/25/97 1150 | 57.63 | 8/26/97 0943 | 11.19 |
| 10/02/97 1053 | 6.30 | 10/2/97 1200 | -- | 10/02/97 1421 | 9.10 | 10/02/97 0921 | 57.66 | 10/02/97 1107 | 11.09 |
| 11/19/97 1240 | 6.77 | 11/18/97 0900 | -- | 11/19/97 0753 | 8.66 | 11/17/97 0805 | 57.57 | 11/18/97 1030 | 10.98 |
| 12/17/97 1103 | 7.04 | 12/17/97 1345 | 10.89 | 12/17/97 1227 | 8.63 | 12/17/97 0955 | 57.59 | 12/17/97 1147 | 11.02 |
| 1/07/98 1205 | 6.84 | 1/7/98 1200 | -- | 1/07/98 1225 | 8.53 | 1/06/98 0850 | -- | 1/8/98 1440 | 10.96 |
| 2/12/98 0930 | 7.05 | 2/12/98 1322 | 10.95 | 2/12/98 1151 | 8.61 | 2/12/98 1111 | 57.59 | 2/12/98 0951 | 10.99 |
| 3/4/98 0832 | 6.41 | 3/4/98 1141 | 10.98 | 3/4/98 1115 | 8.54 | 3/4/98 1045 | 57.54 | 3/4/98 0923 | 10.97 |
| 4/15/98 1043 | 5.86 | 4/15/98 1200 | | 4/14/98 1107 | 8.34 | 4/15/98 0715 | 57.57 | 4/15/98 0916 | 10.87 |
| 5/5/98 1616 | 6.29 | 5/5/98 1205 | 11.04 | 5/5/98 1246 | 8.55 | 5/5/98 1714 | 57.53 | 5/5/98 1546 | 10.87 |
| 6/11/98 0949 | 7.19 | 6/11/98 1437 | 11.40 | 6/11/98 1437 | 11.40 | 6/11/98 1222 | 57.55 | 6/11/98 1149 | 10.88 |
| 7/16/98 1033 | 8.04 | 7/16/98 1200 | -- | 7/15/98 1118 | 9.91 | 7/16/98 1224 | 57.59 | 7/15/98 1415 | 10.88 |
| 8/4/98 0920 | 6.70 | 8/4/98 1241 | 11.10 | 8/4/98 1107 | 8.41 | 8/4/98 1032 | 57.61 | 8/4/98 0909 | 10.60 |
| 9/1/98 1027 | 7.05 | 9/1/98 1202 | 10.87 | 9/1/98 1122 | 8.90 | 9/1/98 0928 | 57.59 | 9/1/98 1016 | 10.56 |
| 10/1/98 0851 | 7.55 | 10/1/98 1538 | 10.80 | 10/1/98 1200 | -- | 10/1/98 1200 | -- | 10/1/98 1000 | 10.60 |
| Min | 5.86 | Min | 10.80 | Min | 8.34 | Min | 56.76 | Min | 10.56 |
| Median | 8.40 | Median | 11.90 | Median | 10.44 | Median | 57.55 | Median | 11.54 |
| Max | 9.90 | Max | 13.42 | Max | 11.40 | Max | 57.91 | Max | 11.95 |

**Table II.3** Monthly water-level and precipitation data for monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

[Date includes time of measurement if that information is available and is of the format *month/day/year time*; ft. bmp, feet below measuring point; Precip., monthly precipitation as measured in a plastic collection-type gage; --, not measured

| Well D11a | | Well D12 | | Well D13 | | Well D14 | | Well D15 | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp |
| (Well 11a not installed until October 1997) | | 10/4/94 1240 | 35.72 | 10/3/94 0930 | 7.15 | 10/3/94 0815 | 12.45 | 9/30/94 0801 | 8.10 |
| | | 11/25/94 1350 | 35.69 | 11/25/94 0959 | 7.18 | 11/25/94 1008 | 12.21 | 11/25/94 1020 | 6.80 |
| | | 12/12/94 1500 | 35.69 | 12/12/94 1158 | 7.18 | 12/12/94 1206 | 12.27 | 12/12/94 1218 | 6.76 |
| | | 1/30/95 | 35.69 | 1/30/95 | 7.12 | 1/30/95 | 12.37 | 1/30/95 | 6.50 |
| | | 3/20/95 | 35.69 | 3/20/95 | 7.01 | 3/20/95 | 12.30 | 3/20/95 | 6.15 |
| | | 4/11/95 | 35.67 | 4/11/95 | 6.95 | 4/11/95 | 12.27 | 4/11/95 | 6.14 |
| | | 5/1/95 | 35.68 | 5/1/95 | 6.82 | 5/4/95 | 12.53 | 5/1/95 | 5.74 |
| | | 6/22/95 | -- | 6/22/95 | | 6/22/95 | 12.29 | 6/22/95 | 4.96 |
| | | 7/12/95 | -- | 7/12/95 | 7.33 | 7/12/95 | 12.14 | 7/12/95 | 5.52 |
| | | 9/20/95 1020 | 35.50 | 9/25/95 1000 | 8.02 | 9/25/95 1100 | 11.39 | 9/25/95 | -- |
| | | 10/30/95 1249 | 35.46 | 10/30/95 1330 | 7.71 | 10/30/95 1337 | 11.44 | 10/30/95 1354 | 6.05 |
| | | 11/30/95 1501 | 35.43 | 11/30/95 1024 | 7.41 | 11/30/95 1039 | 11.45 | 11/30/95 1055 | 5.40 |
| | | 12/12/95 | | 12/13/95 1246 | 7.37 | 12/13/95 1414 | 11.47 | 12/14/95 0845 | 5.38 |
| | | 1/25/96 1125 | 35.40 | 1/25/96 1550 | 7.19 | 1/25/96 1545 | 11.51 | 1/25/96 1400 | 5.21 |
| | | 2/6/96 1430 | 35.42 | 2/6/96 0950 | 7.15 | 2/6/96 0940 | 11.50 | 2/6/96 1005 | 5.42 |
| | | 2/22/96 0839 | 35.45 | 2/21/96 1006 | 7.10 | 2/21/96 1020 | 11.56 | 2/21/96 1040 | 5.21 |
| | | 3/5/96 0855 | 35.43 | 3/6/96 1135 | 7.06 | 3/6/96 0950 | 11.65 | 3/6/96 1308 | 5.10 |
| | | 4/4/96 0940 | 35.44 | 4/4/96 1340 | 6.83 | 4/4/96 1335 | 11.58 | 4/4/96 1350 | 4.52 |
| | | 5/2/96 | 35.46 | 5/2/96 | 6.70 | 5/2/96 | 11.47 | 5/2/96 | 4.44 |
| | | 6/13/96 0820 | 35.46 | 6/13/96 0814 | 6.96 | 6/13/96 | -- | 6/12/96 1421 | 5.00 |
| | | 7/3/96 0958 | 35.49 | 7/3/96 1430 | 6.33 | 7/3/96 1440 | 11.10 | 7/3/96 1450 | 5.51 |
| | | 8/7/96 1530 | 35.45 | 8/7/96 1210 | 5.35 | 8/7/96 1150 | 10.46 | 8/7/96 0830 | 6.39 |
| | | 8/20/96 0855 | 35.46 | 8/20/96 1318 | 5.55 | 8/20/96 1420 | 10.53 | 8/21/96 1337 | 6.62 |
| | | 9/11/96 1010 | 35.43 | 9/11/96 1530 | 5.16 | 9/11/96 1525 | 10.22 | 9/11/96 1515 | 6.32 |
| | | 10/3/96 0910 | 35.42 | 10/4/96 1105 | 5.59 | 10/4/96 1050 | 10.38 | 10/4/96 1032 | 6.30 |
| | | 11/6/96 1200 | 35.39 | 11/7/96 1320 | 5.96 | 11/7/96 1305 | 10.55 | 11/8/96 1434 | 6.27 |

**Table II.3** Monthly water-level and precipitation data for monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

[Date includes time of measurement if that information is available and is of the format *month/day/year time*; ft. bmp, feet below measuring point; Precip., monthly precipitation as measured in a plastic collection-type gage; --, not measured

| Well D11a | | Well D12 | | Well D13 | | Well D14 | | Well D15 | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp |
| | | 12/3/96 910 | 35.37 | 12/3/96 1511 | 5.90 | 12/3/96 1519 | 10.59 | 12/3/96 1528 | 6.05 |
| | | 1/7/97 946 | 35.32 | 1/7/97 1320 | 5.84 | 1/7/97 1316 | 10.68 | 1/7/97 1332 | 5.88 |
| | | 2/4/97 1113 | 35.33 | 2/4/97 1502 | 5.70 | 2/4/97 1451 | 10.88 | 2/4/97 1441 | 5.74 |
| | | 3/6/97 934 | 35.34 | 3/6/97 1425 | 5.69 | 3/6/97 1419 | 10.80 | 3/6/97 1406 | 5.32 |
| | | 4/7/97 1136 | 35.33 | 4/8/97 1013 | 5.84 | 4/8/97 1005 | 10.90 | 4/8/97 1022 | 4.95 |
| | | 5/8/97 1039 | 35.30 | 5/8/97 1431 | 6.12 | 5/8/97 1423 | 10.92 | 5/8/97 1544 | 4.94 |
| | | 6/3/97 1141 | 35.24 | 6/2/97 0916 | 6.55 | 6/2/97 0747 | 10.99 | 6/3/97 1443 | 5.65 |
| | | 7/2/97 0903 | 35.24 | 7/2/97 1445 | 6.98 | 7/2/97 1438 | 10.98 | 7/2/97 1420 | 6.37 |
| | | 8/7/97 1200 | -- | 8/7/97 1200 | -- | 8/7/97 1200 | -- | 8/7/97 1605 | 4.51 |
| | | 8/26/97 1200 | -- | 8/26/97 1200 | -- | 8/25/97 1058 | 11.03 | 8/25/97 1354 | 5.19 |
| | | 10/02/97 0946 | 35.15 | 10/02/97 1502 | 7.09 | 10/02/97 1454 | 10.45 | 10/02/97 1458 | 5.88 |
| | | 11/18/97 1100 | -- | 11/17/97 1034 | 6.38 | 11/17/97 1255 | 10.55 | 11/20/97 0814 | 5.31 |
| 12/17/97 0909 | 112.79 | 12/17/97 1020 | 34.97 | 12/17/97 1435 | 6.22 | 12/17/97 1430 | 10.55 | 12/17/97 1447 | 5.05 |
| 1/8/98 1020 | 112.87 | 1/8/98 1515 | 34.87 | 1/6/98 1300 | 6.04 | 1/6/98 1136 | 10.57 | 1/8/98 1239 | 4.60 |
| 2/12/98 1025 | 113.01 | 2/12/98 0837 | 34.87 | 2/12/98 1340 | 5.93 | 2/12/98 1348 | 10.60 | 2/12/98 1404 | 4.48 |
| 3/4/98 0956 | 112.79 | 3/4/98 0725 | 34.84 | 3/4/98 1244 | 5.70 | 3/4/98 1250 | 10.60 | 3/4/98 1301 | 4.19 |
| 4/13/98 0745 | 113.01 | 4/13/98 1100 | | 4/13/98 1056 | 5.40 | 4/15/98 0713 | 10.55 | 4/14/98 0728 | 3.83 |
| 5/5/98 1336 | 112.78 | 5/5/98 1645 | 34.78 | 5/5/98 1047 | 5.99 | 5/5/98 1057 | 10.46 | 5/5/98 1032 | 4.60 |
| 6/11/98 1255 | 112.85 | 6/11/98 0845 | -- | 6/11/98 1515 | 7.08 | 6/11/98 1523 | 10.50 | 6/11/98 1626 | 5.59 |
| 7/14/98 0852 | 112.87 | 7/14/98 1200 | -- | 7/14/98 0948 | 8.23 | 7/14/98 0754 | 10.78 | 7/16/98 0751 | 6.59 |
| 8/4/98 0945 | 113.04 | 8/4/98 0900 | -- | 8/4/98 1226 | 7.91 | 8/4/98 1220 | 11.01 | 8/4/98 1200 | -- |
| 9/1/98 0841 | 112.97 | 9/1/98 1000 | -- | 9/1/98 1219 | 8.80 | 9/1/98 1214 | 11.49 | 9/1/98 1301 | 5.84 |
| 10/1/98 1409 | 112.80 | 10/1/98 1200 | -- | 10/1/98 1200 | -- | 10/1/98 1200 | -- | 10/1/98 1516 | 6.67 |
| Min | 112.78 | Min | 34.78 | Min | 5.16 | Min | 10.22 | Min | 3.83 |
| Median | 112.87 | Median | 35.43 | Median | 6.83 | Median | 11.00 | Median | 5.52 |
| Max | 113.04 | Max | 35.72 | Max | 8.80 | Max | 12.53 | Max | 8.10 |

**Table II.3** Monthly water-level and precipitation data for monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

[Date includes time of measurement if that information is available and is of the format *month/day/year time*; ft. bmp, feet below measuring point; Precip., monthly precipitation as measured in a plastic collection-type gage; --, not measured]

| Well D16 | | Well D17 | | Well D18 | | Well D19 | | Well D20 | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp |
| 9/30/94 1150 | 8.59 | 9/29/94 1800 | 12.00 | 9/13/94 | dry | 9/30/94 1250 | 22.30 | 9/30/94 1419 | 10.11 |
| 11/25/94 1054 | 7.11 | 11/25/94 1104 | 12.07 | 11/25/94 1040 | dry | 11/25/94 1115 | 22.16 | 11/25/94 1124 | 9.35 |
| 12/12/94 1251 | 7.25 | 12/12/94 1300 | 12.06 | 12/12/94 1244 | dry | 12/12/94 1305 | 22.19 | 12/12/94 1312 | 9.31 |
| 1/30/95 | 7.17 | 1/30/95 | 12.03 | 1/30/95 | dry | 1/30/95 | 22.09 | 1/30/95 | 8.94 |
| 3/20/95 | 7.12 | 3/20/95 | 11.97 | 3/20/95 | dry | 3/20/95 | 22.07 | 3/20/95 | 8.92 |
| 4/11/95 | 7.07 | 4/11/95 | 11.92 | 4/11/95 | dry | 4/11/95 | 22.08 | 4/11/95 | 8.88 |
| 5/1/95 | -- | 5/1/95 | 11.90 | 5/1/95 | dry | 5/1/95 | 22.34 | 5/1/95 | 8.90 |
| 6/22/95 | 5.37 | 6/22/95 | 11.28 | 6/22/95 | dry | 6/22/95 | 22.22 | 6/22/95 | 8.71 |
| 7/12/95 | 6.57 | 7/12/95 | 11.13 | 7/12/95 | -- | 7/12/95 | 22.22 | 7/12/95 | 8.63 |
| 9/26/95 0900 | 7.58 | 9/28/95 1530 | 10.82 | 9/26/95 0824 | dry | 9/26/95 1048 | 22.19 | 9/26/95 1212 | 8.87 |
| 10/30/95 1418 | 7.46 | 10/30/95 1449 | 10.86 | 10/30/95 | dry | 10/30/95 1439 | 22.20 | 10/30/95 1432 | 8.80 |
| 11/30/95 1148 | 6.82 | 11/30/95 1319 | 10.85 | 11/30/95 1140 | dry | 11/30/95 1304 | 22.15 | 11/30/95 1220 | 8.68 |
| 12/14/95 1335 | 7.08 | 12/13/95 | -- | 12/13/95 1135 | dry | 12/12/95 | -- | 12/12/95 1124 | 8.72 |
| 1/25/96 1435 | 7.08 | 1/25/96 1300 | 10.93 | 1/25/96 1135 | dry | 1/25/96 1245 | 22.18 | 1/25/96 1325 | 8.65 |
| 2/6/96 1030 | 7.31 | 2/6/96 1100 | 10.94 | 2/6/96 1050 | dry | 2/6/96 1240 | 22.19 | 2/6/96 1300 | 8.64 |
| 2/21/96 1055 | 7.10 | 2/21/96 | -- | 2/21/96 | -- | 2/21/96 | -- | 2/21/96 1150 | 8.63 |
| 3/7/96 1157 | 7.09 | 3/7/96 | -- | 3/7/96 | -- | 3/7/96 | -- | 3/7/96 1020 | 8.65 |
| 4/4/96 1410 | 6.57 | 4/4/96 1125 | 10.91 | 4/4/96 1405 | dry | 4/4/96 1130 | 22.24 | 4/4/96 1140 | 8.54 |
| 5/2/96 | -- | 5/2/96 | 10.69 | 5/2/96 | -- | 5/2/96 | 22.16 | 5/2/96 | 8.42 |
| 6/12/96 1247 | 5.77 | 6/13/96 | -- | 6/13/96 | -- | 6/13/96 | -- | 6/12/96 1009 | 8.39 |
| 7/3/96 1605 | 7.02 | 7/3/96 1255 | 10.20 | 7/3/96 1555 | dry | 7/3/96 1300 | 22.03 | 7/3/96 1315 | 8.78 |
| 8/7/96 0924 | 8.18 | 8/7/96 1839 | 10.34 | 8/7/96 0945 | -- | 8/7/96 1833 | 21.99 | 8/7/96 0952 | 9.33 |
| 8/21/96 1030 | 8.35 | 8/22/96 0847 | 10.50 | 8/22/96 1240 | -- | 8/22/96 1240 | 21.97 | 8/22/96 1348 | 9.63 |
| 9/11/96 1455 | 8.71 | 9/11/96 1420 | 10.64 | 9/11/96 1510 | dry | 9/11/96 1425 | 21.82 | 9/11/96 1435 | 9.86 |
| 10/4/96 0935 | 8.65 | 10/4/96 0828 | 10.78 | 10/4/96 0840 | -- | 10/4/96 0840 | 21.75 | 10/4/96 0900 | 9.54 |
| 11/8/96 1155 | 8.58 | 11/6/96 855 | 10.85 | 11/6/96 1135 | -- | 11/6/96 1135 | 21.78 | 11/6/96 1309 | 9.31 |

**Table II.3** Monthly water-level and precipitation data for monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

[Date includes time of measurement if that information is available and is of the format *month/day/year time*; ft. bmp, feet below measuring point; Precip., monthly precipitation as measured in a plastic collection-type gage; --, not measured]

| Well D16 | | Well D17 | | Well D18 | | Well D19 | | Well D20 | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp |
| 12/3/96 1547 | 8.38 | 12/3/96 1131 | 10.85 | 12/3/96 1605 | dry | 12/3/96 1127 | 21.79 | 12/3/96 1535 | 9.18 |
| 1/7/97 1351 | 8.27 | 1/7/97 1128 | 10.86 | 1/7/97 1415 | dry | 1/7/97 1125 | 21.82 | 1/7/97 1337 | 9.09 |
| 2/4/97 1430 | 8.08 | 2/4/97 1220 | 10.89 | 2/4/97 1400 | dry | 2/4/97 1217 | 21.87 | 2/4/97 1416 | 9.02 |
| 3/6/97 1314 | 7.84 | 3/6/97 1240 | 10.89 | 3/6/97 1353 | dry | 3/6/97 1237 | 21.91 | 3/6/97 1254 | 8.94 |
| 4/8/97 1056 | 7.78 | 4/8/97 1124 | 10.92 | 4/8/97 1120 | -- | 4/8/97 1120 | 21.95 | 4/8/97 1101 | 8.94 |
| 5/8/97 1450 | 7.77 | 5/8/97 1228 | 10.97 | 5/8/97 1222 | -- | 5/8/97 1222 | 22.00 | 5/8/97 1456 | 8.95 |
| 6/3/97 1418 | 7.76 | 6/3/97 1230 | 11.00 | 6/3/97 1106 | -- | 6/3/97 1106 | 22.02 | 6/3/97 1408 | 8.92 |
| 7/2/97 1355 | 8.27 | 7/2/97 1308 | 11.06 | 7/2/97 | dry | 7/2/97 1300 | 22.00 | 7/2/97 1325 | 9.30 |
| 8/7/97 1200 | -- | 8/7/97 1555 | 11.14 | 8/7/97 1200 | -- | 8/7/97 1200 | -- | 8/7/97 1200 | -- |
| 8/28/97 1200 | -- | 8/25/97 0840 | 10.93 | 8/25/97 1200 | -- | 8/25/97 1200 | -- | 8/25/97 1200 | -- |
| 10/02/97 1551 | 6.57 | 10/02/97 1221 | 10.82 | 10/02/97 1214 | -- | 10/02/97 1214 | 19.45 | 10/02/97 1533 | 9.08 |
| 11/20/97 1005 | 5.86 | 11/17/97 0800 | 10.71 | 11/17/97 0900 | -- | 11/17/97 0900 | -- | 11/20/97 1106 | 8.75 |
| 12/17/97 1508 | 5.76 | 12/17/97 0920 | 10.60 | 12/17/97 0927 | -- | 12/17/97 0927 | 20.19 | 12/17/97 1510 | 8.69 |
| 1/8/98 1300 | 5.24 | 1/6/98 0913 | 10.56 | 1/8/98 1146 | -- | 1/8/98 1146 | 20.28 | 1/7/98 1513 | 8.63 |
| 2/12/98 1436 | 4.79 | 2/12/98 1035 | 10.51 | 2/12/98 1042 | -- | 2/12/98 1042 | 20.43 | 2/12/98 1450 | 8.60 |
| 3/4/98 1340 | 4.91 | 3/4/98 1014 | 10.47 | 3/4/98 1021 | -- | 3/4/98 1021 | 20.48 | 3/4/98 1347 | 8.55 |
| 4/14/98 1200 | -- | 4/14/98 0931 | 10.32 | 4/14/98 1200 | -- | 4/14/98 1200 | -- | 4/16/98 1212 | 8.41 |
| 5/5/98 0930 | 5.46 | 5/5/98 1345 | 10.20 | 5/5/98 1356 | -- | 5/5/98 1356 | 20.66 | 5/5/98 1007 | 8.52 |
| 6/11/98 1618 | 6.19 | 6/11/98 1300 | 10.20 | 6/11/98 1307 | -- | 6/11/98 1307 | 20.72 | 6/11/98 1555 | 8.84 |
| 7/16/98 1200 | -- | 7/14/98 1121 | 10.53 | 7/14/98 1228 | -- | 7/14/98 1228 | 20.73 | 7/14/98 1200 | -- |
| 8/4/98 1230 | -- | 8/4/98 0952 | 10.48 | 8/4/98 0956 | -- | 8/4/98 0956 | 20.64 | 8/4/98 1200 | 8.80 |
| 9/1/98 1238 | 6.85 | 9/1/98 0850 | 10.83 | 9/1/98 0855 | -- | 9/1/98 0855 | 20.58 | 9/1/98 12.32 | 9.51 |
| 10/1/98 1334 | 7.71 | 10/1/98 1415 | 11.19 | 10/1/98 1305 | dry | 10/1/98 1419 | 20.69 | 10/1/98 1200 | -- |
| Min | 4.79 | Min | 10.20 | | | Min | 19.45 | Min | 8.39 |
| Median | 7.12 | Median | 10.86 | | | Median | 21.99 | Median | 8.87 |
| Max | 8.71 | Max | 12.07 | | | Max | 22.34 | Max | 10.11 |

**Table II.3** Monthly water-level and precipitation data for monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

[Date includes time of measurement if that information is available and is of the format *month/day/year time*; ft. bmp, feet below measuring point; Precip., monthly precipitation as measured in a plastic collection-type gage; --, not measured]

| Well D21 | | Well D22 | | Well D23 | | | Well D24 | | Well D25 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Precip., inches | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp |
| 10/3/94 1050 | 11.20 | 10/3/94 1215 | 19.81 | 9/30/94 0950 | 6.92 | -- | (Well D24 not installed until May 1995) | | (Well D25 not installed until May 1995) | |
| 11/25/94 1134 | 9.70 | 11/25/94 1212 | 19.61 | 11/25/94 1034 | 5.20 | -- | | | | |
| 12/12/94 1319 | 9.55 | 12/12/94 1352 | 19.61 | 12/12/94 1227 | 5.18 | -- | | | | |
| 1/30/95 | 9.18 | 1/30/95 | -- | 1/30/95 | 4.99 | -- | | | | |
| 3/20/95 | 9.08 | 3/20/95 | -- | 3/20/95 | 5.01 | -- | | | | |
| 4/11/95 | 9.02 | 4/11/95 | -- | 4/11/95 | 4.81 | -- | | | | |
| 5/1/95 | 8.86 | 5/1/95 | -- | 5/1/95 | 5.03 | -- | | | | |
| 6/22/95 | 9.38 | 6/22/95 | 19.34 | 6/22/95 | -- | -- | 6/22/95 | -- | 6/22/95 | 11.16 |
| 7/12/95 | 10.06 | 7/12/95 | 19.29 | 7/12/95 | 5.36 | -- | 7/12/95 | -- | 7/12/95 | 11.40 |
| 9/26/95 | -- | 9/25/95 | -- | 9/25/95 1323 | 5.41 | -- | 9/28/95 0800 | 22.42 | 9/22/95 0825 | 12.12 |
| 10/30/95 | -- | 10/30/95 | -- | 10/30/95 1408 | 5.03 | -- | 10/30/95 0853 | 22.55 | 10/30/95 0905 | 12.22 |
| 11/30/95 1233 | 9.59 | 11/30/95 | -- | 11/30/95 1119 | 4.95 | -- | 11/30/95 0800 | 22.72 | 11/30/95 0830 | 12.22 |
| 12/12/95 1410 | 9.46 | 12/12/95 | -- | 12/15/95 0905 | 5.06 | -- | 12/14/95 1050 | 22.80 | 12/13/95 0829 | 12.24 |
| 1/25/96 1340 | 9.11 | 1/25/96 | -- | 1/25/96 1414 | 4.59 | -- | 1/25/96 1420 | 22.97 | 1/25/96 1435 | 12.25 |
| 2/6/96 1305 | 9.02 | 2/7/96 1100 | 18.90 | 2/6/96 1015 | 5.53 | -- | 2/6/96 1210 | 23.02 | 2/6/96 1130 | 12.27 |
| 2/21/96 1136 | 9.05 | 2/21/96 | -- | 2/21/96 1110 | 4.94 | -- | 2/21/96 0920 | 23.08 | 2/21/96 0805 | 12.29 |
| 3/7/96 0907 | 9.07 | 3/7/96 | -- | 3/7/96 1340 | 4.98 | -- | 3/6/96 1350 | 23.12 | 3/5/96 1138 | 12.25 |
| 4/4/96 1145 | 8.99 | 4/4/96 1105 | 18.95 | 4/4/96 1400 | 4.96 | -- | 4/4/96 1205 | 23.23 | 4/4/96 1215 | 12.24 |
| 5/2/96 | 8.89 | 5/2/96 | | 5/2/96 | 4.91 | -- | 5/2/96 | 23.35 | 5/2/96 | 12.05 |
| 6/12/96 1126 | 9.56 | 6/12/96 1435 | 18.90 | 6/12/96 0830 | 4.82 | 3.61 | 6/14/96 1100 | 23.52 | 6/11/96 1118 | 11.9 |
| 7/3/96 1320 | 10.60 | 7/3/96 | -- | 7/3/96 1545 | 5.48 | 1.40 | 7/3/96 1345 | 23.55 | 7/3/96 1400 | 9.88 |
| 8/7/96 1015 | 10.97 | 8/7/96 1415 | -- | 8/7/96 0855 | 5.64 | 1.01 | 8/7/96 1442 | 22.84 | 8/7/96 1404 | 7.64 |
| 8/21/96 0820 | 11.12 | 8/23/96 0805 | 18.80 | 8/21/96 1223 | 5.83 | -- | 8/21/96 | -- | 8/20/96 | -- |
| 9/11/96 1445 | 11.39 | 9/11/96 1140 | 18.69 | 9/11/96 1505 | 5.17 | 2.06 | 9/11/96 | -- | 9/11/96 1620 | 6.38 |
| 10/4/96 0915 | 10.75 | 10/4/96 0802 | 18.65 | 10/4/96 0954 | 4.78 | 1.42 | 10/4/96 | -- | 10/4/96 1215 | 6.52 |
| 11/6/96 1435 | 10.06 | 11/6/96 910 | 18.62 | 11/8/ 1996 1315 | 4.61 | 0.22 | 11/8/96 | -- | 11/8/96 834 | 7.67 |

**Table II.3** Monthly water-level and precipitation data for monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

[Date includes time of measurement if that information is available and is of the format *month/day/year time*; ft. bmp, feet below measuring point; Precip., monthly precipitation as measured in a plastic collection-type gage; --, not measured]

| Well D21 | | Well D22 | | Well D23 | | | Well D24 | | Well D25 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Precip., inches | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp |
| 12/3/96 1540 | 9.64 | 12/3/96 1113 | 18.56 | 12/3/96 1558 | 4.50 | 0.07 | 12/3/96 1155 | 22.31 | 12/3/96 1620 | 8.09 |
| 1/7/97 1341 | 9.36 | 1/7/97 1114 | 18.54 | 1/7/97 1400 | 4.39 | -- | 1/7/97 1147 | 22.43 | 1/7/97 1207 | 8.57 |
| 2/4/97 1423 | 9.19 | 2/4/97 1204 | 18.56 | 2/4/97 1322 | 4.51 | 0.02 | 2/4/97 1243 | 22.54 | 2/4/97 1256 | 8.85 |
| 3/6/97 1303 | 9.06 | 3/6/97 1224 | 18.55 | 3/6/97 1333 | 4.50 | 0.19 | 3/6/97 1455 | 22.65 | 3/6/97 1440 | 9.03 |
| 4/8/97 1106 | 9.03 | 4/7/97 1030 | 18.55 | 4/8/97 1045 | 4.60 | 0.12 | 4/8/97 1246 | 22.80 | 4/7/97 1330 | 9.23 |
| 5/8/97 1507 | 9.06 | 5/8/97 1209 | 18.57 | 5/8/97 1527 | 4.72 | 0.53 | 5/8/97 1340 | 22.93 | 5/8/97 1405 | 9.43 |
| 6/2/97 | -- | 6/2/97 0910 | 18.45 | 6/3/97 1428 | 4.95 | 0.87 | 6/3/97 1334 | 22.97 | 6/2/97 1036 | 9.63 |
| 7/2/97 1337 | 10.72 | 7/2/97 1210 | 18.43 | 7/2/97 1409 | 6.18 | 1.65 | 7/2/97 1535 | 23.05 | 7/2/97 1505 | 8.95 |
| 8/7/97 1200 | -- | 8/7/97 1200 | -- | 8/7/97 1520 | 5.29 | 4.26 | 8/7/97 1630 | 23.18 | 8/7/97 1615 | 9.22 |
| 8/25/97 1200 | -- | 8/25/97 1200 | -- | 8/26/97 1249 | 4.99 | 0.90 | 8/25/97 1020 | 23.18 | 8/27/97 0818 | 7.72 |
| 10/02/97 1540 | 10.75 | 10/2/97 1200 | -- | 10/02/97 1521 | 4.95 | 1.11 | 10/02/97 1355 | 23.18 | 10/02/97 1413 | 7.62 |
| 11/20/97 1130 | -- | 11/17/97 1000 | -- | 11/20/97 0820 | 4.43 | -- | 11/17/97 1020 | 23.19 | 11/19/97 0927 | 8.12 |
| 12/17/97 1519 | 9.00 | 12/17/97 1000 | -- | 12/17/97 1450 | 4.41 | 0.40 | 12/17/97 1207 | 23.25 | 12/17/97 1232 | 8.34 |
| 1/7/98 1359 | 8.80 | 1/7/98 1200 | -- | 1/8/98 1218 | 4.29 | -- | 1/8/98 1200 | -- | 1/8/98 0812 | 8.39 |
| 2/12/98 1459 | 8.73 | 2/12/98 1200 | -- | 2/12/98 1200 | | -- | 2/12/98 1120 | 23.41 | 2/12/98 1137 | 8.6 |
| 3/4/98 1353 | 8.71 | 3/4/98 1200 | -- | 3/4/98 1311 | 4.40 | 0.41 | 3/4/98 1052 | 23.45 | 3/4/98 1122 | 8.62 |
| 4/16/98 1200 | -- | 4/16/98 1233 | 18.13 | 4/16/98 1008 | 4.53 | -- | 4/16/98 1200 | -- | 4/16/98 0732 | 8.7 |
| 5/5/98 0945 | 8.70 | 5/5/98 1507 | 18.04 | 5/5/98 0841 | 4.60 | -- | 5/5/98 1720 | 23.63 | 5/5/98 1259 | 8.71 |
| 6/11/98 1545 | 9.77 | 6/11/98 1325 | 18.04 | 6/11/98 1604 | 5.21 | -- | 6/11/98 1650 | 23.71 | 6/11/98 1458 | 9.1 |
| 7/14/98 1350 | 11.09 | 7/15/98 0844 | 18.18 | 7/16/98 1443 | 5.87 | 0.65 | 7/16/98 1200 | -- | 7/16/98 0924 | 9.86 |
| 8/4/98 1300 | -- | 8/4/98 1007 | 18.19 | 8/4/98 1149 | 4.09 | 4.30 | 8/4/98 1038 | 23.70 | 8/4/98 1052 | 8.19 |
| 9/1/98 1200 | -- | 9/1/98 0906 | 18.20 | 9/1/98 1249 | 4.80 | -- | 9/1/98 1104 | 22.60 | 9/1/98 1142 | 7.83 |
| 10/1/98 1348 | 11.05 | 10/1/98 1200 | -- | 10/1/98 1232 | 5.05 | 0.69 | 10/1/98 1443 | 22.25 | 10/1/98 1213 | 8.45 |
| Min | 8.70 | Min | 18.04 | Min | 4.09 | | Min | 22.25 | Min | 6.38 |
| Median | 9.37 | Median | 18.57 | Median | 4.95 | | Median | 23.05 | Median | 9.03 |
| Max | 11.39 | Max | 19.81 | Max | 6.92 | | Max | 23.71 | Max | 12.29 |

**Table II.3** Monthly water-level and precipitation data for monitoring wells near Deer Trail, Colorado, 1993-98.—Continued

[Date includes time of measurement if that information is available and is of the format *month/day/year time*; ft. bmp, feet below measuring point; Precip., monthly precipitation as measured in a plastic collection-type gage; --, not measured]

| Well D26 | | Well D27 | | Well D28 | | Well D29 | | Well D30 | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp |
| 6/22/95 | -- | 6/22/95 | 12.93 | 6/22/95 | 15.66 | (Well D29 not installed until November 1997) | | 6/22/95 | -- |
| 7/12/95 | -- | 7/12/95 | 12.91 | 7/12/95 | 15.63 | | | 7/12/95 | -- |
| 9/22/95 1400 | 37.40 | 9/22/95 | -- | 9/25/95 0830 | 15.47 | | | 9/20/95 1300 | 6.95 |
| 10/30/95 0929 | 36.81 | 10/30/95 | -- | 10/30/95 0952 | 15.48 | | | 10/30/95 1224 | 6.59 |
| 11/30/95 0931 | 36.53 | 11/30/95 | -- | 11/30/95 0959 | 15.49 | | | 11/30/95 1521 | 9.39 |
| 12/14/95 0835 | 36.70 | 12/13/95 1135 | -- | 12/15/95 0910 | 15.53 | | | 12/15/95 1336 | 6.42 |
| 1/25/96 1455 | 36.77 | 1/25/96 1135 | -- | 1/25/96 1525 | 15.49 | | | 1/25/96 1055 | 6.25 |
| 2/6/96 1145 | 37.21 | 2/7/96 0950 | 12.82 | 2/7/96 0915 | 15.53 | | | 2/6/96 1415 | 6.19 |
| 2/21/96 0851 | 37.07 | 2/21/96 | | 2/21/96 0942 | 15.57 | | | 2/22/96 0856 | 6.27 |
| 3/6/96 0820 | 37.23 | 3/7/96 | | 3/5/96 1330 | 15.55 | | | 3/5/96 1305 | 6.21 |
| 4/4/96 1230 | 37.18 | 4/4/96 1310 | 12.83 | 4/4/96 1245 | 15.58 | | | 4/4/96 0930 | 6.22 |
| 5/2/96 | 36.91 | 5/2/96 | -- | 5/2/96 | 15.59 | | | 5/2/96 | 6.23 |
| 6/14/96 0930 | 37.07 | 6/13/96 | -- | 6/11/96 1258 | 15.57 | | | 6/12/96 1110 | 6.40 |
| 7/3/96 | -- | 7/3/96 | -- | 7/3/96 1420 | 15.34 | | | 7/3/96 1100 | 6.27 |
| 8/7/96 1415 | -- | 8/7/96 1333 | 11.75 | 8/7/96 1258 | 15.04 | | | 8/7/96 1631 | 5.43 |
| 8/20/96 | -- | 8/20/96 1129 | 11.47 | 8/20/96 1248 | 14.99 | | | 8/21/96 1015 | 5.41 |
| 9/11/96 | -- | 9/11/96 1600 | 10.55 | 9/11/96 1550 | 14.71 | | | 9/11/96 1045 | 5.22 |
| 10/4/96 | -- | 10/4/96 1153 | 10.94 | 10/4/96 1130 | 14.74 | | | 10/3/96 0938 | 5.19 |
| 11/7/96 | -- | 11/7/96 1125 | 11.26 | 11/7/96 824 | 14.84 | | | 11/7/96 840 | 5.32 |
| 12/3/96 1247 | 35.12 | 12/3/96 1435 | 11.40 | 12/3/96 1456 | 14.83 | | | 12/3/96 1021 | 5.28 |
| 1/7/97 1242 | 35.07 | 1/7/97 1224 | 11.54 | 1/7/97 1217 | 14.89 | | | 1/7/97 1029 | 5.14 |
| 2/4/97 1532 | 35.17 | 2/4/97 1519 | 11.66 | 2/4/97 1512 | 14.95 | | | 2/4/97 1120 | 5.06 |
| 3/6/97 1122 | 34.78 | 3/6/97 1201 | 11.71 | 3/6/97 1112 | 15.00 | | | 3/6/97 1025 | 5.07 |
| 4/7/97 1429 | 34.70 | 4/7/97 1400 | 11.79 | 4/7/97 1344 | 15.02 | | | 4/7/97 1158 | 5.21 |

**Table II.3** Monthly water-level and precipitation data for monitoring wells near Deer Trail, Colorado, 1993-98.—Continued

[Date includes time of measurement if that information is available and is of the format *month/day/year time*; ft. bmp, feet below measuring point; Precip., monthly precipitation as measured in a plastic collection-type gage; --, not measured]

| Well D26 | | Well D27 | | Well D28 | | Well D29 | | Well D30 | |
|---|---|---|---|---|---|---|---|---|---|
| Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp |
| 5/8/97 1254 | 34.78 | 5/8/97 1609 | 11.88 | 5/8/97 1558 | 15.06 | | | 5/8/97 1115 | 5.41 |
| 6/3/97 1302 | 34.75 | 6/3/97 0938 | 11.97 | 6/3/97 0655 | 15.08 | | | 6/2/97 1100 | 5.04 |
| 7/2/97 1125 | 34.80 | 7/2/97 1200 | -- | 7/2/97 1145 | 15.05 | | | 7/2/97 0930 | 5.22 |
| 8/7/97 1200 | -- | 8/7/97 1200 | -- | 8/7/97 1200 | -- | | | 8/7/97 1345 | 4.60 |
| 8/26/97 0835 | 34.35 | 8/26/97 1200 | -- | 8/26/97 1200 | -- | | | 8/25/97 1340 | 4.95 |
| 10/02/97 1312 | 33.62 | 10/2/97 1200 | -- | 10/02/97 1439 | 14.68 | | | 10/02/97 1031 | 5.24 |
| 11/19/97 0900 | -- | 11/18/97 0745 | 11.24 | 11/18/97 0941 | 14.76 | | | 11/19/97 1010 | 4.75 |
| 12/17/97 1350 | 33.70 | 12/17/97 1406 | 11.21 | 12/17/97 1304 | 14.73 | 12/17/97 0945 | 154.44 | 12/17/97 1005 | 4.75 |
| 1/8/98 1200 | -- | 1/7/98 1045 | 11.16 | 1/7/98 0840 | 14.71 | 1/8/98 1430 | 154.10 | 1/6/98 1357 | 4.71 |
| 2/12/98 1231 | 33.81 | 2/12/98 1303 | 11.20 | 2/12/98 1215 | 14.71 | 2/12/98 1100 | 154.54 | 2/12/98 0912 | 4.70 |
| 3/4/98 1222 | 33.81 | 3/4/98 1156 | 11.23 | 3/4/98 1134 | 14.73 | 3/4/98 1036 | 154.22 | 3/4/98 0808 | 4.60 |
| 4/16/98 1200 | | 4/13/98 0919 | 11.19 | 4/13/98 0710 | 14.71 | 4/14/98 0740 | 154.29 | 4/13/98 1125 | 4.59 |
| 5/5/98 1156 | 33.96 | 5/5/98 1134 | 11.17 | 5/5/98 1224 | 14.68 | 5/5/98 1536 | 154.21 | 5/5/98 1638 | 4.91 |
| 6/11/98 13.53 | 33.99 | 6/11/98 1424 | 11.48 | 6/11/98 1413 | 14.64 | 6/11/98 1233 | 154.27 | 6/11/98 0932 | 5.40 |
| 7/16/98 1200 | -- | 7/15/98 0951 | 11.88 | 7/15/98 0803 | 14.57 | 7/14/98 1127 | 154.39 | 7/15/98 1318 | 6.30 |
| 8/4/98 1115 | 34.19 | 8/4/98 1245 | 11.01 | 8/4/98 1251 | 14.32 | 8/4/98 1023 | 154.65 | 8/4/98 0858 | 5.07 |
| 9/1/98 1130 | 34.03 | 9/1/98 1157 | 11.22 | 9/1/98 1142 | 14.20 | 9/1/98 0922 | 154.45 | 9/1/98 1005 | 5.40 |
| 10/1/98 1200 | -- | 10/1/98 1544 | 11.31 | 10/1/98 1532 | 14.09 | 10/1/98 1434 | 154.30 | 10/1/98 1024 | 5.53 |
| Min | 33.62 | Min | 10.55 | Min | 14.09 | Min | 154.10 | Min | 4.59 |
| Median | 34.94 | Median | 11.44 | Median | 15.00 | Median | 154.30 | Median | 5.30 |
| Max | 37.40 | Max | 12.93 | Max | 15.66 | Max | 154.65 | Max | 9.39 |

**Table II.3** Monthly water-level and precipitation data for monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

[Date includes time of measurement if that information is available and is of the format *month/day/year time*; ft. bmp, feet below measuring point; Precip., monthly precipitation as measured in a plastic collection-type gage; --, not measured]

| Well D31 | | Well D32 | | Well D33 | |
|---|---|---|---|---|---|
| Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp |
| 6/22/95 | -- | 6/22/95 | -- | 6/22/95 | -- |
| 7/12/95 | -- | 7/12/95 | -- | 7/12/95 | -- |
| 9/20/95 1130 | 6.87 | 9/28/95 1053 | 27.87 | 9/27/95 0835 | 14.94 |
| 10/30/95 1211 | 6.86 | 10/30/95 1055 | 27.81 | 10/30/95 1011 | 15.04 |
| 11/30/95 1512 | 7.05 | 11/30/95 1437 | 27.77 | 11/30/95 1351 | 15.03 |
| 12/15/95 1148 | 7.15 | 12/13/95 0845 | 27.80 | 12/12/95 1005 | 15.09 |
| 1/25/96 1110 | 7.33 | 1/25/96 1030 | 27.80 | 1/25/96 0955 | 15.10 |
| 2/6/96 1425 | 7.36 | 2/6/96 1355 | 27.77 | 2/6/96 1335 | 14.98 |
| 2/22/96 0821 | 7.47 | 2/22/96 0933 | 27.82 | 2/22/96 0958 | 15.13 |
| 3/5/96 1140 | 7.43 | 3/7/96 0935 | 27.85 | 3/8/96 0820 | 15.14 |
| 4/4/96 0935 | 7.35 | 4/4/96 1040 | 27.87 | 4/4/96 1020 | 15.14 |
| 5/2/96 | 6.81 | 5/2/96 | 27.92 | 5/2/96 | 14.95 |
| 6/12/96 1010 | 6.49 | 6/13/96 1045 | 27.99 | 6/12/96 1315 | 15.07 |
| 7/3/96 1050 | 6.38 | 7/3/96 1235 | 28.01 | 7/3/96 1230 | 15.11 |
| 8/7/96 1553 | 5.11 | 8/7/96 1811 | 28.09 | 8/7/96 1800 | 14.89 |
| 8/21/96 1215 | 5.55 | 8/20/96 1250 | 28.06 | 8/22/96 1240 | 14.84 |
| 9/11/96 1020 | 5.77 | 9/11/96 1120 | 28.14 | 9/11/96 1115 | 14.69 |
| 10/3/96 0850 | 5.98 | 10/3/96 1018 | 28.13 | 10/3/96 1040 | 14.76 |
| 11/7/96 955 | 6.26 | 11/7/96 | -- | 11/8/96 1020 | 14.81 |
| 12/3/96 1015 | 6.38 | 12/3/96 1049 | 28.16 | 12/3/96 1036 | 14.83 |
| 1/7/97 953 | 6.51 | 1/7/97 1055 | 28.15 | 1/7/97 1045 | 14.84 |
| 2/4/97 1108 | 6.46 | 2/4/97 1143 | 28.17 | 2/4/97 1132 | 14.81 |

**Table II.3** Monthly water-level and precipitation data for monitoring wells near Deer Trail, Colorado, 1993–98.—Continued

[Date includes time of measurement if that information is available and is of the format *month/day/year time*; ft. bmp, feet below measuring point; Precip., monthly precipitation as measured in a plastic collection-type gage; --, not measured]

| Well D31 | | Well D32 | | Well D33 | |
|---|---|---|---|---|---|
| Date | Water Level, ft. bmp | Date | Water Level, ft. bmp | Date | Water Level, ft. bmp |
| 3/6/97 946 | 6.35 | 3/6/97 1058 | 28.18 | 3/6/97 1039 | 14.81 |
| 4/7/97 1152 | 6.32 | 4/8/97 1156 | 28.20 | 4/8/97 1215 | 14.79 |
| 5/8/97 1044 | 6.53 | 5/8/97 1147 | 28.24 | 5/8/97 1133 | 14.77 |
| 6/3/97 1023 | 6.33 | 6/2/97 1342 | 28.20 | 6/2/97 1330 | 14.68 |
| 7/2/97 0825 | 6.41 | 7/2/97 0955 | 28.27 | 7/2/97 1030 | 14.66 |
| 8/7/97 1330 | 6.22 | 8/7/97 1200 | -- | 8/7/97 1200 | -- |
| 8/27/97 1030 | 6.17 | 8/26/97 1215 | 28.28 | 8/26/97 1325 | 14.25 |
| 10/02/97 1024 | 6.46 | 10/02/97 1126 | 28.21 | 10/02/97 1114 | 14.34 |
| 11/18/97 1100 | -- | 11/18/97 0815 | 28.01 | 11/18/97 1135 | 14.34 |
| 12/17/97 1056 | 6.09 | 12/17/97 1139 | 27.96 | 12/17/97 1152 | 14.32 |
| 1/6/98 1200 | -- | 1/7/98 1340 | 27.89 | 1/8/98 1448 | 14.33 |
| 2/12/98 0905 | 6.06 | 2/12/98 0922 | 27.84 | 2/12/98 0957 | 14.40 |
| 3/4/98 0801 | 5.39 | 3/4/98 0815 | 27.80 | 3/4/98 0924 | 14.40 |
| 4/13/98 1200 | -- | 4/13/98 1200 | -- | 4/13/98 1200 | -- |
| 5/5/98 1707 | 4.97 | 5/5/98 1630 | 27.76 | 5/5/98 1557 | 14.36 |
| 6/11/98 0926 | 5.88 | 6/11/98 0940 | 27.78 | 6/11/98 1155 | 14.30 |
| 7/15/98 1200 | -- | 7/15/98 1108 | 27.79 | 7/15/98 1450 | 14.47 |
| 8/4/98 0900 | -- | 8/4/98 0924 | 27.78 | 8/4/98 0913 | 14.50 |
| 9/1/98 1000 | -- | 9/1/98 1052 | 27.78 | 9/1/98 1020 | 14.58 |
| 10/1/98 1159 | 6.25 | 10/1/ 1998 1200 | -- | 10/1/98 1012 | 14.70 |
| Min | 4.97 | Min | 27.76 | Min | 14.25 |
| Median | 6.38 | Median | 27.94 | Median | 14.80 |
| Max | 7.47 | Max | 28.28 | Max | 15.14 |

**Table II.4.** Textural data for core samples collected from D31 and D33 boreholes during drilling near Deer Trail, Colorado, May 1995.

[ft bls, feet below land surface; ft. bmp, feet below measuring point; %, percent; --, no data]

| Sample location (fig. 2) | Sample type[1] | Sample depth, ft bls | Sample date | Sample medium | % Sand | % Clay | % Silt | Sample texture[3] |
|---|---|---|---|---|---|---|---|---|
| D31 | Core | 0–0.17 | 5/4/95 | soil | 52 | 15 | 33 | clay loam |
| D31 | Core | 0.17–1.7 | 5/4/95 | soil | 48 | 19 | 33 | loamy sand |
| D31 | Core | 1.7–2.4 | 5/4/95 | soil | 48 | 17 | 35 | clay loam + sand |
| D31 | Core | 5.0–6.0 | 5/4/95 | alluvium | 49 | 21 | 30 | clay loam |
| D31 | Core | 6.0–7.0 | 5/4/95 | alluvium | 49 | 12 | 39 | clay loam |
| D31 | Core | 8.0–9.0 | 5/4/95 | alluvium | 52 | 12 | 36 | clay loam |
| D31 | Core | 9.0–11.7 | 5/4/95 | alluvium | 60 | 18 | 22 | clay-rich silty sand |
| D31 | Core | 11.7–12 | 5/4/95 | alluvium | 60 | 16 | 24 | silty sand |
| D33 | Core | 0–0.33 | 5/5/95 | soil | -- | -- | -- | sandy loam |
| D33 | Core | 0.75–2.25 | 5/5/95 | soil | -- | -- | -- | loamy sand |
| D33 | Core | 2.25–3.0 | 5/5/95 | soil | -- | -- | -- | loamy sand |
| D33 | Core | 4.5–5.0 | 5/5/95 | alluvium | -- | -- | -- | sandy loam |
| D33 | Core | 5.0–5.5 | 5/5/95 | alluvium | -- | -- | -- | clayey sand |
| D33 | Core | 9.0–12.0 | 5/5/95 | alluvium | -- | -- | -- | loamy sand |

[1] Core obtained from split-spoon auger during drilling of the borehole for the monitoring well.
[2] Textural analysis from hydrometer data provided by James Tindall, U.S.Geological Survey Unsaturated Zone Field Studies.
[3] From geologist's description of core.

**Table II.5.** Dissolved-gas data and calculated information for selected monitoring wells near Deer Trail, Colorado, November 1998.

[Dissolved-gas sampling methods and calculations are described in Busenberg and others (1999), Heaton (1981), Heaton and Vogel (1981), Heaton and others (1983), Plummer and others (2001), Stute and Schlosser (1999), Stute and others (1992), and Wilson and McNeill (1997); Temp., temperature in degrees Celsius; mg/L, milligrams per liter; $N_2$, nitrogen; Ar, argon; $O_2$, oxygen; $CO_2$, carbon dioxide; $CH_4$, methane; alt, altitude in feet above NGVD 29; mm Hg, millimeters of mercury; BP, barometric pressure; Ex Air, excess air; cc STP/L, cubic centimeters of gas at standard temperature and pressure per liter]

| Sample name and date | Sample field temp | Dissolved-gas data | | | | | Calculation variables | | | Calculated information | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | mg/L $N_2$ | mg/L Ar | mg/L $O_2$ | mg/L $CO_2$ | mg/L $CH_4$ | Estimated mg/L Excess $N_2$ | Estimated recharge alt | mm Hg BP | Recharge Temp | Ex Air cc STP/L |
| D5 11/19/98 | 12 | 16.18 | 0.55 | 0.05 | 21.70 | 0 | 2 | 5,217 | 627.49 | 11.17 | 0.05 |
| D5 11/19/98 | 12 | 16.36 | 0.56 | 0.05 | 21.41 | 0 | 2 | 5,217 | 627.49 | 11.09 | 0.22 |
| D6 11/24/98 | 12.9 | 17.71 | 0.52 | 0.04 | 61.40 | 0 | 3 | 5,217 | 627.49 | 15.51 | 1.35 |
| D6 11/24/98 | 12.9 | 17.14 | 0.51 | 0.04 | 60.95 | 0 | 3 | 5,217 | 627.49 | 15.61 | 0.80 |
| D9 11/17/98 | 16.5 | 14.33 | 0.54 | 3.54 | 45.71 | 0 | 0 | 5,225 | 627.31 | 11.98 | -0.05 |
| D10 11/19/98 | 13.2 | 15.88 | 0.56 | 0.04 | 41.10 | 0 | 1 | 5,220 | 627.43 | 11.45 | 0.45 |
| D13 11/18/98 | 11.9 | 20.60 | 0.56 | 0.81 | 27.41 | 0 | 6 | 5,264 | 626.41 | 10.98 | 0.45 |
| D14 11/24/98 | 12.4 | 16.65 | 0.55 | 0.05 | 15.91 | 0 | 2 | 5,264 | 626.41 | 12.31 | 0.81 |
| D17 11/18/98 | 14.3 | 16.97 | 0.56 | 0.05 | 9.49 | 0 | 2 | 5,264 | 626.41 | 10.97 | 0.31 |
| D17 11/18/98 | 14.3 | 17.09 | 0.56 | 0.06 | 9.20 | 0 | 2 | 5,264 | 626.41 | 10.81 | 0.38 |
| D24 11/17/98 | 12.8 | 14.61 | 0.54 | 4.01 | 109.91 | 0 | 0 | 5,200 | 627.89 | 12.60 | 0.41 |
| D24 11/17/98 | 12.8 | 14.50 | 0.54 | 3.44 | 105.56 | 0 | 0 | 5,200 | 627.89 | 13.00 | 0.42 |
| D25 11/18/98 | 13 | 21.70 | 0.61 | 0.57 | 61.63 | 0.05 | 4 | 5,160 | 628.81 | 9.89 | 2.70 |

**Table II.6.** Chlorofluorocarbon data and calculated information for selected monitoring wells near Deer Trail, Colorado, November 1998.

[Recharge temperature and elevation calculated from dissolved-gas information in table II.5; sampling methods and calculations explained in Busenberg and Plummer (1992), Plummer and Friedman (1999), Plummer and Busenberg (1999), and Plummer and others (2001); No., number; Temp., temperature; Alt, altitude in feet above NGVD 29; BP, barometric pressure; °C, degrees Celsius; mm, millimeters of mercury; pM/kg, picomoles per kilogram; pg/kg, picogram per kilogram, TK, temperature in Kelvin; CFC, chlorofluorocarbon; F-11, chlorofluorocarbon 11; F-12, chlorofluorocarbon 12; F-113, chlorofluorocarbon 113; Contam., contaminated; <, less than]

| Sample site (fig. 2) | Vial no. | Sampling date | Estimated recharge | | | Concentration in solution | | | | | | | Calculated CFC recharge dates | | | Mole ratio | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Temp. (°C) | Alt (feet) | BP (mm) | pM/kg CFC-11 | pM/kg CFC-12 | pM/kg CFC-113 | pg/kg CFC-11 | pg/kg CFC-12 | pg/kg CFC-113 | T K | CFC-11 | CFC-12 | CFC-113 | F-11/F-12 | F-113/F-12 |
| D3 | 2 | 11/17/98 | 13.0 | 5,200 | 628 | 1.028 | 0.621 | 1.162 | 141.2 | 75.1 | 217.8 | 286.15 | 1971 | 1972 | Contam. | 1.656 | 1.872 |
| D3 | 4 | 11/17/98 | 15.0 | 5,200 | 628 | 1.040 | 0.626 | 1.224 | 142.8 | 75.7 | 229.3 | 288.15 | 1972 | 1972.5 | Contam. | 1.660 | 1.954 |
| D3 | 5 | 11/17/98 | 10.0 | 5,151 | 629 | 1.078 | 0.644 | 1.161 | 148.1 | 77.9 | 217.5 | 283.15 | 1970 | 1971 | Contam. | 1.675 | 1.803 |
| D5 | 1 | 11/19/98 | 11.2 | 5,217 | 627 | 0.963 | 1.123 | 0.090 | 132.2 | 135.7 | 16.9 | 284.35 | 1970 | 1977 | 1978 | 0.858 | 0.080 |
| D5 | 2 | 11/19/98 | 11.1 | 5,180 | 628 | 0.996 | 1.116 | 0.068 | 136.8 | 135.0 | 12.7 | 284.25 | 1970 | 1977 | 1976 | 0.892 | 0.061 |
| D5 | 3 | 11/19/98 | 11.2 | 5,217 | 627 | 0.907 | 1.078 | 0.060 | 124.6 | 130.3 | 11.2 | 284.35 | 1969.5 | 1976.5 | 1975 | 0.842 | 0.056 |
| D6 | 2 | 11/24/98 | 15.6 | 5,217 | 627 | 0.034 | 0.179 | 0.042 | 4.7 | 21.7 | 7.9 | 288.75 | 1954 | 1963 | 1974.5 | 0.192 | 0.237 |
| D6 | 4 | 11/24/98 | 15.5 | 5,200 | 628 | 0.048 | 0.175 | 0.071 | 6.5 | 21.2 | 13.4 | 288.65 | 1955 | 1963 | 1978 | 0.271 | 0.407 |
| D6 | 5 | 11/24/98 | 15.5 | 5,200 | 628 | 0.154 | 0.357 | 0.109 | 21.2 | 43.2 | 20.5 | 288.65 | 1960.5 | 1968 | 1981.5 | 0.432 | 0.306 |
| D9 | 3 | 11/17/98 | 12.0 | 5,163 | 629 | 3.869 | 2.198 | 1.287 | 531.5 | 265.8 | 241.2 | 285.15 | 1988 | 1996.5 | Contam. | 1.760 | 0.586 |
| D9 | 5 | 11/17/98 | 12.0 | 5,163 | 629 | 3.910 | 2.180 | 6.579 | 537.0 | 263.6 | 1,232.7 | 285.15 | 1988 | 1996 | Contam. | 1.793 | 3.018 |
| D10 | 2 | 11/19/98 | 11.5 | 5,220 | 627 | 2.068 | 1.562 | 0.197 | 284.0 | 188.8 | 36.9 | 284.65 | 1976 | 1984 | 1984.5 | 1.324 | 0.126 |
| D10 | 4 | 11/19/98 | 11.5 | 5,197 | 628 | 2.106 | 1.649 | 0.193 | 289.2 | 199.4 | 36.2 | 284.65 | 1976 | 1985.5 | 1984 | 1.277 | 0.117 |
| D10 | 5 | 11/19/98 | 11.5 | 5,220 | 627 | 1.971 | 1.530 | 0.212 | 270.8 | 185.0 | 39.7 | 284.65 | 1975.5 | 1983.5 | 1985 | 1.289 | 0.138 |
| D13 | 2 | 11/18/98 | 11.0 | 5,264 | 626 | 0.603 | 0.704 | 0.072 | 82.8 | 85.1 | 13.4 | 284.15 | 1967 | 1972 | 1976.5 | 0.856 | 0.102 |
| D13 | 4 | 11/18/98 | 11.0 | 5,200 | 628 | 0.594 | 0.684 | 0.070 | 81.7 | 82.8 | 13.1 | 284.15 | 1966.5 | 1972 | 1976 | 0.869 | 0.102 |
| D13 | 5 | 11/18/98 | 11.0 | 5,240 | 627 | 0.640 | 0.713 | 0.071 | 87.9 | 86.2 | 13.3 | 284.15 | 1967 | 1972 | 1976 | 0.897 | 0.100 |
| D14 | 2 | 11/24/98 | 12.3 | 5,264 | 626 | 0.238 | 0.790 | 0.025 | 32.8 | 95.5 | 4.6 | 285.45 | 1962 | 1973.5 | 1969 | 0.302 | 0.031 |
| D14 | 4 | 11/24/98 | 12.3 | 5,264 | 626 | 0.240 | 0.770 | 0.027 | 33.0 | 93.1 | 5.1 | 285.45 | 1962 | 1973.5 | 1970 | 0.312 | 0.036 |
| D14 | 5 | 11/24/98 | 12.3 | 5,271 | 626 | 0.235 | 0.786 | 0.024 | 32.3 | 95.0 | 4.5 | 285.45 | 1962 | 1973.5 | 1969 | 0.299 | 0.031 |
| D17 | 2 | 11/18/98 | 10.8 | 5,264 | 626 | 0.395 | 0.329 | 0.061 | 54.2 | 39.8 | 11.5 | 283.95 | 1964 | 1966 | 1975 | 1.199 | 0.186 |
| D17 | 4 | 11/18/98 | 11.0 | 5,264 | 626 | 0.447 | 0.338 | 0.035 | 61.4 | 40.9 | 6.5 | 284.15 | 1965 | 1966 | 1971 | 1.320 | 0.103 |
| D17 | 5 | 11/18/98 | 11.0 | 5,276 | 626 | 0.491 | 0.387 | 0.035 | 67.4 | 46.8 | 6.6 | 284.15 | 1965.5 | 1967 | 1971 | 1.268 | 0.092 |

**Table II.6.** Chlorofluorocarbon data and calculated information for selected monitoring wells near Deer Trail, Colorado, November 1998.—Continued

[Recharge temperature and elevation calculated from dissolved-gas information in table II.5; sampling methods and calculations explained in Busenberg and Plummer (1992), Plummer and Friedman (1999), Plummer and Busenberg (1999), and Plummer and others (2001); No., number; Temp., temperature; Alt, altitude in feet above NGVD 29; BP, barometric pressure; °C, degrees Celsius; mm, millimeters of mercury; pM/kg, picomoles per kilogram; pg/kg, picogram per kilogram, TK, temperature in Kelvin; CFC, chlorofluorocarbon; F-11, chlorofluorocarbon 11; F-12, chlorofluorocarbon 12; F-113, chlorofluorocarbon 113; Contam., contaminated; <, less than]

| Sample site (fig. 2) | Vial no. | Sampling date | Estimated recharge | | | Concentration in solution | | | | | | T K | Calculated CFC recharge dates | | | Mole ratio | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Temp. (°C) | Alt (feet) | BP (mm) | pM/kg CFC-11 | pM/kg CFC-12 | pM/kg CFC-113 | pg/kg CFC-11 | pg/kg CFC-12 | pg/kg CFC-113 | | CFC-11 | CFC-12 | CFC-113 | F-11/F-12 | F-113/F-12 |
| D24 | 2 | 11/17/98 | 13.0 | 5,200 | 628 | 2.236 | 1.726 | 0.869 | 307.2 | 208.7 | 162.8 | 286.15 | 1978 | 1987.5 | Contam. | 1.296 | 0.503 |
| D24 | 3 | 11/17/98 | 12.6 | 5,200 | 628 | 2.741 | 1.949 | 1.050 | 376.4 | 235.6 | 196.7 | 285.75 | 1981.5 | 1990.5 | Contam. | 1.406 | 0.539 |
| D24 | 5 | 11/17/98 | 13.0 | 5,220 | 627 | 2.848 | 2.032 | 0.929 | 391.3 | 245.7 | 174.1 | 286.15 | 1983 | 1994 | Contam. | 1.402 | 0.457 |
| D25 | 2 | 11/18/98 | 7.8 | 5,160 | 629 | 0.022 | 0.115 | 0.000 | 3.0 | 13.9 | 0.0 | 280.95 | 1951.5 | 1957 | <1955 | 0.192 | 0 |
| D25 | 3 | 11/18/98 | 7.8 | 5,200 | 628 | 0.021 | 0.126 | 0.000 | 2.9 | 15.2 | 0.0 | 280.95 | 1951.5 | 1957.5 | <1955 | 0.170 | 0 |
| D25 | 4 | 11/18/98 | 7.8 | 5,200 | 628 | 0.021 | 1.136 | 0.000 | 2.9 | 137.4 | 0.0 | 280.95 | 1951.5 | 1975 | <1955 | 0.019 | 0 |
| D25 | 5 | 11/18/98 | 9.9 | 5,200 | 628 | 0.014 | 0.130 | 0.000 | 2.0 | 15.7 | 0.0 | 283.05 | 1950.5 | 1958.5 | <1955 | 0.111 | 0 |